

Uckelmann | Romagnoli | Baalsrud Hauge | Kammerlohr [Eds.]

# Online-Labs in Education

Proceedings of the 1st International Conference  
on Online-Labs in Education,  
10 – 12 March 2022, Stuttgart, Germany



Nomos

Edition  
Rainer  
Hampp

Dieter Uckelmann | Giovanni Romagnoli  
Jannicke Baalsrud Hauge | Valentin Kammerlohr [Eds.]

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The Digilab4U project, the conference and these conference proceedings were funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112. The responsibility for the content of this publication lies with the authors.

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**The Deutsche Nationalbibliothek** lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>

ISBN 978-3-98542-036-0 (Print)  
978-3-95710-410-6 (ePDF)

**British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

ISBN 978-3-98542-036-0 (Print)  
978-3-95710-410-6 (ePDF)

**Library of Congress Cataloging-in-Publication Data**

Uckelmann, Dieter | Romagnoli, Giovanni | Baalsrud Hauge, Jannicke  
Kammerlohr, Valentin

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501 pp.

Includes bibliographic references.

ISBN 978-3-98542-036-0 (Print)  
978-3-95710-410-6 (ePDF)

Edition Rainer Hampf in der Nomos Verlagsgesellschaft

1st Edition 2022

© The Authors

Published by

Nomos Verlagsgesellschaft mbH & Co. KG

Waldseestraße 3–5 | 76530 Baden-Baden

[www.nomos.de](http://www.nomos.de)

Production of the printed version:

Nomos Verlagsgesellschaft mbH & Co. KG

Waldseestraße 3–5 | 76530 Baden-Baden

ISBN 978-3-98542-036-0 (Print)

ISBN 978-3-95710-410-6 (ePDF)

DOI <https://doi.org/10.5771/9783957104106>



Onlineversion  
Nomos eLibrary



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## Preface

The *Online-Labs in Education* conference, held on March 10-11, 2022 at HFT Stuttgart, Germany, marked the final phase of the DigiLab4U project ([www.digilab4u.com](http://www.digilab4u.com)). The goal of the conference was to disseminate the results of the project and to bring together a vibrant research community that is continuously working to enable the use of online labs in research and education without institutional boundaries.

Similar to digitalization in administration and industry, the digitalization or virtualization of lab equipment promises numerous benefits for involved stakeholders. The economic benefits of shared lab infrastructures, remote access to labs anytime and anywhere, the convenience of use, shared lab courses, fully online-labs, and experiments via online platforms are just a few of the benefits that come to mind when thinking of a federated lab network infrastructure. However, the effort required to digitalize ‘physical things’ should not be underestimated. The DigiLab4U project has investigated technical, organizational, and didactic issues related to online labs and lab-sharing networks. The scientific results have been published in numerous publications (see <https://digilab4u.com/publications/>). In our perception, publishing and discussing lab-based lecture content among peers is not common practice at scientific conferences, which leads to low visibility of what exists and hinders the uptake and re-use of existing online and remote labs.

For this reason, the *Online-Labs in Education* conference called for not only scientific contributions, but also lab-based lecture chapters. We would like to express our thanks to all authors for their contributions. The conference and the proceedings presented here followed the same structure and were complemented by interactive demonstrations. The conference proceedings are structured into the following main sections:

- General topics and organizational issues
- Technical topics
- Didactical considerations
- Educational learning chapters  
(educational considerations – learning chapters are available online)
- Interactive demos (abstracts)

There are institutions and people we would like to thank for their support of the conference. First, we would like to thank the *Federal Ministry for Education and Research (BMBF) Germany* for funding the project and the

conference. Second, we would like to thank our local institution, *Verein Freunde der HFT Stuttgart e.V.*, for their support. Third, we would like to thank the members of the advisory board and the program committee:

Advisory Board:

- Dr. Peter Ferdinand, Institut für Wissensmedien, Universität Koblenz-Landau
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- Mattia Neroni, University of Parma
- Anke Pfeiffer, HFT Stuttgart
- Davide Reverberi, University of Parma
- David Schepkowski, IWM, Universität Koblenz-Landau

Last, but not least, we want to thank the organizing committee, including Anja Ernst, Anke Pfeiffer, Andreas Jäkel, Elisabeth Kraxner, Kevin Kutzner, and Marc Philipp Jensen for spending countless hours enabling a hybrid conference format.

The discussion at the end of the conference showed that further research and activities related to online-labs in education are expected. Some of the mentioned topics included:

- a demand for more universities collaborating and sharing labs;
- a need for a marketing platform to promote the usage of online labs;
- a need for more events to share experiences on using online labs in engineering education;
- interest in sharing experience on using Learning Analytics (LA) – not only in relation to online labs;
- the need for sustainable financing of labs and lab networks.

It will be interesting in the future to see the sharing of online labs by universities and eventually, cooperation between industries and lab teams will also be well accepted. However, this would require a fundamental shift in existing mindsets, budgets and funding programs.

*Dieter Uckelmann  
Giovanni Romagnoli  
Jannicke Baalsrud Hauge  
Valentin Kammerlohr*

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# 1 Scientific Contributions on Online Labs



# 1.1 General Topics and Organizational Issues



*Valentin Kammerlohr and David Paradise*

# **Fundamental Organizational Aspects of Shared Lab-Networks: Trust, Business- and Maturity-Model Considerations in DigiLab4U**

## Abstract

Online labs form the basis of digital exchange in networks and are thus candidates for the use of shared knowledge, shared infrastructure, and shared facilities through the application of ICT technology. In addition to technical and didactic considerations, the importance of organizational considerations in this respect is increasing due to shared use. In this paper, the organizational foundations of digital sharing are highlighted, providing a long-term perspective on lab networks. To this end, three organizational aspects are addressed: (1) a platform business model for activating online lab sharing, (2) considerations on building initial and long-term trust between actors as a critical challenge of a lab sharing platform, and (3) a maturity model for capturing the organizational transformation of online labs for platform actors. Using the case study DigiLab4U, a time-limited, funded research project on online lab sharing, this paper shows how the three organizational considerations can contribute to sustainability over the funding period. The reader is thereby shown which success criteria and functional requirements are necessary for the sustainability of a lab-sharing network.

## Keywords

Sharing economy, Online labs, Platform business model, Trust, Transformation maturity model

## 1 Introduction

Science, technology, engineering, and mathematics (STEM) education requires applied tasks and problems to promote conceptual understanding, practical knowledge, and experience (Feisel & Rosa, 2005). Laboratories (labs) provide students with a special hands-on engineering experience and allow them to explore systems and their real-world behavior in a protected environment (Zutin et al., 2010). However, for universities, these specialized

labs involve high investment and operating costs, their utilization is often low, access is limited to local user groups (students and researchers), and the labs are subject to rapid loss of innovation (Heradio et al., 2016). In addition, funding for the labs is solely dependent on budgetary resources and grants and is therefore subject to corresponding funding fluctuations.

Digitalization technologies can be used to transform traditional labs, making them available online, allowing access to labs across locations, eliminating the need for in-person lab attendance, and thus enabling the delivery of lab experiences via distance learning (Mani & Patvardhan, 2006). These online labs are experiments supported by information and communication technologies (ICT) in which manual efforts are eliminated and can be accessed via the Internet (Zutin et al., 2010). According to Zutin et al. (2010), online labs are divided into software simulations (or virtual labs) and labs with real hardware equipment (or remote labs), through which they achieve advantages in availability, observability, accessibility, and security (Heradio et al., 2016). Expanded availability, where users can access online labs from anywhere and at any time, offers universities wide-ranging opportunities to increase usage through new business areas created by the transformed labs, as they can be used outside class hours (Gardel et al., 2012).

By making the labs available online, they can be shared with other facilities and users, opening up a new area of business and thus a potential constant source of revenue. The sharing economy describes behavior that promotes the sharing of resources to benefit from increased resource utilization, cost advantages, and access to new knowledge (Goudin, 2016). The digital transformation of labs to online labs makes them good candidates for the sharing economy, which means additional users can be reached. Several didactic and technological studies have already been conducted to measure the transformation from real to online labs, such as in Brinson (2015) and García-Zubía (2021). Research by Uckelmann (2012) has shown that in addition to didactics and technology, an organizational element is required for online lab sharing, so this paper explores (RQ): What are the fundamental organizational aspects of shared lab networks?

Using a case study methodology, this study focuses on three key organizational aspects: (1) a platform business model for activating online lab sharing, (2) considerations for building initial and long-term trust between actors as a critical challenge of a lab sharing platform, and (3) a maturity model for capturing the organizational transformation of online labs for platform actors. The case study is described in Section 2 and introduces the DigiLab4U research project, which explores lab sharing as part of the research mission and, like most such research projects, faces the challenge

of being sustained through the adoption of a business model after the funding period (Esposito et al., 2021). Section 3 then describes the three fundamental organizational aspects of shared lab-networks, further possible approaches, and their interplay for sustainable online lab sharing. For the business model as the first aspect, the following problem is addressed. Labs involve high investment costs, utilization is often low, access is limited to local user groups, labs are subject to rapid loss of innovation, and funding is solely dependent on budget and grant funding and thus subject to corresponding fluctuations. While classic business models do not seem to work, the question of what success criteria and functional requirements should be placed on digital labs is outlined. The second aspect describes the success criterion of trust for the business model in more detail. Trust should be a core element in sharing digital goods such as online labs (Gossen et al., 2019). We, therefore, show how technology-based initial and long-term trust development is approached. Building on this, we show why this is a core element for the sustainability of the sharing business model and how initial and long-term trust can be leveraged for sharing labs. Finally, as a third aspect, it is clear that the effectiveness of the digital transformation of the lab should be made transparent to the user and the platform operator, as has been shown many times for both didactic and technical transformation (Heradio et al., 2016). This could be used by lab operators for design, implementation, or improvement and by users such as students for comparability to build trust. Section 4 then discusses the results, interplay, further approaches, open challenges, and a possible way forward for shared laboratory networks before Section 5 concludes the paper.

The authors point out that individual aspects of this publication have been published before, but the interaction of the aspects is new.

## **2 DigiLab4U as a Case Study for Shared Online Labs**

The mission of the DigiLab4U research project is to make real labs accessible and shared online. Participating institutions work across international borders to achieve common goals for teaching, learning, and research. Collaboration among universities and research institutions allows resources to be pooled so that faculties, learners, and researchers have access to a greater variety of digital courses based on different labs. Currently, the project relies solely on budget and grant funding and is therefore subject to corresponding fluctuations. The inclusion of potential user fees is intended to open up a third pillar of funding and thus create a viable business model that enables sustainability beyond grant funding.

Many research projects, such as the DigiLab4U research project, can be seen as a virtual organization whose typical customer is the funding organization. Their common goal and vision are described in the project proposal and in the statement of work (Seifert, 2009). These are temporary and end when the funding ends. When the temporary lab network is transformed into a sustained, long-term form of collaboration, the goals of the participants may change from jointly meeting the needs of the funder to goals that fit into the long-term business strategy. In some cases, the goals will change only slightly. In other cases, the partners will have such different goals that they will end the collaboration. The corresponding business model will change, however, as the revenue streams will change because the interested funder will have to be replaced by a different type of customer.

Various technical and didactic measures have been taken to best meet the needs and preferences of DigiLab4U stakeholders. The success of operating shared resources in a collaborative network depends not only on business considerations that take into account the needs of all stakeholders, but also on trust between stakeholders and the maturity of the online lab transformation. The introduction of a user fee as a business model changes, among other things, the stakeholders and their goals and relationships.

### 3 Trust, Business and Maturity Models as Organizational Aspects

Students, researchers, professors, universities, and institutions need organizational measures that go beyond technical and didactic measures to organize and sustainably map the sharing between the stakeholders. These organizational aspects are outlined below and thus form the necessary framework for the successful introduction of a sharing business model. To this end, we first outline a business model that addresses stakeholder needs, initial and long-term technology-based trust to leverage the business model, and a maturity model that maps the effectiveness of transforming an online lab for users.

#### 3.1 *A Multi-Sided Platform to Activate the Sharing of Online Labs*

Sharing is originally a private matter, but new concepts for sharing goods and services between individuals and companies are emerging worldwide (Beutin, 2018). Sharing is now taking on far-reaching new forms, such as car sharing, code sharing, file sharing or food sharing, and is conquering new business areas with innovative business models. The underlying concept

of the sharing economy describes behavior in which either individuals or organizations seek to share existing resources, such as human, tangible, and intangible resources (Goudin, 2016). At first glance, the sharing economy for digital labs offers benefits to providers through increased utilization, and the customer side gains access to a greater supply of labs.

According to Eikaas et al. (2003), a major obstacle to a sustainable business model is "*the willingness of customers to buy access to laboratory resources*". The benefits of sharing must be demonstrated over direct access, and the real benefits are the selling point. Customers expect valuable content, ease of use, affordable services, access to otherwise inaccessible materials and equipment, and customer support (Kammerlohr et al., 2021). In addition, sharing must be trustworthy. This point relates to both the functional and success criteria of sharing. Compared to physical markets, where trust is built through relationships, the digital environment currently uses transparent rating systems that consider the quality and reliability of the actors (Schallmo et al., 2017). Nevertheless, this does not achieve the interpersonal trust that comes into play in social contacts, as discussed in more detail in Section 3.2. However, a closer look at possible user groups, such as industry and students, also shows that they have different requirements (Kammerlohr et al., 2021). For industry, for example, integration into the corporate structure, data security, and the protection of intellectual property are of great importance. For students, on the other hand, the added value must be recognizable in comparison to or in addition to their regular lectures.

Thus, a business model for online labs is needed that is tailored to the needs of customers and providers while fulfilling the trust in network organizations. Following the business models of the leading providers in the sharing economy, a multi-sided platform would be suitable for the activation of the concept. A multi-sided platform is an intermediary for exchanging value between interested parties and providers from two or more markets (Zhao et al., 2019); for example, it is used by Airbnb (landlords and renters), eBay (buyers and sellers), and Facebook (users, advertisers, and content developers). In the DigiLab4U concept, the universities would offer various online labs, and students could meet their needs via a corresponding platform. Here, the interested parties are the students, and the providers are the universities. The marketplace is the DigiLab4U platform, where the joint exchange and coordination service takes place and supports matching providers with buyers (European Commission, 2013). The main difference with a traditional business model is that the DigiLab4U marketplace does not acquire ownership of the resource traded and therefore has no influence on the way it is presented or the price. The terms of sharing are therefore directly controlled by the provider and the buyer. The online lab provider

must therefore keep its offer and prices attractive to attract and retain buyers. More users on both sides (supply and demand) increase the benefits of the DigiLab4U marketplace, the so-called network effect (Abdelkafi et al., 2019).

The challenges of a multi-sided platform, according to Henseling et al. (2018), are: (1) building user trust, (2) evolving what the marketplace offers, and (3) attracting new user groups. In addition, the life cycle of a marketplace is described as consisting of three phases (Abdelkafi et al., 2019 ; Otto & Jarke, 2019): (1) design: technological architecture and innovation of the platform (software and hardware), (2) dynamics: evolution of the platform and ecosystem by attracting users and adding new functionalities, and (3) performance: scaling, growth, and competitive success. The challenges for a multi-sided platform, such as developing trust, need to be addressed first, and depending on the current phase of the marketplace, the other goals and associated challenges afterward. Trust is extremely important for the development of the online lab, as a loss of trust could lead to the collapse of the network effect.

In the example of DigiLab4U, the user must trust that the online lab will be available at the right time and in the expected condition, while the operator, e.g. the university, trusts that the lab will be used correctly and under the conditions agreed upon and that no damage will occur. Particularly with online resources such as online labs, the parties involved may not know each other and must have confidence that each other's requirements will be met. Independent information from third parties can provide clues to this and help to build initial trust before one's own experience can be gained (Ba et al., 2003). Two further organizational aspects for the DigiLab4U shared lab network can be derived from the business model: first, a model for the marketplace that initially, but also in the long term, builds trust between the provider and customer to avoid disruptions in the network; second, a maturity model that allows providers to pre-evaluate the effectiveness of the online lab's transformation, and that provides a kind of trust reference for the user of a third actor that evaluates the effectiveness of the online lab's organizational transformation.

### *3.2 Trust to Leverage the Business Model and Increase Organizational Effectiveness*

In general, trust arises from and in relationships, and therefore it can be created and destroyed (Flores & Solomon, 1998). A trust relationship involves two parties, there is uncertainty and risk, and the trust giver relies on the honesty and goodwill of the trust taker (Siau & Shen, 2003). A distinction

is made between weak and strong trust relationships, with a strong relationship characterized by feeling secure and trusting that our partner can rely on us and will respond to our needs (Rempel et al., 2001). Trust occurs in various social contexts and can arise both between individuals and between individuals and organizations as a hybrid form (Zaheer et al., 1998). A further distinction is made between trust that already arises on the basis of an existing trust relationship and trust that must first be established. In addition to initial trust, there are trust models that reflect the development of trust during the interaction of the parties, such as that of Lewicki and Bunker (2010). The transitional stages of their trust development model describe how two parties form and develop a new relationship and explain how trust and relationships change, develop, or decline over time and how trust can be restored. In doing so, the transitional stages of the trust model maps different benefits and different costs for each stage (sequential iteration) (Lewicki & Bunker, 2010).

In contrast to trust in a social context, online trust or technology-based trust is increasingly being studied, e.g., e-commerce (Gefen, 2000), trust in smart personal assistants (Zierau et al., 2020), in blockchain platforms (Zavolokina et al., 2020), or for entire research disciplines such as information systems (Söllner et al., 2016). The difference with online trust is that in an online situation, it is more difficult to reasonably assess the potential harm and goodwill intended by others (Friedman et al., 2000). To this end, new methods have been developed, such as a user-centered rating system, trusted third-party certifications, or trusted third-party recommendations. Long-term trust conditions have not yet been used in technology practice because the focus to date has been on initial trust rather than the impact of long-term development. Similar to Lewicki and Bunker's (2010) model, Williamson's (1993) transaction cost theory follows a parallel idea when parties begin to validate activities in terms of trust to build a knowledge base about their needs, preferences, and priorities. According to this theory, a transaction can be processed and organized more or less efficiently, which describes the transaction costs. An adaptation of this transaction concept for trust in a technology context could map trust interactions into a trust-level model and promote benevolent behavior through lower (transaction) costs. For example, a user with a higher level of trust will be more willing to accept a trusted online lab offer because they will expect the transaction costs to be lower. One way to provide information to users to build long-term trust is to develop technology maturity models, as described in the next section, which are enabled by a business model by influencing costs through trust levels. The combination of a business model and a maturity model, both of which promote long-term trust, should ensure that after

the initial trust, there is stakeholder interest in building a long-term trust relationship, thus underpinning the sharing.

### 3.3 Maturity Model for the Effectiveness of Digital Lab Transformation

Digital transformation is defined by Pousttchi et al. (2019) as a change process that companies undergo due to the emergence of new technologies and their social and economic impact. Digital transformation of labs is therefore defined as a continuous development process that goes beyond the emergence of new technologies and their social and economic impact to include the construction of a new business ecosystem. Various studies measure this transformation from a didactic and technical perspective in order to make its effectiveness transparent to stakeholders and to build trust. The pedagogical effectiveness of online labs at different stages of digital transformation as an indicator of the usefulness of an experiment to achieve the desired goal has been studied by various authors, e.g., Brinson (2015). Similarly, studies on technological effectiveness, such as the design, development, and implementation of different digital lab transformations have been pursued, as by Prada et al. (2015). Corresponding maturity models for both areas can also be found in research literature (Abbas, 2019), but a model that takes into account organizational change towards sharing between institutions and thus the needs of users and operators is currently lacking. The organizational effectiveness of digital lab transformation has not been further researched since then but has gained importance over time due to the changing requirements of lab sharing, such as building initial trust between different actors and organizations. Numerous international research projects involving online labs have failed to continue the environments developed after the project funding phase (Esposito et al., 2021), not least due to lack of effectiveness.

Digital lab transformation effectiveness is defined as the evaluation of the lab's digital transformation efforts with the goal of sharing (Kuntsman & Arenkov, 2019). In this study, effectiveness is specifically defined as the quality of the change process organizations undergo that involves technology and its social and economic impact. Specifically, effectiveness is about four dimensions: (1) universality and accessibility, (2) user management, (3) scalability and extensibility, and (4) learning support. These are aligned with Garcá-Zubía's (2021) structures for the requirements of a remote lab management system and the characteristics of a remote experiment. Universality and accessibility describe if and how a lab is accessible to the user in any technological scenario and refer to the original design of the experiment (Garcá-Zubía, 2021). In this context, Prada et al. (2015) added easier

support and efficient management. The second requirement, user management, consists of four subsections that describe how users gain access to online labs, how their data is managed, what user rights they have, and how their experiment data set is stored (García-Zubía, 2021 ; Ying & Zhu, 2004). The third requirement is scalability and extensibility, which consists of five subcategories. Scalability and extensibility describe how easy it is to adapt the labs to new audiences, expand them to include more experiments, extend them to more facilities, certify the results, and ensure sustainability (García-Zubía, 2021). The fourth requirement is learning support or pedagogical effectiveness, i.e., whether and to what extent the online laboratory supports coursework (García-Zubía, 2021). As Kara et al. (2010) stated, “*effective learning in engineering education can only be achieved through approaches that link theoretical courses to the laboratory*.” The lab supports not only experimentation, but also social coordination, the lab environment, and individual differences (Nickerson et al., 2007). We distinguish between learning environment, interactivity and realism, technical support and maintenance, and didactic support.

In terms of application in the DigiLab4U project, it should therefore be further investigated whether the effectiveness of digital lab transformation in support of the sharing economy can be mapped in a maturity model. The practical use of DigiLab4U promises comparability of the effectiveness of shared labs, both from the provider’s perspective in terms of administrability and financial and personnel effort, and from the perspective of demand in terms of learning success. The theoretical perspective has shown that the effectiveness of digital lab transformation assumes that criteria are subject to multiple truths and that these are determined by the subject matter and the underlying use case. Therefore, a constructivist approach based on multi-stakeholder interaction should be used to gain insights into and build knowledge about the effectiveness of labs’ digital transformation within the shared DigiLab4U network.

## 4 Discussion

Returning to the research questions, we can conclude that this research has provided an overview of the fundamental organizational aspects of shared lab networks through a general understanding of business models, trust, and maturity models for digital labs. Specifically, a business model that promotes sustainability by enabling online lab sharing. A maturity model that can determine the effectiveness of digital lab transformation, and a consideration of trust as a key element of platform business.

As described in the second phase dynamics of the life cycle of the multi-sided marketplace, the platform and the ecosystem should be further developed depending on the current situation (Otto & Jarke, 2019). In addition to the three organizational aspects already described, there are numerous other ways to further develop the business model marketplace and keep it attractive to customers, which we divide into central services, individual services, and community services. By central services, we mean applications that are offered centrally from the marketplace to improve matching, for example. We think of cooperative resource management, from which a common booking and billing process, work properties and resources, and common and standardized terms of use emerge, but also a booking system that is able to cover the different needs of user roles, such as a recurring event for a lecture series. Associated with this should be a flexible billing system on a transaction basis to map the described levels of trust, individual but also standardized, national and international, and billing for companies and universities. Individual services are services provided by the marketplace on an individual basis, such as lab didactic or transformation services, research services, or the sale of processed research data. Community services are actions taken to build and sustain the community as an ecosystem around the marketplace. Simple things like a shared vision, or mission statement can help, but so can conferences, awards, badges linked to learning paths for external visibility of learning success, or individualized advertising for job openings or research contracts.

Generalizations can be applied to related application areas such as vocational training, but also to broader areas such as shared infrastructures and digital transformation, e.g., the business model of shared resources, as in research facilities for industry and research, or the effectiveness of transforming the digital infrastructure of government agencies or universities. Technology-based initial trust and long-term trust could be generalized in order to build trust in new technologies.

Limitations arise from differences in the education system, such as regional differences in the willingness to pay for education and the degree of digitalization. One problematic issue is the willingness to pay; traditionally, education in Europe has been free. Students accept that the cost of a digital lab must be paid, but there is considerable dispute about whether the state, the university, or the students themselves should pay for it. Another limitation is the language and cultural differences that affect the type of education (practical vs. theoretical) and the level of education (BA, MS, PHD). In addition, regional taxes and public sector billing may impose limitations.

## 5 Conclusion

This paper addresses the problem of sharing online digital education resources for STEM subjects. Lab exercises to gain hands-on experience and practical knowledge play an important role in the education of future engineers and scientists. Online labs can be used to gain this experience online. However, sharing online labs is currently insufficient; in fact, a large percentage of lab providers fail to keep them running (profitably) after research funding. This paper addresses this problem by highlighting the organizational aspects of online lab sharing to provide a long-term perspective for lab networks and to serve as a foundation for online lab sharing between providers and buyer. The analysis includes three different organizational proposals for improving the sharing of these labs to increase sustainability, using DigiLab4U as an example. The research potential, generalizations, and limitations were highlighted.

The next step is to further explore the organizational aspects scientifically and put them into practice using DigiLab4U as an example to gain insights and experience. This will provide a more detailed insight into the community, further elaborate on buyer and provider demand, make different online lab transformations organizationally comparable, clarify dependencies in more detail, and test the initial but also the long-term trust network. In addition, experience can be gained from later life cycle phases of the multi-sided platform business model for sharing online labs.

## Acknowledgements

This work has been funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112.

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## **Research Data Management for Laboratory Services: the DigiLab4U Use Case of Dataverse**

### Abstract

The ongoing digitalization of academia and research institutes has led to an increasing need for suitable processes of data management and dissemination. As a result, research is increasingly asking for standardized data management processes. Research data management (RDM) has emerged as an important concern for the whole scientific community, and several platforms to support data deposits have been designed and released. Actually, (i) rules of management and (ii) the curation of advanced data catalogues seem to be generally lacking. Moreover, one of the major challenges is encouraging consultation and ‘buy-in’ from researchers and senior managers. This paper presents the implementation of Dataverse by the DigiLab4U consortium from this standpoint. The benchmarking process among research data management (RDM) platforms available on the open-source market, and the hierarchical structure for storing and managing data are introduced and discussed.

### Keywords

Research Data Management (RDM), Dataverse, Servitization

## **1 Introduction**

The ongoing digitalization of academia and research institutes has led to an increasing need for suitable processes of data management and dissemination. As a result, important scientific journals, academia, but also third-party funding institutions are increasingly asking for standardized data management processes (Wilms et al., 2018). Research data management (RDM) has emerged as an important concern for the whole scientific community, and several platforms to support data deposits have been designed and released (Amorim et al., 2015). Technological progress, especially under the advent of the Internet of Things (IoT) era, created a state of the art involving

high-level performances, with respect to the possibility of storing huge amounts of data, and accessing them everywhere by means of cloud services, for instance. This allowed providers to supply advanced data management services. Although these important results were achieved, the management and curation of advanced data catalogues seem to be lacking (Cox et al., 2017). As a consequence, institutions that eventually share the data must establish their own rules for the suitable management and promotion of research data (Wilms et al., 2018), otherwise, data catalogues could result in a mess. In addition, major challenges include (i) resourcing, (ii) adaptive capacities and communicability with other services, and especially (iii) encouraging consultation and ‘buy in’ from researchers and senior managers (Cox et al., 2017). The ‘buy in’ formula for the provisioning of data especially is a new and important topic in research, and it is gaining attention, especially from business entities that are interested in buying research data and scientific knowledge from academia and research institutes (Esposito et al., 2021). Therefore, this paper presents the implementation of Dataverse by the DigiLab4U consortium. The DigiLab4U consortium, under the Open DigiLab4U project funded by the German Federal Ministry of Education and Research (BMBF), aims at creating a network of digitalized labs via the Internet of Things, towards hybrid education, cross-institutional research, and cross industrial cooperation. Dataverse is a type of open-source software for the management of files in the academic field. It has been selected within a benchmarking assessment, with respect to some requirements required by the DigiLab4U, and identified according to Amorim et al., (2015). This paper provides a standardized hierarchical structure for organizing the research material in a RDM system and hence answers the research question about a possible solution to managing the curation of content in research data catalogues. The remainder of the paper is as follows: section 2 provides an overview of the literature on digital online labs and RDM in this field. Section 3 briefly introduces the DigiLab4U case and provides the benchmarking assessments of the RDM platforms and software. In section 4, the hierarchical structure is presented and tested, and then its validation is discussed. Finally, section 5 addresses conclusions and outlooks for future works.

## 2 Literature review

The literature on digital online labs has been increasing even more over the last decade (Heradio et al., 2016). Basically, two research lines have arisen: one about the didactical perspective, and one about technical implementati-

on (Zappatore et al., 2015). What is missing is a deep analysis of financial and organisational aspects for making labs and networks in which they are inserted robust from a life cycle perspective (Esposito, Kammerlohr, et al., 2021). In this regard, Esposito, Mezzogori, et al. (2021) have showed that most digital online experiences last only for the time in which they are funded by institutions and organizations under the programs of national or international projects. From this point of view, Esposito, Kammerlohr, et al. (2021) analyzed the possibility of using research data for business partnerships upon payment, with generally positive results from several Italian companies. As a result, platforms for data curation and sharing are needed of course. Although advisory and consultancy services have been recently stressed, technology and data deposit assistance seem still to be lacking and are only forecast in the near future (Corrall et al., 2013). As a counterproof, a single result is obtained by querying Scopus with the following search string: ( TITLE-ABS-KEY ( "Research Data Management" OR RDM ) ) AND ( ( ( "data curation" ) ) AND ( "data curation" ) ) AND ( "data catalogue" ), and the only work by Cox et al. (2017) attests to the lack of works and research on data catalogues and the active curation of data.

### 3 Dataverse within the DigiLab4U environment

In this chapter, firstly the DigiLab4U case is described. The technical system is just referenced here using the work by Galli et al. (2020) and Kammerlohr et al. (2021) since it is not of interest in this paper and is not discussed further. A deeper overview of the services provided is discussed, instead. Secondly, the requirements of the DigiLab4U for the selection of the RDM system are introduced. There are four key aspects to identify the DigiLab4U requirements, according to Amorim et al. (2015): (1) architecture, (2) meta-data handling capabilities, (3) interoperability, content dissemination, and search features, and finally (4) community acceptance. Lastly, commercial solutions are analyzed in a benchmarking assessment, resulting in the selection of Dataverse.

#### *The DigiLab4U case and its services*

DigiLab4U is the cross-Institutional network of Industry 4.0 lab infrastructure. The consortium is led by the Hochschule für Technik Stuttgart (HFT), and joined by the other four founding members: the Bremen Institute for Production and Logistics (BIBA), the Institut für Wissensmedien

(IWM) of Koblenz-Landau, the Rheinisch-Westfälische Technische Hochschule (RWTH) of Aachen, and the University of Parma. Nowadays, it has another nine partners all around the world (see <https://digilab4u.com/consortium/>). The network was funded by the German Federal Ministry of Education and Research (BMBF) for developing the project ‘Open Digital Lab for You’, which created an integrated, hybrid learning and research environment consisting of a large variety of lab technologies offering digital services and reaching all kinds of possible users. The digitized lab environment intends to enable a real IoT learning marketplace, consisting of both digital labs from several suppliers and users who access to the labs. The cooperation between universities, research institutions and industry allows the suppliers to be pooled so that users have access to a larger variety of digital courses based on different IoT labs. As a consequence, one of the main features of such a network is the availability of tracked and traceable data repositories for research data, and suitable systems for retrieving and accessing them. Hence, an RDM was needed.

#### *Requirements of the DigiLab4U for the RDM system*

The proposed system must comply with two main functionalities of storing data: their ownership is assigned and they can be retrieved with a suitable reference system. First, from the user’s perspective, people have access to old batches of data or new data generated by remote, performing analysis without collecting data physically in a lab. Second, from a content uploader’s perspective, while they are uploading a data set, a new DOI must be automatically created, making data referencing easier and faster when using them and the information generated by them. Lastly, an efficient and organized framework to store all the data is required to promote data consultation and referencing. These translate into the following seven requirements, and each one is related to the four key aspects of Amorim et al. (2015): (i) the tool must support REST API, (ii) it possibly needs to be open source, and (iii) data must be hosted within Germany—these three requirements meet the key aspect (1); (iv) the ability to visualize the stored data must be accomplished, (v) it must support a wide range of data formats, based on the recommendations by the German association “Verbund Forschungsdaten Bildung”, and (vi) the facility to generate edit and back up data is required—these three requirements meet the key aspects (3) and (4); finally, (vii) extraction of metadata from data must be simple and structured—this requirement meets the key aspects (2) and (3).

### *Benchmarking commercial solutions*

Several RDM systems are commercially available, and in this phase, some have been analyzed with respect to the requirements of the DigiLab4U. Software identified from a market investigation performed on the Web are listed here: CKAN, RADAR, bwScienceToShare, Freidok plus, Dataverse, EdShare, dSPACE, and DKAN. Functionalities and characteristics have been mapped through ten main features, according to the requirements. These are (i) support for file formats, REST API, service support, and community, (ii) suitable data visualization; (iii) consistently building technology; (iv) type of license and price; finally, (v) host and service provider, and main users. If a single requirement is missing from the above features, the software is neglected. As a result, two types of software have been selected for comparison here: Dataverse from the Dataverse project, and dSPACE by dSPACE GmbH. Dataverse is rich in features and has an active service and user community to support users and service providers. Hence, the benchmarking has been concluded selecting Dataverse, which meets all the DigiLab4U requirements.

## **4 The structure and its transposition**

Dataverse is an open-source Web application from the Dataverse Project, developed to share, preserve, cite, explore, and analyze research data. Mainly used by academia, it allows researchers, journals, data authors, publishers, data distributors, and affiliated institutions to access and replicate data from research, ensuring academic credit and Web visibility. A Dataverse repository (wordplay for data-and-universe) is the software installation, which then hosts multiple virtual archives called Dataverse collections, administrated by its creator, who has access to managing all the settings. A Dataverse collection is a container for data sets, each one containing data files (e.g., research data, code, documentation) and related descriptive metadata (e.g., tag and keywords, including documentation and a code that accompanies the data). Once a file is uploaded into a data set, it is no longer possible to eliminate it from the Dataverse. Also, the Dataverses can hold one or more Dataverse collections, which can be set up for individual researchers, departments, journals, and organizations. Dataverses and data sets within the main Dataverse can be created and placed arbitrarily, and they can also be categorized by means of Dataverse categories that identify the type of data hub (e.g., institution, laboratory) and address possible query strings. Hence, the need for a standard framework for uploading and managing con-

tent, ensuring ease of retrieving and accessing data. The proposed structure consists of a five-level structure in a father-son manner, from the Dataverse of the single institution within the main DigiLab4U Dataverse (at the top of the hierarchy) to the file attribute (at the bottom of the hierarchy). The structure is provided in Figure 1, with reference to an example in which two partners upload data from experiments performed in their respective remote laboratories. Each level is described in the following. At level 0 it is possible to find every key partner in the Digilab4U network. Every institution will have its own Dataverse collection in the main DigiLab4U Dataverse. Level 1 contains all the labs of every institution. Level 2 refers to all the specific experiments or analyses that can be performed by a laboratory. Level 3 contains all the data sets of a specific type of experiment or analysis. Lower level 4 contains all the files of a specific data set. Three actions are envisaged when uploading content. First, before uploading data, they all need to be renamed using a formatting standard consistent with the uploading session. Second, specific tags need to be applied to every single file. Third, if the files need to be collected and organized in folders according to their characteristics, compressed files can be used, which enables tree visualization.

LEVEL 0 - Partner / Institution Dataverse	UNIPR			HFT
LEVEL 1 - Laboratory Dataverse	Logistic RFID LAB		SCM Serious Game	RFID LAB
LEVEL 2 - Group of experiment Dataverse	Reading Optimization Analysis	RSSI curve Analysis	Financial Feasibility	... Anechoic Chamber
LEVEL 3 - Experiment Dataset	Experiment on 10/06/2020	...	...	...
LEVEL 4 - Data and data/files	Far Field signal	Near Field Signal		

*Figure 1: Hierarchical structure for storing Dataverses and data sets*

The hierarchical structure so formalized has been discussed by a panel of 8 experts in the field of education and data management from HFT, BIBA, and Parma. The installation and the efficiency of the structure have been discussed, and no concerns arose. Therefore, the demo of the DigiLab4U Dataverse has been officially presented and validated by the experts. The verification of its functionalities and its approval has been achieved, and the system has been recognized as suitable with respect to the original requirements of the DigiLab4U and is now approaching the Go-Live phase.

## 5 Discussion and Conclusions

In this paper, a hierarchical structure for RDM in Dataverse is presented, referring to the DigiLab4U case. The novelty presented in this paper refers to a more efficient and organized way to store data on the RDM platform Dataverse by means of a five-level structure. This has been chosen as the best compromise between the redundancy of Dataverses and levels of detail in the data catalog. This structure has been verified with respect to (i) the simplicity of the query for retrieving data, and (ii) the suitability of the data catalog structure fostering data consultation. Although this is not evidenced by the paper, it has been discussed, with the several experts involved in the validation and verification process, that companies could be interested in acquiring research results that mostly fit their needs, creating room for the supposed financial sustainability of labs and the network. Future works could analyze this topic, and authors are working on this.

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*Jens Doveren, Birte Heinemann and Ulrik Schroeder*

# **Towards Guidelines for Data Protection and Privacy in Learning Analytics Implementation**

## Abstract

While leveraging data collected from learners to improve teaching and learning outcomes has an inherently desirable end goal, Learning Analytics researchers have to be aware of data protection policies and the justified desire for privacy while learning when rolling out such data collection efforts. Successful implementation requires knowing legal frameworks, coordinating with the personnel responsible at the individual institution, and clearly and openly communicating the extent and goal of the data collection effort to the learners and teachers.

In this paper, we present existing community guidelines and our own experiences from a rollout of Learning Analytics in the DigiLab4U project.

## Keywords

Learning Analytics, Data Protection, Privacy

## **1 Introduction**

The field of Learning Analytics seeks to leverage quantitative data about learning processes to improve teaching efficacy and learning outcomes. These improvements can derive from data directly, e.g., by presenting learners with insights into their own behaviour, or more indirectly, e.g., by informing decisions about how to improve future iterations of a course.

While such improvements to teaching are inherently desirable for students, gathering data about learning processes while they happen requires a certain degree of interference with the learner's privacy. Depending on the specific learning environment, the kind of data collection, as well as the mode of a collection, can vary widely, but examples include clickstream analysis in learning management systems or gaze and movement analysis in virtual reality applications. Some users might perceive such data collection as surveillance, which might in turn have an adverse effect on their willing-

ness to engage with the learning environment or might even lead to them refusing to engage at all.

Another complicating factor in data collection for Learning Analytics purposes, especially when working in an environment involving institutions from different jurisdictions, are different data protection policies and legal requirements. The intricacies of different data protection policies require communication and individual clearing with every institution that is involved.

Regardless of individual regulations, learners must be able to make an informed decision about whether they consent to the collection of their data. From this requirement follow two implications: one technical and one communicational. On the technical side, systems must be designed in a way that respects users' consent or the lack thereof, i.e., they must provide baseline functionality for users that have opted out of data collection, and they must be able to delete user data should consent to be withdrawn. On the communications side, challenges include finding ways to explain what pieces of data are collected and processed to potentially not particularly tech-savvy learners, as well as clearly communicating the potential benefits learners might reap from participation.

We aim to develop guidelines for researchers that intend to implement Learning Analytics data collection in real-world scenarios. These guidelines will be informed by previous work in that field, our own experience in rolling out Learning Analytics in various institutions of a multi-national research consortium, as well as a series of interviews with researchers and students about their expectations towards Learning Analytics, attitudes towards privacy and how they value the trade-off between the two.

## 2 Background

### 2.1 Data Protection Regulation

The European Union and its member states have long enacted regulations regarding the processing of personal data. As per (REGULATION (EU) 2016/679 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, 2016), all handling of personal data must guarantee the following:

- Lawful processing
- Specified, explicit, and legitimate use
- Protection from secondary use
- Protection from inadequate and irrelevant processing

- Protection from the use of outdated information
- Protection from unnecessarily long data retention

In addition, the General Data Protection Regulation (GDPR) explicitly codifies the following people's privacy rights (What Is GDPR, the EU's New Data Protection Law?, 2020):

1. The right to be informed
2. The right of access
3. The right to rectification
4. The right to erasure
5. The right to restrict processing
6. The right to data portability
7. The right to object
8. Rights in relation to automated decision-making and profiling

The intricacies of how these principles influence the implementation of Learning Analytics are beyond the scope of this paper but are summarized in (Lukarov, 2019), as well as (Hoel et al., 2017). Underneath the overarching European regulation, there is an entire stack of more specific regulations and ordinances from a national down to an institutional level. Considering these highly heterogeneous regulations and institutional practices, the only general advice one could give to the aspiring Learning Analytics implementer is to communicate with the data protection officer responsible.

## 2.2 Community Experience

We are far from the first group to implement Learning Analytics in a real-world context, and the issue of privacy and data protection looms over all these efforts. After some rather unfortunate learning experiences, such as the failure of the Gates-funded inBloom (Singer, Natasha, 2014), where overzealous and ill-communicated collection of learning data from sensitive subjects led to a very public backlash, the Learning Analytics community has developed guidelines and checklists for effective communication and stakeholder involvement, such as the DELICATE checklist in (Drachler & Greller, 2016) and (Schumacher & Ifenthaler, 2018).

The privacy implications of different technology stacks and processing methods are the subject of ongoing research in the Learning Analytics community, having led to the use of such elaborate methods as differential privacy (Steil et al., 2019). A survey of the available literature can be found in (Ciordas-Hertel et al., 2019).

Apart from careful technology choice, open and honest communication is the most important ingredient to a successful rollout of Learning Analytics. That entails explaining what is stored, for how long, and how it is being used, but also making sure learners see a tangible benefit from having their data analysed.

### 3 Own Contributions

#### 3.1 *Choice of Data Warehousing Solution*

When gathering data from learners, the technical implementation of how that data is stored is of particular importance when considering data ownership and privacy. In order to be able to make any guarantees with regard to retention policies, deletion of data upon user request, and such, a thorough understanding of the selected data warehousing solution is required.

As it would be dishonest to promise users properties that we ourselves have no way of ensuring, we only considered self-hosted solutions that are free and open source. All hosting and maintenance of the data warehousing solution in the DigiLab4U project were done at RWTH Aachen University.

Although that might seem counterintuitive to those who have never implemented a software system with data persistence, architecting such a system in a way that ensures data integrity, prevents accidental loss of data, and enables arbitrary user data to be deleted at will is a surprisingly tricky endeavour. Hence, many implementations of xAPI learning record stores do not allow the true deletion of data, which we did not deem satisfactory.

These considerations and a thorough survey of the options available led to the choice of *Learning Locker* as the learning record store in the DigiLab4U project. A more detailed description of the decision-making process, as well as an overview of the privacy implications of many ready-to-use Learning Analytics data warehousing solutions on the market can be found in (Lukarov et al., 2020).

#### 3.2 *Stakeholder Survey*

One of the lab environments enhanced with Learning Analytics as part of the DigiLab4U project is the RFID measuring chamber at HFT Stuttgart. In late 2021, the students of the bachelor program in Information Logistics were asked to take a survey containing questions of interest to various research groups in the DigiLab4U project. We were particularly interested in

students' pre-existing experience with Learning Analytics, the value they see in it, as well as their attitude toward sharing their data to enable Learning Analytics not only for them personally but also for fellow students.

Of the 41 participants, 34 filled in the survey completely. The results are hence to be treated more as anecdotal data but can nevertheless give us pointers on how to improve the rollout of Learning Analytics in future courses.

The two aspects relevant to the acceptance of data collection for Learning Analytics purposes in this context are the perceived value for the learners and whether it is great enough to overcome an inherent reluctance towards data sharing. In order to judge the degree to which attitudes toward Learning Analytics results might be tainted by a general lack of statistical literacy, we asked participants to specify their pre-existing knowledge in statistics in general and data visualization interpretation in particular.

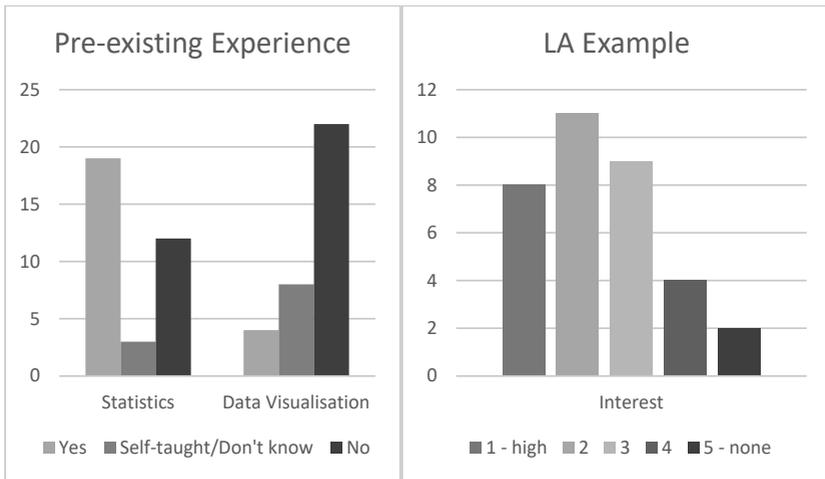


Figure 1 – Student Survey Results

As regards experience with statistics, of the 34 participants, 19 reported having taken a statistics course, 3 reported to be self-taught, and 12 reported no experience. In that same cluster of questions, 4 out of 34 students explicitly reported experience with interpreting data visualizations, 8 did not know, and 23 reported no experience.

Presented with a fictional example of data visualizations for learning feedback and asked whether they would find such feedback interesting, 8 respondents gave a 1 (very interested) on a five-step Likert scale, 11 gave a 2, 9 gave a 3, 4 gave a 4, and the remaining 2 gave a 5. When asked whether they would be willing to share their learning data to help in the generation of such feedback, only one participant gave an unconditionally positive response, 20 specified that they would require their data to be anonymized, and 13 did not give any response.

#### **4 Closing Thoughts**

The results of the learner survey suggest a certain degree of hesitation towards sharing their data. One possible cause may be a failure to see how they might personally benefit from feedback generated using Learning Analytics. Over 40% of participants reported only middling or no interest in the examples that were provided, which might explain the lack of enthusiasm.

These experiences once again underline the importance of early communication with learners as stakeholders. Only they can articulate their needs and the value that they attach to any given form of feedback, which in turn must be evaluated by teachers with respect to its didactical value.

Another factor that was beyond the scope of this paper is the issue of scaling up Learning Analytics infrastructures—moving from a smaller, more experimental rollout to a larger, institution-wide one often requires the use of different, industry-grade big data processing frameworks, which again come with their own privacy considerations. The bigger such a project grows, the higher the incentive for standardization, which on one hand facilitates collaboration and exchange of knowledge, but on the other hand, to a certain degree limits technological choices.

#### **Acknowledgements**

This work has been funded by the German Federal Ministry of Education and Research (BMBF) through the project DigiLab4U (No. 16DH2114).

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## **Remote, Virtual and Physical Labs in Engineering Education: What is the Best for What?**

### Abstract

Lab work plays an important role in engineering education to ensure that the students have familiarized themselves with and acquired the right practical and scientific competence in engineering, specifically procedural and practical knowledge and skills when leaving university. However, physical labs are costly, require specialized staff, are often underutilized, and in dynamic fields like manufacturing and logistics, they age fast. The rapid development of new educational technologies and the digitalization of both educational and industrial sectors offer new digital channels for delivering lab education to students, both with remote access and/or as fully virtual (online) labs. However, due to the lack of standardized assessments, there is an academic discussion going on about the extent to which these new forms of providing lab work to students can replace, improve, or complement physical labs work. This paper presents the results of a systematic literature review using the search terms: “remote labs”, “virtual labs”, and “physical labs” in the domain of teaching engineering. The main objective of this study is to develop an overview of what is identified as the advantages and disadvantages of each lab type in the scientific research literature. The secondary objective is to see if there was an explicit understanding of when to select a specific type of lab based on the learning achievements aimed at and learning activities for the students. Thirdly, its goal is to investigate if these types of labs are based on the same pedagogical foundation—like social or cognitive constructivism.

### Keywords

Virtual Labs, Remote Labs, Physical Labs, Engineering Education, Cognitive Constructivism

## 1 Introduction

Due to the COVID-19 pandemic in the last two years, many higher education institutions had to offer their programs completely online [1, 2]. Most engineering and science schools offer a content-centered education with a focus on developing both ‘critical-thinking’ as well as ‘problem-solving’ skills, often through active-learning approaches, which are much more hands-on and project-based [3–6], and thus laboratories and internships play a vital role in educating future engineers [7, 8]. However, physical labs are costly, tend to have low utilization rates, and require specialized knowledge for their operation and maintenance [9, 10]. The DigiLab4U project was initialized before the COVID-19 pandemic hit the global education system and since then it has been focused on developing an international network of laboratories sharing their facilities in a virtual and/or remote operation way. This vision has come “just in time” to meet the upcoming challenges by providing future engineering students with the required hands-on skills to succeed in the Industry 4.0 era. The project is specifically focused on the Internet of Things (IoT) role in engineering education both at the undergraduate and postgraduate levels [11]. Moreover, online teaching is not new but many universities had only implemented it for lectures and not, for example, for situations that implied teaching subjects/courses within engineering education which required a high degree of lab work and physical interaction (e.g., with specialized equipment) [12]. In terms of online labs, their digital transformation from physical to digital has been described by [13] and [14]. These may be divided into software-driven labs (like simulations) and hardware-focused labs [7], while [15] have a slightly different understanding. The distinct understanding of what is meant by online, virtual, and remote labs might, however, increase the barrier to building a network of laboratories that offer education for each other’s students [9, 16, 17]. The authors, therefore, carried out a “systematic literature” review to shed some light on the evolution and understanding of remote, virtual, and online labs in engineering education during the last five years. The reason for limiting the study to the past five years is rapid technological change, which directly impacts the possibility of creating suitable online, virtual, and remotely operated physical labs at lower costs.

## 2 Research Methodology

This paper aims to determine the research coverage in terms of the state of the art related to remote, virtual, and physical labs in STEM (Science,

Technology, Engineering, and Mathematics) subjects. In this context, the study seeks an answer to two main research questions:

RQ1: What is the current state of the art related to remote and virtual labs?

RQ2: How does the digital transformation journey trend impact the way we serve education?

This work utilizes a systematic literature review (SLR) as its primary method. An SLR seeks to systematically search for, appraise, and synthesize research evidence on what type of lab (*viz.*: remote, virtual, or physical) is best for what learning achievements and learning activities for the students in engineering education. Therefore, it requires detailed work on the queries' definition and rigorous evaluation of the terms used (keywords) to ensure the search is widespread without being vague or general; given the context of the topic, it could quickly become overly broad, comprising all types of laboratory work provided to students.

An SLR aims to produce an objective protocol that is not compromised by the researchers' subjectivity. According to [18], this helps in defining what is known and what is unknown. In this review, we followed the SLR strategy proposed by [19], which implements a four-stage protocol. The reason for selecting this approach is that it has been utilized by several researchers [20–24] and we have good experience in carrying out its guidelines. The four stages reviewed and included in this SLR are:

1. Planning the review—Selecting the population or sample, *i.e.* the focus of the study.
2. Conducting the review—This stage involves four critical steps:
  - i. Identifying keywords and search terms (from scoping study) from the literature review and discussion with a team.
  - ii. Searching for published journals, bibliographic databases, unpublished studies, conference proceedings, industrial trials, the Internet, and even personal requests.
  - iii. Providing a complete list of results (articles and papers) on which the review will be based.
  - iv. Constructing data extraction forms, which reduce errors. These can be constructed on paper or by computer.
3. Reporting—Stating the findings in thematic analysis; identifying critical emerging terms/topics and research questions.
4. Disseminating.

A more detailed description of the SLR approach can be found in [24]

### 3 An SLR on Virtual, Remote and Online Labs

Basing our work on the method described in Section 2, we carried out an SLR according to the four-stage protocol. The progression of the four stages was: (i) plan the review, (ii) conduct the review, (iii) report, and (iv) disseminate—all of which are presented in the following sub-sections.

#### 3.1 Stage 1: Planning the Review

Stage 1 comprises planning the SLR and determining the study sample, which is the focus of the study. This paper emphasizes various forms of online labs and their utilization in engineering education. The database we employed in the SLR is Scopus. This source is recognized for information on engineering education. The initial draft of the planning phase included the use of several databases. However, the authors removed them for two principal reasons: (a) low search results, and (b) limited space in this paper for dissemination of the results.

#### 3.2 Stage 2: Conducting the Review

Setting inclusion and exclusion rules for a particular study are essential to conducting a review. In this case, the search was limited to fully available peer-reviewed academic journals. The period covered was from 2015 to 2021.

The search criteria were: “TITLE-ABS-KEY ( remote AND labs ", " virtual AND labs ", and " physical AND labs ) AND ( LIMIT-TO ( PUBYEAR , 2020 ) OR LIMIT-TO ( PUBYEAR , 2019 ) OR LIMIT-TO ( PUBYEAR , 2018 ) OR LIMIT-TO ( PUBYEAR , 2017 ) OR LIMIT-TO ( PUBYEAR , 2016 ) OR LIMIT-TO ( PUBYEAR , 2015 ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ”; which identified 22 results. However, since both authors teach engineering subjects/courses, and that is also the main field of the DigiLab4U project, we excluded articles not related to engineering education, which then yielded eight hits. In the first general screening, the search terms were title, keywords, and abstract. We discussed excluding one result since it was a conference paper. However, we decided to keep it. We did not, in this first step, establish alternative and associated terms to expand the search. The authors selected Scopus as the initial database to test the search terms with the completed list of terms, and this was considered sufficient for a first initial investigation.

### 3.3 Stage 3: Reporting

In the next step, we carried out the analysis on title, keywords, and abstracts, being accessible and in English.

From screening on coding criteria and duplicate elimination, only eight articles met all the requirements established. The complete list is presented in Table 3, which indicates each article's categorization, which is further explained in Stage 4. Following the search queries, the results obtained can be summarized as follows: Out of the seven articles identified in Scopus, five are reviews, surveys or bibliographies comprising the development of virtual and remote labs in recent decades. One specifically addresses the evolution of education in software engineering, while the conference paper focuses on how to facilitate the creation of labs. Only one article investigates the effects of remote labs on learning outcomes in higher education.

### 3.4 Stage 4: Dissemination

The relevant articles identified are limited in number but can be classified into the following groups: (a) Surveys and bibliographies proving an overall overview of the field from different perspectives (five articles), and (b) one is related to the effect on learning outcomes.

## 4 Findings

The search in Scopus with the keywords described in Section 3 with the limitation of being in the field of engineering education gave a quite small sample size. The complete list can be seen in Table 1.

*Table 1 SLR Outcomes*

Author(s)	Publication Date	Title-Description
Grodotzki, J; Ortelt, T.R, Erman Tekkaya, A.	2018	Remote and Virtual Labs for Engineering Education 4.0
Heradio, R., De La Torre, L., Dormido, S.	2015	Virtual and Remote Labs in Control Education: A Survey
Heradio, R. et al.	2016	Virtual and Remote Labs in Education: A Bibliometric Analysis

Author(s)	Publication Date	Title–Description
Potkonjak, V. et al.	2016	Virtual Laboratories for Education in Science, Technology and Engineering: A Review
Esquembre, F.	2015	Facilitating the Creation of Virtual and Remote Laboratories for Science and Engineering Education
Zalewski, J., Gonzalez, F.	2017	Evolution in the Education of Software Engineers: Online Course on Cyber-physical Systems with Remote Access to Robotic Devices
Post, L.S et al.	2019	Effects of Remote Labs on Cognitive, Behavioral, and Affective Learning Outcome in Higher Education
Bhute, V. J. et al.	2021	Transforming Traditional Teaching Laboratories for Effective Remote Delivery—A Review

The small number of relevant articles identified was surprising us. Therefore, we did a new search without restricting ourselves to the field of engineering education or only to articles. That result yielded 149 hits and excluding conference papers, but not limiting the search to engineering yielded 69 hits. A second interesting observation is that the majority of the journal articles’ authors work in European organizations. The next section discusses in more detail the different findings and outlines the following steps.

## 5 Discussion and Conclusion

### 5.1 Contribution to the Research Questions.

RQ1: We aimed at investigating the current state of the art in remote and virtual labs. The articles identified, specifically the reviews, show that there are still several barriers to overcome before remote labs can be expected to deliver the same quality in terms of learning outcomes as traditional haptic labs. Furthermore, they also indicate that there are still several technical barriers to overcome on the one hand, but on the other hand, there is also a challenge for labs in keeping pace with technical developments. There have not been many thorough considerations of the cost factors, including maintaining and reducing the risk of lab aging in the articles we identified. Since we know that most of the authors are European and that there are

publicly financed universities in large parts of the continent, this is a little surprising. There were also only a few considerations as to what a shift towards more remote labs would mean in terms of the technical and didactical qualification needs of the employees operating the lab.

In terms of virtual labs, the literature identified reports more mature and integrated concepts, which have been in daily operation longer and work as an integrated part of the education. Besides the challenge of facilitation, it seems that, to a large extent, these labs achieve the same quality as on-site labs.

RQ2: How does the digital transformation journey impact the way we serve education? Three of the eight articles specifically addressed how digital transformation impacts the way we deliver engineering education. However, while [30 and 32] describe in more detail the organizational and practical changes that the transformation has caused, article [31] investigates its influences on cognitive, behavioral, and affective learning outcomes based on an analysis of 23 articles reporting the effect in higher education. Even though the findings are very interesting, it is still too early to conclude under which circumstances we should offer students remote labs and when not, since there are so many unknown factors that need to be further investigated.

Furthermore, it is too early to conclude that the digital transformation of education that we have seen during the COVID-19 pandemic period will progress at an equal pace for remote and virtual labs since their setup is different and also the successful achievement of intended learning outcomes seems to be diverging. It can also be mentioned that hardly any of the articles address how remote and virtual labs influence different non-technical competence, which according to ABET (Accreditation Board for Engineering and Technology, Inc.), however, is of utmost importance.

### *5.2 Limitations in Our Study*

We did only use one database to identify relevant articles. Searching more databases as well as carrying out a complementary snowballing approach would have given a more detailed picture of all lab developments. While the inclusion of more databases might provide a broader data set, the snowballing approach allows the researcher to identify relevant articles that may not necessarily appear in the database search using a search string [33] but can be identified in the articles in the search string. A quick look into the articles we analyzed showed, as expected since these are reviews, that this would provide us with a much larger data set. The starting point is the initial list of relevant articles selected as applicable in this area. The backward approach consists of scanning through the referenced articles in

the initial list. Based on the defined inclusion and exclusion criteria, new articles are selected. The final inclusion decision is given after reading the full pre-selected papers. This might be an approach to consider in the next steps.

### 5.3 Future Work

The outcome of the SLR showed that even though the great focus has been put on the digital transformation of laboratories within engineering education during the last few (pandemic) years, there are not many journal contributions that systematically investigate all aspects of this transformation. We, therefore, intend to first complement this research by adding more databases like IEEE and Web of Science.

## Acknowledgements

This work has been funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding codes 16DHB2112 and 16DH-B2113, EU INTERREG Central Baltic project number CB743.

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## 1.2 Technical Topics



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## **Digitalization of an Indoor-Positioning Lab Using a Mobile Robot and IIoT Integration**

### Abstract

Industry 4.0, the Industrial Internet of Things (IIoT) as well as Smart Logistics depend on locating mobile assets. In contrast to outdoor locating, GPS is not reliable for indoor positioning. Instead, different real-time locating systems (RTLS) are used in industries for indoor locating when there is no chance of obtaining GPS-satellite signals. Students in engineering disciplines should know about the chances offered by and the limits of RTLS, for example through corresponding lab experiments. However, measuring the accuracy of RTLS is a time-consuming task. Our goal is to provide a remote RTLS-accuracy measurement experiment by digitalizing and automating the whole process.

This paper discusses adding remote experiment service to this lab, thus providing access to the lab infrastructure anytime and anywhere. A mobile robot was used to move an ultra-wideband (UWB) transponder and expose it to the RTLS measurement infrastructure. By optimizing the routing algorithm of a mobile robot, the required accuracy and appropriate safety features were justified and the accuracy of the robot reached 2 cm. It also passed all the static and dynamic obstacles with acceptable safety thanks to inbuilt sensors. The remote operation was also done in an IIoT environment by implementing the MQTT data transfer protocol. For remote users to be able to operate our RTLS system via MQTT, we developed a software program. When running this program, our DigiLab4U Laboratory Management System (LabMS) is able to send commands to the RTLS system and receive positioning measurements of a mobile object (in our case RTLS tag) via MQTT messages. Thus, the real route and the measured route can be compared and the difference can be analyzed by students remotely.

## Keywords

Automated Guided Vehicle (AGV), RTLS, Industrial Internet of Things (IIoT)

## 1 Introduction

To enable indoor positioning within industrial applications different real-time locating systems (RTLS) are used by some industries (Uckelmann & Wendeborg, 2015). The University of Applied Sciences Stuttgart (HFT Stuttgart) provides laboratories equipped with different RTLS solutions to be used for research and education. In industrial environments and indoor applications particularly, high accuracy is sought after for position estimation. Objects within the range of the system can be located in real-time through the use of active UWB transponders. In the past, a person placed UWB transponders at specific locations inside the Position Lab and used the Ubisense system to locate the asset. However, in some conditions, this person would be placed between the tag and Ubisense receivers, which could affect the experiment's accuracy. In parallel, the real position was measured manually. Both sensor measurement and physical measurement were compared to analyze the accuracy of the results provided by the system. In engineering education, students need to understand the accuracy and limits of such systems. Doing experiments in this lab, students are able to learn more about the general concepts of positing as well as take a deep dive into a specific RTLS configuration. However, up to now, students had to do lab experiments in the lab, thus limiting the access HFT students have to it and its operational hours, which have been even more limited during the current coronavirus pandemic.

The research project Open Digital Lab 4 You (DigiLab4U) (Pfeiffer & Uckelmann, 2019) aimed to digitalize and automate real laboratories in order to allow remote access to corresponding lab infrastructures. Automating the RTLS transponder placement was identified as the main challenge. Furthermore, the integration of remote access to control the available laboratory instruments using the Internet is the second requirement that is discussed in this paper. In the following sections, the research background of the project as well as its main challenges and proposed solutions will be discussed.

## **2 Background**

In order to enable remote experiments for the DigiLab4U Positioning Laboratory, the main challenge was the automation of transponder movement. The corresponding lab is placed in a room which is not only being used as a laboratory, but also as a lecture room. Thus, it contains rigid and movable equipment. So, our proposed solution should be able to be flexible enough to operate in such an environment. Different automation methods such as a 3D-portal robot, controllable drones, and integrating several PLC controllers and a quadcopter (Keßler et al., 2021) were considered in an initial approach. Each of these methods has its own implementation, control, and integration challenges to satisfy the remote criteria. Finally, the Robotino mobile robot (Essaidi et al., 2020; Masmoudi et al., 2016), made by the company Festo, was selected as a suitable solution. The Robotino platform provides specific functionalities designed to be operated in a laboratory environment. It supports odometry functionality to move from its actual position to the desired destination (Baatar et al., 2014). Position estimation is another important feature that is also supported by an odometer (Bischoff et al., 2012). But, its accuracy can be affected by surface materials as well as the speed of the robot. Therefore, some marking labels were added to the laboratory floor to achieve more accurate autonomous movements (Panigrahi & Bisoy, 2021). This functionality can be supported by different sensors such as Lidar (Wang et al., 2019), a North star sensor, or a camera (Alcantarilla et al., 2010). Detecting those labels via image processing algorithms, the mobile robot can calibrate itself and compensate for the occurring error between two marking labels. As a result, once the robot is in the vicinity of a nearby marking label, its movement strategy will be changed according to a set of behavior strategies (Goel et al., 1999). Robotino also has the ability to bypass static and dynamic obstacles and avoid any collision. The movement functionality developed for the Robotino will be discussed in more detail in the following sections. Defining an instruction set and developing a MQTT interface are the next steps to enable the mobile robot to be operated remotely.

## **3 Ubisense System and Data Communication**

GPS has successfully proven its ability to accurately determine positions when used outdoors. However, it is known that this technology is not suitable for indoor positioning. Therefore, tracking systems that provide real-time indoor locating are required. In comparison to GPS for an outdoor

application, indoor RTLS solutions are less standardized and differ in accuracy when determining positions. The authors (Ruiz & Granja, 2017) specifically refer to the UWB-Ubisense platform, as it achieves higher accuracy compared to Bluetooth Low Energy or WiFi-based RTLS solutions by using better algorithms and including additional parameters to calculate real-time position data. Now, more and more UWB-based solutions are competing in a small market.

Like other Ubisense installations (Corrales et al., 2008), the specified setup used in the DigiLab4U positioning laboratory consists of the installation of four Ubisense satellites (Figure 1).

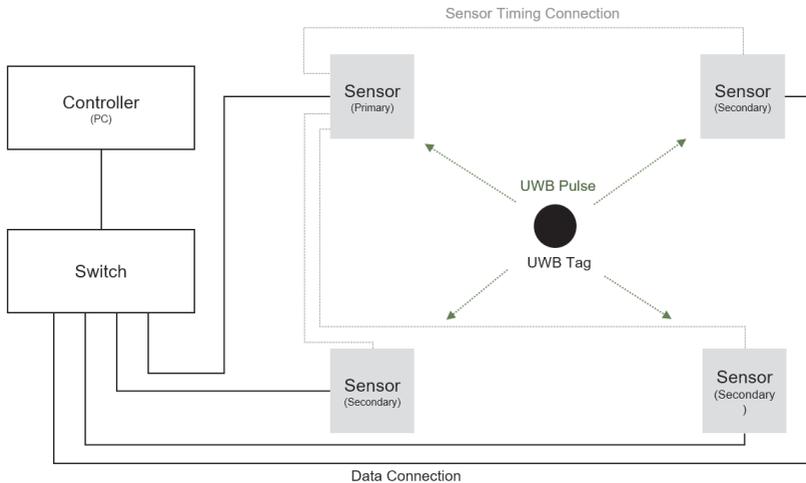


Figure 1: Ubisense architecture (Corrales et al., 2008)

These sensors are positioned in the corners of the laboratory area. The system determines the current positions of the transponders and reports the coordinates to the tracking system. This includes information on the current coordinates (X, Y, Z) with a time stamp and a parameter indicating the standard error.

Ubisense provides a software interface for application development. For the development of the position laboratory, a software component was implemented using the .NET library. Here, the application enables the processing of the position data calculated by the Ubisense system.

The Position Lab connects a variety of systems to perform experiments. Within the system components, different sets of data are processed. In addition to measurement results and telemetry data, it is also necessary that the system can process control commands. Furthermore, the communication interface should satisfy special requirements in order design a robust system with a high degree of flexibility. MQTT has become a standard choice for M2M applications in IoT environments due to these properties (Mishra & Kertesz, 2020).

The server and client architecture specified in the MQTT standard allow data to be communicated between IT systems. Messages are transmitted via a central broker to clients with an active connection. A client is able to transmit data in a strictly structured way by subscribing to or publishing a topic. The communication in the DigiLab4U position laboratory is managed by two central topics, which handle the exchange of sensor readings and the execution of control commands. The fact that control commands are processed by this system means that special security requirements must be met. Only authorized users should be able to send control commands through the designated topics. Therefore, each user must be authenticated.

The proposed architecture allows the communication of the measurement results and control of components that are relevant for the operation of measurements. As a result, the system provides the data required for the user to be able to compare and assess the accuracy of the position data.

## **4 Mobile Robot Automation**

Previously, robot systems were restricted to a stationary position. Mobile robots represent the next step in the development of robotics in that they can execute the same tasks as their stationary predecessors but, in addition, can move away from one position to another. This provides the prerequisites for dealing with countless additional tasks. The main motivation for the creation and development of mobile robots is due to the desire to use the robots to operate alongside humans in the same environment. This part of the paper contains a scheme for efficient automation of a mobile robot (Robotino) with an indoor positioning system (Ubisense). Three wheels on the robot are used to control the omnidirectional movements (Panigrahi & Bisoy, 2021). The wheels are mounted symmetrically at 120 degrees from each other. Robotino is a fully functional, high-quality mobile robot system with omnidirectional drive. In addition, it is equipped with a webcam and several types of sensors, analog for distance measurement, e.g., binary for collision protection and digital for checking the current speed. The

programming of the robot was done in a Sequential Function Chart (SFC), a Function Block Diagram (FBD), and Lua script languages using Robotino View.

As part of the remote experiment infrastructure, this robot should be integrated into DigiLab4U LabMS. This feature is implemented by creating a Python application that communicates with the robot via UDP. As a LabMS supports MQTT (Adineh et al., 2022), the application implemented should use the interface to the LabMS provided.

### Robotino View

Robotino View is an integrated development environment (IDE) specifically designed for the Robotino robot. The IDE supports fast and easy development of SFC, FBD, and Lua script programs. It is a professional tool for creating simulation models. The programming of the Robotino is implemented by creating the function blocks and these function blocks are operated via SFC.

### Outline of the Robotino's Automation

The goal of the Robotino is to move inside a specified zone in the laboratory environment. The mapping of the Positioning lab is shown in figure 2.

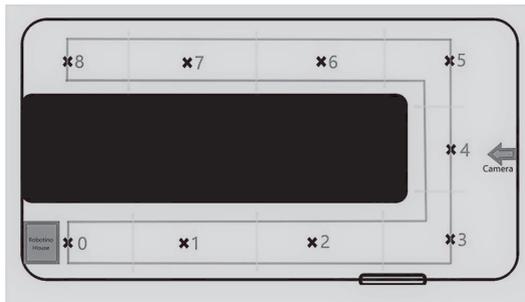


Figure 2: Room mapping with marking labels (crossed points)

There is a U-shaped area for the robot's movement and the crossed points are the marking label locations. The area can also contain some static and dynamic obstacles. The goal of the robot is to receive the command based on the 3D dimension and arrive safely at the desired position within an optimized time frame. 9 marking labels are attached to the ground to be identified and mapped by the camera. The Robotino will move between the

marking labels and after an initial calibration, the robot will move to the defined position using 2D coordinates. Finally, a Z-axis actuator will play its role in enabling the robot to reach its final position. The main function blocks implemented are:

- Rotate and approach
- Marking label settings
- Angle calibration
- Collision-free
- Movements around the obstacles
- Driving

A rotate and approach function block has the controls to rotate the Robotino and to find and approach the marking label to compensate for an encoder error. Marking label settings generate the commands for the Robotino to go to the specified marking labels based on the nearest current marking label and the nearest marking label to the final position. Angle calibration is another important function block for appropriate positioning. This function block operates based on the upcoming marking label to specify the fixed angle of the gyroscope that is attached to the robot. Collision-free and movement between and around the obstacles were also a big challenge to ensure that the mobile robot can be operated remotely. These function blocks work with the signals generated from infrared sensors, collision detection sensors, and a laser scanner. Finally, the drive function block has the controls to move the robot based on an odometer and control the movements using all the signals generated.

## 5 Conclusions

In the course of the research, an investigation into multiple feasible methods of “RTLS transponder positioning automation” was conducted, resulting in the selection of a Festo Robotino platform to be integrated into the laboratory environment. The mobile robot can be programmed with the “Robotino View” application, a visual drag and drop programming environment. It supports “close loop control” and “concurrent functions block operation” via a sequential function chart (SFC). The developments were inspired by similar concepts for an Automated Guide Vehicle. For example, the Robotino was programmed to be able to detect and bypass obstacles. Furthermore, the use of label markings on the floor as well as image processing algorithms allowed the system to achieve a higher accuracy in planning and mapping the defined routes.

Additionally, the integration of the Ubisense RTLS into the Position Lab infrastructure was achieved. The communication of the individual components was implemented by using an MQTT interface.

## 6 Future Work

After automated RTLS transponder positioning and a remotely operable Ubisense system have been integrated, remote experiments can be executed. Furthermore, implementing Laboratory Management System (LabMS) libraries from DigiLab4U will enable the development of an integrated platform to manage remote experiments by interacting with instruments using IIoT protocols for device communication. By providing a web-based user interface, as has been done for RFID Labs (Pfeiffer et al., 2022), the DigiLab4U infrastructure and underlying services can be accessed by users.

Safety is currently provided by limiting access to the corresponding room during test cycles. However, this process is not yet automated. As the room can be accessed by students when no testing is performed, the robot needs to be secured to avoid (un-)intended damage. To achieve this, an automated robot garage is planned. The educational outcomes still need to be evaluated during lectures. A corresponding evaluation is planned during the summer term 2022.

## Acknowledgements

The DigiLab4U project, on which this paper is based, was funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112. The responsibility for the content of this publication lies with the authors.

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*Eva Ngo, Tobias Ableitner, Sebastian Koch,  
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## **Virtualization of a Smart Home Lab: Design, Implementation and Evaluation**

### Abstract

Experimentation in the laboratory plays an important role in students' education in order to acquire the necessary practical knowledge. However, this laboratory experience cannot be offered to all students due to various reasons, such as expensive equipment, limited access, or insufficient capacity. For this reason, virtual labs have been gaining interest for several years to make lab work more accessible. This paper is dedicated to this topic, showing the possibilities and highlighting the important role of virtual labs in education. However, there is a lack of didactically and qualitatively sophisticated digital solutions in many areas. With a case study, this paper aims to extend the state of research around virtual labs and investigate the feasibility of virtualizing a smart home lab. In addition to the design phase, in which the requirements for the solution are elaborated, the implementation of the virtual lab with suitable technologies as well as the evaluation of the application with the help of user tests is presented. The results show that the virtual PUX lab is seen as a useful alternative to the real lab. The identified weaknesses from the user tests could be used to further improve the prototype for its integration into the DigiLab4U platform and its productive application in lectures and workshops.

### Keywords

E-learning, virtual lab, OpenHAB

### **1 Introduction**

With the constant development of internet technologies and increasing digitization in many different areas, education has also changed significantly in the past two decades (Schlenker, 2015). Digital and interactive media have rapidly spread as ways to enhance teaching and learning, replacing traditional teaching methods (Hoffmann et al., 2014 ; Unger, 2014). While

physical textbooks and traditional face-to-face lectures were mainly used in the past, nowadays various e-learning tools are used and new modern concepts such as blended learning and distance learning are implemented (Kamińska et al., 2019).

Developments in e-learning range from computer-based training (CBTs) and web-based training (WBTs) to extensive learning management systems (LMS) (Arnold et al., 2018 ; Sims, 2021). Moreover, with the availability of higher bandwidths, lower access costs and advances in computer graphics, another form of learning emerged using the new technology of virtual reality (VR), which marked the shift from conventional digital media to immersive learning environments (Huang et al., 2010). Oriented to scenarios from computer games, these platforms are also called serious games and make use of the visual-spatial dimension in which learners are immersed in a constructed 3D world and interact with modeled learning objects (Schlenker, 2015).

Meanwhile, digital technologies are an integral part of colleges and universities to improve the learning experience. By using modern multimedia and telecommunication technologies, e-learning offers some new possibilities. Most importantly, improved accessibility, flexibility, interactivity, increased motivation, various tools for organizing studies as well as collaboration across spatial boundaries are among the advantages. (Henderson et al., 2017 ; Seel and Ifenthaler, 2009)

The benefits are especially evident in times of a pandemic when face-to-face teaching is no longer possible (Glassey and Magalhães, 2020). Due to the pandemic, most colleges and universities had to adapt their teaching methods and switch to online teaching (Glassey and Magalhães, 2020). The transition to online lectures is relatively easy, but other areas face some challenges (Glassey and Magalhães, 2020). Due to the limitations of physical contact as well as logistical and security factors, developing a solution to effectively deliver the lab experience is a difficult task (Bhute et al., 2021). According to a McKinsey survey, teachers and learners are least satisfied with the digital form of lab work (McKinsey and Stifterverband für die Deutsche Wissenschaft, 2020). While the conversion of lectures was rated positively by students, the transition of teaching formats in smaller groups such as laboratory work with a high practical content was perceived rather negatively (Winde et al., 2020). Possible reasons are the higher demands regarding digital didactics and interactivity as well as the often longer development time that these e-learning formats require (Winde et al., 2020).

This shows that better and more effective methods still need to be found to achieve the required learning outcomes. Especially in STEM fields, hands-on experimentation in the laboratory is of high importance to apply

theory to practice and to gain the relevant experience and skills of practical laboratory work (Burghardt et al., 2021). Transferring this form of learning to a distance learning approach is challenging because it requires physical laboratory equipment and the laboratory environment (Gokhan and Saleem, 2008). However, research has already been conducted in this area for several years to find new approaches (Romagnoli et al., 2020). Virtual laboratories have been explored as solutions that enable laboratory practices over the network regardless of location and time (Romagnoli et al., 2020).

Virtual labs use simulation, animation and other technologies such as VR to replicate the real lab as closely as possible and to provide a similar lab experience (Rivera, 2014). Based on computer simulations, they enable conducting experiments without having to be physically present at the laboratory workstation (Esquembre, 2015 ; Ray et al., 2012). In some cases, simulation can even provide a better laboratory experience or any laboratory experience at all (Koskela et al., 2005). This is because virtual labs are not only useful during pandemic times, but also in situations where the real experiments pose a danger to learners or the equipment and materials are too expensive or poorly accessible (Koskela et al., 2005). Since virtualization requires only a computer device and an internet connection instead of the entire lab equipment, virtual labs allow for high scaling as well, so that in principle any number of instances can be created, and thus several students can be served in parallel (Seiler, 2012).

Although research around virtual labs already exists, there is still a lot of unexplored potentials, for example in the field of the internet of things (IoT) and industry 4.0 (I4.0), due to the lack of effective and high-quality solutions for digitized labs (Kokot, 2019). Accordingly, this paper will try to expand the state of the research with a selected case study.

## **2 Case Study: Virtual PUX-Lab**

The application resulting from the technical implementation of the case study should be integrated into a central platform that is developed within the DigiLab4U research project. For this reason, an overview of the research project will be given first, in order to clarify the theoretical background and motivation behind the project. Afterwards, the PUX lab, which is to be virtualized, will be presented.

## 2.1 *DigiLab4U*

DigiLab4U stands for Open Digital Lab For You and is a research project managed by several educational institutions that have the goal to develop an open, digital platform for laboratories focusing on I4.0 and IoT (Pfeiffer and Uckelmann, 2019).

Real laboratory infrastructures are associated with high costs and are usually only accessible to a specific institution. DigiLab4U, therefore, aims to counteract this problem by providing an open, cross-institutional platform for I4.0 and IoT labs that allows lab infrastructures to be networked and used effectively and sustainably. The goals are to facilitate the exchange of research and teaching facilities through the lab network and to make the digitized, hands-on lab environments accessible to as many students, teachers, and researchers as possible. (Open Digital Lab for You, n. d.)

The platform is implemented with a client-server architecture and the core of the platform is the central LMS as the entry point for the users. Implemented with the open-source learning platform Moodle, this platform will offer general functionalities such as booking, payment, authentication and management of the labs. In addition, a framework software package called LabMS, short for Laboratory Management System is provided to facilitate the integration of the labs into the central platform. (Galli et al., n. d.)

A project that should be digitized and integrated into the central platform of the DigiLab4U research project is the PUX lab, which is presented in the next section.

## 2.2 *PUX Lab*

The research group Responsive Media Experience (REMEX) exists since 2013 at the Hochschule der Medien Stuttgart and has the goal to research and develop innovative solutions that address the user and his needs to achieve the best user experience. Research focuses, for example, on personalized and accessible user interfaces or smart homes & ambient assisted living (AAL). (Forschungsbericht 2020, 2021)

In order to implement and evaluate the solutions in practice, the PUX lab has been established. This is available to researchers and students for various projects. The lab houses devices such as smart Philips Hue lamp systems, smart sockets, and smart carpets, which can be used in personalized smart homes and AAL scenarios, for example. (Ein Netzwerk, das alles verbindet, 2021)

As smart homes and networked devices become increasingly relevant, students should accordingly be able to gain the necessary practical experience in their education. Therefore, a virtual environment is valuable to provide access to the lab and the devices to a higher number of students. A virtual version also represents a useful alternative considering the pandemic when equipment had to be borrowed by the students and was only available in limited quantities. For this reason, the case study of virtualizing the PUX lab will be presented in this paper.

The use case is as follows: In the real PUX lab, an OpenHAB server exists which can be used to control smart devices from different manufacturers uniformly. In the case study, only the smart lamp systems are initially considered for the prototype. Students can therefore program their smart home applications and, by addressing the OpenHAB API, influence the lamps in the PUX Lab, e.g. switch them on and off, change the color or adjust the brightness. This scenario should also be possible in the virtual PUX Lab and should be mapped realistically. In the virtual PUX lab, students should learn how smart devices can be controlled with the help of OpenHAB, analogously to the real PUX Lab. In the future, the application is to be integrated into the DigiLab4U Moodle as a lab course and thus be available to a large number of students within workshops or lectures.

### **3 Requirements Analysis**

In this section, requirements for the design of a possible solution for the virtual PUX lab are collected. These requirements are elaborated in three steps:

- Literature research
- Analysis of existing virtual labs
- Focus group discussion

A literature review is conducted to identify characteristics of virtual labs that have a positive impact on the learning experience and outcome. Moreover, existing virtual labs and learning environments are selected and analyzed to identify common features and frequently used elements. In the last step, a focus group discussion will be conducted to further complete the requirements and, if necessary, evaluate and prioritize them regarding their suitability for the virtual PUX lab.

### 3.1 Literature Research

From the literature, some requirements or possible elements for virtual learning environments can already be identified. A learning environment requires a well-thought-out combination of pedagogical, social and technological components to achieve the desired learning success (Wang, 2009). The overall didactic concept must be put together coherently, the learning objectives must be clear and the learning content should be prepared with the help of suitable media elements (Arnold et al., 2018). (Wendt, 2003) suggests diverse elements for a didactically meaningful concept. These include an intro sequence, the main menu for navigation, an introductory test for adaptive content, exercise and tutorial learning modules, an explorative practical learning environment, a learning success control, a learning management module and technical as well as content-related assistance (Wendt, 2003).

User-friendly design is also frequently recommended in the literature for learning environments (Arnold et al., 2018). The user interface must be clear and understandable so that learners can easily find their way around (Arnold et al., 2018). This includes, among other things, support for accessibility and multilingualism (Arnold et al., 2018). While (Gokhan and Saleem, 2008) list aesthetically pleasing and intuitive design, (Liu et al., 2009) mention four other critical features: accessibility of information, ease of navigation, interactivity of the system and system support. Moreover, (Mueller and Strohmeier, 2011) highlight further system-related criteria such as feedback, flexibility, adaptability, and reliability as well as information-related aspects like course quality, presentation format, and relevance.

(Romagnoli et al., 2020) formulate four criteria specifically related to the virtualization of laboratories: realistic user interface, realistic system replication, realistic graphical representation, and support for communication and collaboration. First, the user interface of a virtual laboratory must replicate the real device. Second, the behavior of the virtual system must match the behavior of the physical system. Furthermore, the virtual lab must be designed in a way that the learners feel as if they are performing the experiment in a real environment. In addition, the laboratory environment should include features to enable communication and collaboration. (Romagnoli et al., 2020)

### 3.2 Analysis of existing applications

To determine the characteristics and commonly used elements of virtual labs and learning environments, seven different applications of virtualized

labs were analyzed. The selection included, for example, a virtual microscopy lab, a virtual lab tour, and remote control of a robotics lab.

By investigating the applications, the following common elements and features could be identified: instructional videos, experiments, multi-language support, full-screen mode, and the possibility to contact supervisors. Furthermore, quiz questions, simulations, remote access, help resources, tutorials, 360-degree tour, 3D visualization and gamification in the form of an avatar, progress tracking, and sound/audio appear to some extent. Elements that all applications have in common are an explanation of how to use and operate the application, as well as a description of the learning objective or benefit of the application.

The suitability of the requirements identified so far for the virtualization of the smart home lab is determined in the next step with the help of a focus group discussion.

### *3.3 Focus group discussion*

Focus groups are moderated group discussions and belong to the qualitative methods. In a small group, usually consisting of six to ten people, a selected topic is discussed to obtain information about the thoughts and different perspectives of the individuals. The selection of participants is done deliberately by selecting individuals who have certain characteristics regarding the focus group topic. (Bär et al., 2020, Krueger and Casey, 2014)

In the case study, the focus group is used to gather requirements and ideas for a solution concept for the virtual PUX lab. A total of seven people participated in the focus group. Among the participants were staff members of the DigiLab4U research project and the REMEX research group as well as students as representatives of the future target group. Due to the contact restrictions of the pandemic, the focus group was conducted remotely within a 90-minute online meeting.

The participants were asked to collect possible elements and characteristics of virtual learning environments interactively in a mind map. On the one hand, some of the same characteristics as in the analysis of existing applications were identified, on the other hand, new points were also added to the mind map. These identified aspects were then prioritized and evaluated with regard to a solution for the virtual PUX lab.

The participants named interaction with the system that is as practical and realistic as possible as the highest-rated characteristic. In terms of user-friendliness, independence of place and time, support for different devices/operating systems/browsers, and accessibility are most important. FAQ, introduction/explanation, and links to help resources were favored

as support features. Regarding the use of media, participants voted for a 2D representation, and in the category of adaptability, they prioritized the support for multiple languages. For teaching elements, the participants see tutorial videos, quiz questions, and experiments as appropriate. Feedback should be provided in the form of a presentation of the result and an associated evaluation.

These features can be considered requirements for the virtual PUX lab and should be considered in the concept of the application.

#### 4 Implementation

The application was implemented with a composition of several components according to the client-server model. These components and their communication with each other can be seen in Figure 1.

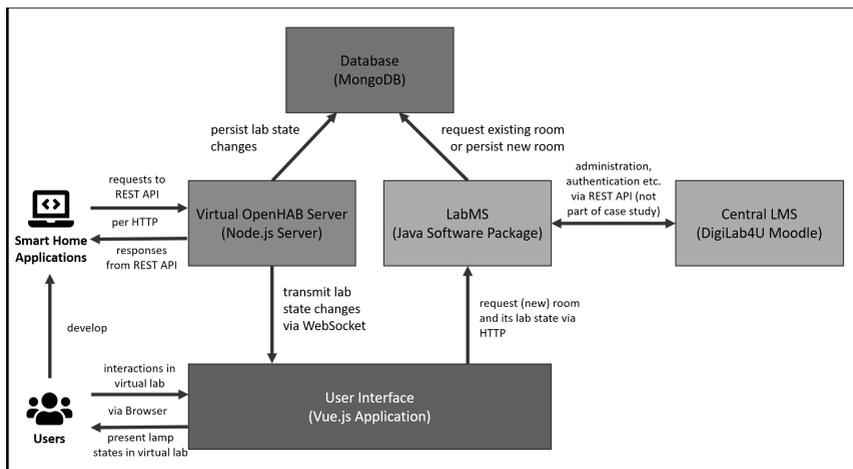


Figure 1. Architecture and components of the application

In the following, the individual components are described in more detail, which includes justifying the choice of technologies and the explanation of the implemented functionalities per component.

#### 4.1 User Interface

The user interface represents the visual component, the so-called client, and is the entry point for users. Before starting with the development, a design concept was first created. Not only the layout and different components of the application were designed, but also the visualization of the virtual PUX lab. The real PUX lab is designed like a living room and consists, among other things, of shelves, an armchair, a small side table, a TV, and several lamps. This should also be reflected in the virtual version. For this, each element was created with the Figma program. Figma is a web-based vector graphics editor and serves as a prototyping and design tool. The program allowed us to quickly and easily create the elements as 2D representations using simple geometric shapes. All of the lamps in the PUX lab were modeled. These include four-floor lamps, four light strips, and a small table lamp. The lamps were arranged as in the real PUX Lab so that a third dimension can be guessed by the positioning, i.e. one-floor lamp in each corner of the room. The light strips could also be realistically placed behind the decorative elements such as the shelf or the TV. In addition, the lampshades and the glow of the light strips could be represented quite realistically with Figma by using effects such as color gradients and soft edges. The export of the models as SVG elements allows flexible adaptation so that dynamic and authentic animation, e.g. of the color change of a lamp, is possible.

The JavaScript framework Vue.js in combination with TypeScript was chosen for the implementation of the frontend. Vue.js belongs to the best-known and most widely used JavaScript frameworks to build reactive web applications relatively easily and quickly (Vue.js, 2021). In addition, Tailwind was used as a CSS framework. With Tailwind, the desired styling of a page can be efficiently implemented using utility classes (Tailwind, n. d.). Figure 2 shows the main user interface implemented in the case study. The most important components are briefly explained:

**Language Selection** Possibility to switch between English and German.

**Introduction** Short introduction to the virtual PUX lab, briefly explains what the virtual PUX lab is and how it can be used.

**OpenHAB Information & Interaction Options** Presenting important OpenHAB information likeserver address of the virtual OpenHAB server and the current room ID. Possibility to enter orcreate a new room.

**Visualization of virtual lab state** Main area showing the virtual depiction of the PUX lab as aninteractive SVG image. Colour and brightness as well as the on/off state of the lamps aredisplayed.

**List of Things and Items** Textual information about the OpenHAB Things and the associated Items and Item Groups.

**Action Log** Log of requests that change the state of the Items.

**Help Section** Important resources that might help to use the virtual PUX lab, e.g. explanatory video, FAQ, and external resources.

Further features implemented throughout the application are tooltips, toast messages, buttons to quickly copy relevant text to the clipboard like server address or Item names, responsive design for different screen sizes, as well as accessibility aspects such as support for keyboard navigation and screen readers.

## 4.2 LabMS

The LabMS is a framework software package that includes all necessary software and logic components and is already designed to communicate with the central LMS. Each lab, that should become part of the DigiLab4U platform, can be set up with the help of its own LabMS instance, so that the integration is facilitated by the already existing interface to the central platform, which is responsible for e.g. authentication, booking, and the collection of learning analytics data. In this respect, the technology for the backend is already given: The LabMS is based on Java and uses the Spring-boot framework, which simplifies the programming of web applications, e.g. the construction and use of REST interfaces.

The LabMS also represents the server or the backend to the frontend application and is responsible for processing the requests from the frontend. On the one hand, the user interface offers the possibility to create a new room. For this, the LabMS generates a new token consisting of 84 characters, which uniquely identifies the new room, and the new lab instance is stored in the database with the initial default state including the newly generated room ID.

On the other hand, users can enter different rooms via the user interface using room IDs. For this purpose, the LabMS loads the state of the respective lab instance from the database using the room ID sent by the frontend and sends the requested state back to the Vue.js application.

All further interactions from the user, such as changing a lab state, are done via the virtual OpenHAB server.

## 4.3 Database

In order to be able to persist the lab state of the respective rooms, the application also includes a database. MongoDB was selected as the technolo-

gy for this. MongoDB belongs to the document-based NoSQL databases, which have been developed for modern applications with scalability and flexibility in mind. MongoDB stores data in a JSON-like document format. This form is very close to the structure of object-oriented programming, which leads to efficient work with data. In addition, MongoDB allows for flexible customization of the data structure, powerful and flexible queries, and can also handle a large amount of data (Was ist MongoDB?, 2021).

The virtual PUX lab data is stored in a specific document structure. However, since MongoDB does not enforce a schema, this can be flexibly adapted in the future, e.g. if additional smart devices are to be simulated. There is one document per lab instance and the data is stored in the form of nested objects and arrays. At the top level, the room ID or API token is stored, which uniquely identifies the lab instance. Two timestamps are also recorded. Both the time of creation and of the last modification to the lab instance are stored. Furthermore, the Things and the associated Items as well as the Item Groups persisted, which as a whole, form the lab state.

#### *4.4 Virtual OpenHAB Server*

The virtual OpenHAB server simulates the functionalities of the real OpenHAB server in the PUX Lab. For this purpose, a part of the REST API of OpenHAB is replicated in the virtual variant to realize the same behavior. The use case is supposed to be the following: Instead of students sending the HTTP requests of their smart home applications to the real OpenHAB server to control the real lamps in the PUX Lab, they should send the HTTP request to the virtual OpenHAB server and accordingly see the effect in the virtual PUX lab.

For the implementation, the first step was to analyze the REST API and the OpenHAB ecosystem. OpenHAB stands for Open Home Automation Bus and is an open-source home automation platform, which means it allows the building of a customized smart home system. OpenHAB supports more than 200 technologies and integrates about 2000 devices using add-ons. Thus, a flexibly configurable platform with a uniform user interface for the management and control of smart home devices is provided. This means that, for example, the smart Philips Hue and Ikea Trådfri lamps can both be controlled in exactly the same way via OpenHAB, regardless of the interfaces of the different manufacturers. (OpenHAB, 2021)

For the use case, the specific entities Things and Items are relevant, and are used to build the OpenHAB model of the PUX Lab. In short, Things represent the physical layer, i.e. the physical devices like the different lamps in the case study, and Items describe the virtual layer, i.e. the information

about the devices. Each Item can be changed with an appropriate request and the Things respond to these events sent for an associated Item. There are specific Item types that decide which commands are allowed to change the state in a certain way. (Things, 2021)

To replace the real OpenHAB server for the virtual PUX lab, a Node.js server was developed using the Fastify framework. Fastify is one of the fastest web frameworks, which can be used to implement performant servers efficiently with low overhead and a powerful plugin architecture (Fastify, 2021). For the simulation, three relevant REST endpoints of the OpenHAB API were replicated. For the previously described Things and Items entities, the respective GET endpoints were implemented. By taking the JSON response of the real OpenHAB server as a template for both endpoints and adapting it if necessary, realistic behavior can be ensured.

As the third and most important endpoint, the POST endpoint of the Items was implemented, with which the state of a lamp can be changed. For this, the behavior of the real OpenHAB server was analyzed in detail. On the one hand, the same validation was implemented, so that only the commands and numerical values allowed per Item type are permitted in the defined range. On the other hand, the same reaction to incorrect input was implemented, i.e. the same HTTP error codes and responses are returned if, for example, an unknown Item name, an invalid command, or a missing or unknown API token is sent. For a valid request, the state is updated according to the command and written to the database for the respective lab instance. In addition to regular Items, there are special Items, called Item Groups, that comprise other Items. When a request goes to an Item group, in addition to the Item Group state, the states of all affected Items must be updated accordingly.

The state changes must also be reflected in the user interface. For this purpose, the WebSocket protocol is used to enable communication from the virtual OpenHAB server to the frontend. In case of a state change, all required information, i.e. timestamp of the request, affected Item, and new state, is communicated to the frontend. Errors are also communicated so that they can be presented in a user-friendly manner in the action log of the Vue.js application. The Socket.io library was used to implement the WebSocket protocol, which greatly simplifies the establishment of connections between the backend and frontend (Socket.IO, 2021). In addition, Socket.io enables the creation of so-called rooms (Socket.IO, 2021). A room is a channel that multiple sockets can enter or leave (Socket.IO, 2021). This fits perfectly with the case study where users can enter a room or a lab instance. As soon as a user enters a room via the user interface, the client establishes a socket connection to the backend and joins the respective Socket.io room, which

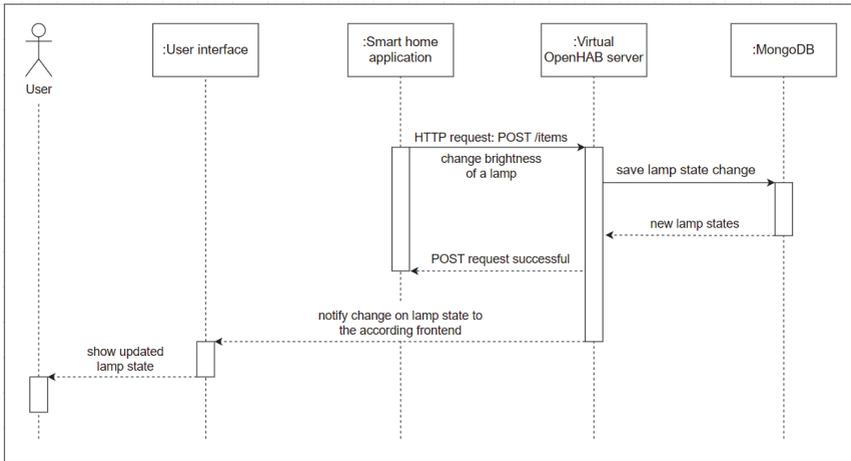


Figure 3. Sequence diagram of a typical scenario

is uniquely identified by the room ID. Socket.io rooms can thus be used to send state changes to a subset of clients, namely only those clients that belong to the respective Socket.io room at that time.

The possibility of sending an API token along with OpenHAB requests was exploited to uniquely identify lab instances. Therefore, in the OpenHAB virtual server, all three implemented endpoints expect an API token in the Authentication Header in the Basic Auth format to perform the actions for the correct lab instance. The API token from the request is thus used to identify from which lab instance the state needs to be returned or updated. If the API token is missing, the same error code and response will be returned as for the real OpenHAB server.

In order to better understand the communication of the described components, an exemplary scenario is visualized in Figure 3. The sequence diagram shows the process in which, for example, the brightness of a lamp is changed. It starts with an HTTP request from the smart home application to the virtual OpenHAB server. The server validates and evaluates the request and saves the change of the lab state in the database. The smart home application is then informed that the HTTP request was successful. In addition, the virtual OpenHAB server notifies the user interface about the change to the lab state, but only the accordingly affected clients. The user can then see the updated lamp state in the user interface.

## 5 Evaluation

The evaluation phase of the implemented virtual PUX lab application was conducted with the help of user tests as well as in consideration of the previously defined requirements. The results will be examined to check whether and to what extent the requirements could be met.

### 5.1 User Tests

In user testing, participants who represent the relevant target group of the application are observed during a specific task related to the use of a product in order to discover both strengths and weaknesses and the corresponding opportunities for improvement (Niegemann et al., 2004).

A total of six user tests were conducted. All participants are students with a technical focus representing the future target group of the application under investigation. Each user test lasted about one hour and was conducted as an online meeting with the help of remote access on a computer where all required programs were already set up. In the beginning, all participants were given the same three tasks to solve by using the application and the OpenHAB interface of the virtual PUX lab:

1. Turn on and off all the lamps.
2. Change the brightness of the HueLampLittleTable to 70 %.
3. Change the color of the HueLampBackLeft to red.

The think-aloud method was used during the user tests. In this method, participants are asked to say out loud everything that is going through their minds without interpretation or analysis while completing a specific task (Güss, 2018).

After completing the tasks, participants were asked open-ended questions about their experience with the application in order to obtain feedback. In addition, a questionnaire with seven questions on a 5-point Likert scale was answered by each participant in order to check the various aspects of user-friendliness such as satisfaction, usability, comprehensibility, learnability, and efficiency.

The overall result of the users' tests is generally positive as all questions were answered either with 'Strongly agree' or 'Somewhat agree'. When asked about their first impression of the application, all respondents mainly emphasize the nicely designed user interface and the visualization of the virtual lab and refer to the general clarity and logical structure. The participants also rate the user-friendly operating aids such as the copy buttons

and the tooltips positively and see components such as the FAQ and the examples in the help section as well as the action log as useful and helpful.

All participants have successfully mastered the three given tasks. Since there was little to no knowledge of OpenHAB among all participants at the time of the user tests, a clear learning success can be observed. All of the participants describe a similar experience in that they first had to learn and get familiar with the OpenHAB system in the beginning, but with some help and time, as well as the first successful request, working with OpenHAB is relatively easy after that.

Everyone agrees that the virtual PUX lab requires significantly less effort. On the one hand, there is no need for the hardware set-up process, and on the other hand, physical devices are no longer necessary. The participants see a great added value in the virtual lab, as it enables them to work in the PUX lab without being on-site. Respondents also describe the application as a practical, real-world environment in which students can try out, experiment, and test on their own in projects regardless of location. All respondents would use the virtual PUX lab to gain hands-on experience with OpenHAB and smart devices, and see the benefit, especially in online courses. The possibility of collaboration in the same lab instance using the room ID is also mentioned as a positive aspect. Furthermore, the respondents envision the use of the virtual PUX lab in many different use cases and projects in the future and show interest in the possibility of flexible further development of the application to support even more smart devices.

Further potential for improvement is discovered in the area of user-friendliness and comprehensibility. The user tests proved to be very helpful in this regard in identifying usability weaknesses that only become apparent when tested with real users. The deficits identified regarding the layout or the presentation of the state, the group membership or the current room, could therefore be eliminated for a better user experience. With the incorporated suggestions for improvement, the prototype of the virtual PUX lab is now in a mature state and can be productively tested in lectures and workshops.

## *5.2 Review of Requirements*

Furthermore, the requirements elaborated in Requirements Analysis<sup>3</sup> could also be met to a great extent. Most importantly, the following features and functionalities were successfully implemented:

- Introduction text and help section with explanation video, FAQ and help resources

- Further user-friendly auxiliary functions like toast notifications, tooltips and copy buttons
- Realistic representation of state changes through animation in the SVG
- Interaction possibilities like entering or creating a room and controlling lamps by OpenHAB requests
- Feedback for requests in form of an action log and for other actions with toast notifications
- Collaboration with others in the same room through room ID
- Support for different device types and operating systems, as long as a current browser is available and JavaScript execution has not been disabled by the user
- Responsive web design for mobile devices, i.e. adapting the layout to different screen sizes
- Support for multiple languages as well as accessibility features such as keyboard navigation and screen reader support

## 6 Conclusion and Future Work

The paper has shown that laboratory experience is of high importance in the education of students. Hands-on learning and experimentation on real-world problems are necessary to acquire important skills and to transfer theoretical concepts into practice. Technological advancements in e-learning have led to increased exploration of virtual labs as an alternative to making these experiences more flexible and accessible to a larger number of students. This area of research holds great potential, which is why this paper has looked at the virtualization of a smart home lab within a case study.

The PUX lab was chosen as a case study to explore the feasibility of virtualizing a smart home lab. To design a potential solution, requirements were drawn from the literature and an analysis of existing applications and narrowed down to the case study in more detail using a focus group discussion. Subsequently, the first prototype was implemented as a web application. The evaluation phase, which included user tests, confirmed the feasibility of virtualizing a smart home lab. The previously defined requirements were largely met and the concept of the application with the implemented functionalities left an overall positive impression on the target group. The virtual PUX lab is accepted as a useful alternative to the real lab. In particular, the time- and location-independent access without the need for physical laboratory equipment is considered valuable for efficient work, especially with regard to an extraordinary situation such as a pandemic. Exploiting economies of scale and location-independent collaboration on

projects were also cited as additional benefits of the virtual version, allowing for a real-world hands-on laboratory experience for a wide range of students.

It has been shown that the virtualization of a smart home lab is possible. The suggestions regarding usability, layout, and other forms of assistance that emerged from the user tests in the evaluation phase could be incorporated into the prototype to allow for an improved user experience. The application is now in a mature state so that the virtual PUX lab can be integrated into the DigiLab4U platform and tested in productive settings as in lectures and workshops.

Currently, the virtual PUX lab is designed as an open environment, which allows a variety of creative use cases in projects. In future work or further developments, an expansion of the didactic concept would be conceivable. For this purpose, tasks and predefined experiments with specific learning objectives as well as automatic evaluation could be integrated to verify the desired learning success. In addition, further smart devices could be supported and simulated in the virtual PUX lab.

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## **Enabling Remote Laboratories with LabMS – Fundamental Considerations and Proof of Concept**

### Abstract

In recent years, new resource-sharing concepts have been developed and implemented, for example, in applications such as car sharing or office space sharing. Sharing large research infrastructures such as particle accelerators is also common. The operation of laboratories for educational purposes is an example of how we can benefit from implementing the concept of sharing knowledge, infrastructure, and facilities in the educational field. However, a corresponding networked IT infrastructure is needed to enable the sharing of laboratories between different institutions.

The joint project DigiLab4U is developing, testing, and evaluating a digitally trans-formed laboratory environment that enables cross-site networking of real and virtual laboratory facilities.

Multiple services and applications have been designed, developed, implemented, and deployed for the DigiLab4U project. One of the main components, the Laboratory Management System (LabMS) application, provides an integrated platform to manage remote experiments. Mainly, it interacts with laboratory instruments via IIoT integration protocols and provides web-based user interface for remote users. It can be run in standalone mode, or by interacting with the DigiLab4U infrastructure and services.

This paper focuses on DigiLab4U LabMS architecture, its Application Programming Interface (API) and functionalities, as well as security and safety concerns in digitalized remote laboratories.

## Keywords

Remote Laboratories, IoT, Digitalization

## 1 Introduction and Problem Statement

Laboratory experimentation plays an essential role in engineering and scientific education (Heradio et al., 2016). There have been several approaches to developing laboratory-network infrastructures in the past. In recent years, new and innovative types of virtual and remote laboratories, such as VR labs and serious games, have become more and more common (Adineh et al., 2022).

For remote experiments, robots can be used to automate manual operation procedures. Consider a robot arm that gets three numbers as target coordinates to move to. The goal is to develop a remote experiment that contains a user interface to get the target coordinates from the user, submit it to the robot, receive robot feedback, and return it to the user. At the same time, the user should be able to monitor what is happening inside the laboratory via a camera. Only one user at a time can perform the remote experiment and thus the user needs to book a time slot in advance. While real-time protocols are needed for time-critical operation (e.g. safety), other commands and responses may be communicated via Internet Protocol (IP). In some cases, however, there is no opportunity for the laboratory owner to provide a static IP address to the LabMS server due to university regulations. Additionally, remote experiments in universities should be able to be called from a Learning Management System (LMS) inside a specific course to simplify the learning environment. This paper contains information about our proposed Laboratory Management System (LabMS), to reduce the time and effort required to operate remote lab experiments.

Section two provides insights into the research background and prior activities. Section three explains the LabMS' architecture and its functionalities. In section four, a case study is presented to prove the usability of LabMS. In section five, outcomes and conclusions are discussed.

## 2 Research Background

There are already many studies and approaches about how to make laboratories available remotely, whereby the motivation differs (costs, too little equipment, practical experience, workload, ...). Their focus is on technical

aspects and how a laboratory can be operated remotely and what technical possibilities there are in terms of implementation. For example, at the Higher Colleges of Technology in Dubai, a LabVIEW interface was designed and implemented to remotely connect to a FESTO MPS PA workstation required for process control training (Ahmad et al., 2020). At the University of Negeri Makassar, due to the insufficient laboratory equipment available, it was investigated how effectiveness and practicability could be increased through a remote laboratory (Jaya et al., 2020). The University of Parma, in cooperation with the University of Modena and Reggio Emilia (Modena) and the University of Applied Sciences Stuttgart, have designed a general multi-layer model for networked remote access laboratories based on criteria from previous work and have validated it with a mini-Delphi method (Romagnoli et al., 2020).

In general, remote IT-based operation of laboratories can be regarded as an application in the Internet of Things. Therefore, we have been looking at recent developments in IoT frameworks and protocols and we have compared existing approaches in other laboratory network developments. When the DigiLab4U (Pfeiffer & Uckelmann, 2019) project started, the main projects with somehow overlapping goals were LiLa (Richter et al., 2011), UniLabs (Saenz et al., 2015), NetLab (Siddiqui et al., 2016), and Go-Lab (Govaerts et al., 2013). However, none of them focused on utilizing recent IoT developments. Therefore, the decision was taken to develop a new architecture as well as software services to provide IoT-specific interfaces and communication protocols for the project's technical implementation. Moreover, in terms of cross-university collaboration between industry-related, physical, and digital laboratories, there is a need for a collaborating and connecting platform which is also easily adaptable to future needs.

Thus, within DigiLab4U we defined a modular IoT-based architecture including different services and applications. Some of them are running on central servers and shared among laboratories, e.g. Learning Management System, Billing, Booking, Research Data Management and Learning Analytics. However, the LabMS was developed to be operated within the laboratories home institutions. This on-site application should be compatible with the shared services mentioned above and the general DigiLab4U architecture. Moreover, it must be able to interact with laboratory instruments to operate them while running the users' requested remote experiment. Basically, LabMS tries to abstract the laboratory in such a way as to be available as a software service through the Internet. This complies with the concept of Laboratory as a Service (LaaS), as described in Halimi et al. (2018). Figure 1 illustrates standard layers for remote Laboratories as a Service. As

regards DigiLab4U specifications and requirements, the LabMS architecture is generally the improved and customized version of this architecture.

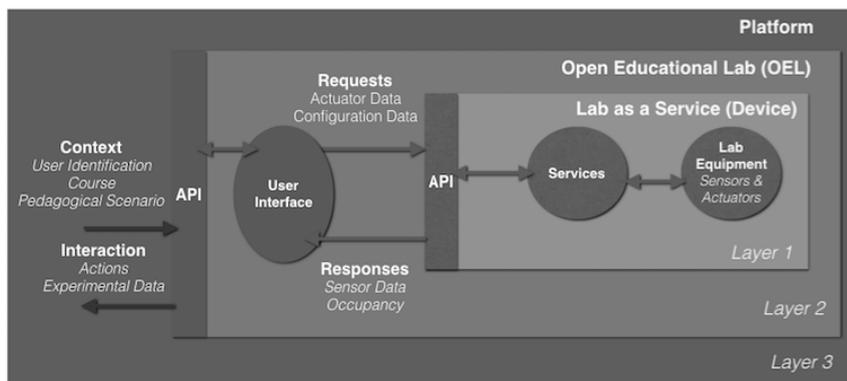


Figure 1. Standardization Layers for Remote Labs Integration (Halimi et al., 2018)

### 3 Laboratory Management System (LabMS)

For communication between the laboratory devices and the end users a middleware is needed to simplify remote access and enable the integration of laboratories into a shared lab environment (DigiLab4U). DigiLab4U LabMS was designed, developed, and implemented for this purpose. To achieve this goal, the following requirements were considered in LabMS:

1. Enable remote experiments
2. Interact with laboratory infrastructures in engineering disciplines
3. Provide means for lightweight access (e.g. REST)
4. Support laboratories with constrained access capabilities (e.g. if no static IP address laboratory servers can be provided; more information about this requirement can be seen at Adineh et al. (2022))
5. Interact with common Learning Management Systems (Moodle) and other DigiLab4U shared services (e.g. booking, data management)
6. Consider security and safety requirements (see (Uckelmann et al., 2021))

DigiLab4U LabMS libraries are a set of Java classes and packages which has been written by the DigiLab4U technical team based on the Spring Boot framework. In many cases, requirements mentioned in the “Introduction and Problem Statement” section could be covered automatically by imple-

menting LabMS libraries. It makes the development process easier and more flexible.

In the case of developing remote experiments with LabMS libraries, by using the provided sample LabMS, the focus is on how to run the remote experiment from the laboratory's side. In a similar way to creating a new Maven project, relevant dependencies (e.g. LabMS and Spring boot packages) are added, a Java class that extends "LabExperimentRunner" is defined, and overriding the "startExperiment" function is implemented in line with the logic of the experiment. In the following a suitable web-based user interface (UI) for the experiment can be developed and the lab experiment can be executed.

To monitor the experiment via camera, LabMS uses the WebcamXP application. This application should be configured to capture the camera's video while its internal web server is running. LabMS is able to get captured frames and send them to the UI via REST API. To manage bandwidth consumption, these frames could only be shared with the user during the experiment's running time.

### 3.1 LMS integration

DigiLab4U uses Moodle as its central LMS. All user credentials as well as courses are defined within this Moodle. LabMS, as an external service of the Moodle, needs to receive the credentials of the user who is running the remote experiment. To provide this single sign-on feature, LabMS benefits from IMS LTI to enhance secure interactions with Moodle. The Learning Tool Interoperability (LTI) from Instructional Management Systems (IMS) is a specification which describes easy and secure communication between LMS and other learning applications (Gavin Henrick, 2012). In our scenario, by clicking on the remote experiment link inside a Moodle course, the user's ID as well as roles will be shared securely with LabMS through the LTI protocol.

### 3.2 Connecting to Laboratories without Static-IP

Every LabMS server must provide a static IP address to be able to be called up from the Moodle server as well as by remote users. Some laboratories are not able to provide such a capability. This problem is discussed in detail in the paper "Challenges and solutions to integrate remote laboratories in a cross-university network" (Adineh et al., 2022). It showed that combining AMQP (Advanced Message Queuing Protocol) and RPC (Remote Procedure

Call) protocols makes local laboratories (without a static IP on the laboratory's side) addresses available to remote users (Figure 2).

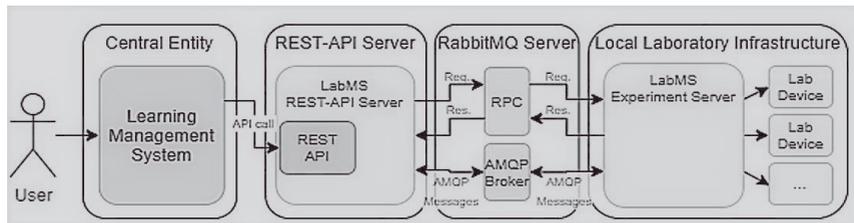


Figure 2. Combining AMQP and RPC protocols can enable communication for remote users with local laboratories without IP addresses (Adineh et al., 2022)

We continue this section with the help of an example. Consider that you have developed a remote laboratory application based on LabMS libraries. This application could be installed and run in your laboratory server and serve the web-based experiment requests as well. The server has access to the Internet, but the remote users do not have access to it. Hopefully, you can have access to a Virtual Private Server (VPS), maybe outside your laboratory. This VPS could be accessed from all over the world via its IP address or domain name. Now you just need to install and run an exact copy of your remote laboratory application. LabMS libraries, from version 0.9 could internally manage this situation.

LabMS is able to automatically adapt itself to its desired role by reading the value of “SERVICE\_TYPE” parameter from its configuration file. This parameter could be set up by one of the following values:

- “LabMS”: This value means that the application is running on a laboratory server which has a static IP address. So, it could server requests in a standalone mode.
- “ExperimentService”: LabMS applications with this service type, run in a laboratory which does not have a static IP address and could not be seen directly by remote users. Thus, it should communicate with its partner LabMS via the VPS mentioned.
- “RestService”: This value reveals that running a LabMS application is the partner of the ExperimentService mentioned. Then, it is responsible for receiving requests from remote users, sending them to the ExperimentService, receiving the results from it, and submitting them to the users.

As mentioned earlier, all those situations are handled dynamically by the LabMS and would not require extra development efforts from the developer. The communication between the RestService and ExperimentService is coordinated through an AMQP broker named RabbitMQ. The laboratory credentials of a RabbitMQ broker should be added to the relevant parameters in the LabMS configuration file.

#### 4 Case Study: Remote RFID Lab at HFT

Radio Frequency Identification Transponders (RFID) are used in logistics to track the flows of goods or production processes, both within and across companies. In order to meet the requirements of the various use cases, there are many different RFID transponders on the market.

The RFID laboratory at the Stuttgart University of Applied Sciences (HFT Stuttgart) has been used as the first laboratory test-case to be implemented via LabMS. Interacting with industrial robots, operating the RFID measurement chamber, identifying security and safety challenges, as well as providing a media didactically designed user-friendly web-based user interface (as described in Pfeiffer et al. (2022)) were the main requirements for the technical concept.

##### 4.1 Automation and Safety

Normally, a person should be present in the laboratory to move the RFID tags between the Tag-bank and RFID Measuring Chamber. The remote experiment does not depend on human operation in the lab. This means, at least, that manipulating RFID tags should be done automatically.

Implementing a Mitsubishi RV-2SDB MELFA robot arm enabled this process to be automated. Using MELFA language, this robot was programmed to operate as a server, get commands from the LabMS via TCP sockets, perform relevant movements and finally send an acknowledgement back to the LabMS.

Operating an industrial robot arm at a laboratory site raises safety concerns. On-site operation, maintenance and configuration, remote experimentation, and users with different skill levels need to be considered. In order to be able to guarantee on-site security at all times, different components and technologies are used. These are connected with one another by means of the LabMS in order to be able to ensure a secure process during a remote exercise, both online and on-site.

The RFID measurement cabinet was first used in an open-shared lab space. Multiple user-groups have access to this area. While safety was provided through a laser-based surveillance-system, every safety incident caused an emergency stop. The restart had to be done locally—which conflicted with the requirement of fully remote operation. Additionally, the old Mitsubishi robot caused other problems due to lacking interfaces and documentation, defective and rare batteries, and limited reach. Thus, it was replaced by a new collaborative robot. However, generally the process and interaction with the LabMS is the same. For additional resilience and safety, we added a machine protection fence including a door sensor, which in turn is connected to the robot via an I/O interface. These systems are described below in more detail.

#### 4.1.1 Cobot

An Aubo i10 robot is used to load RFID probe-tags to the RFID measuring chamber. This robot is a cobot (collaborative robot). This type of robot is designed to be able to act in direct contact with humans without seriously injuring them. To ensure this, the Aubo i10 is equipped with sensors that can detect blockages in its movements. The sensitivity can be set to ten different levels (collision class 1 to 10). The higher the level, the less force is required to stop the robot after collision detection. According to the User Manual, the robot is configured before shipping so that it can be operated without additional safety devices. However, for a concrete risk assessment by the robot manufacturer, the intended operational workplace must also be taken into consideration.

#### 4.1.2 Laser-based Safety System

The system from Pilz, a German manufacturer of safety systems, consists, in our case, of a laser scanner and a non-contact safety switch. The laser scanner divides the known area of the robot's environment into three different zones and can thus recognize and distinguish whether a person is inside or outside a safety-relevant area. In the first area, the person is outside the safety zone or no person is present and the robot operates normally. If a person is in the second area, the robot moves at reduced speed. If a person enters the third safety zone while the robot is moving, it immediately stops all movement.

The non-contact safety switch is used to detect the status of the door of the measurement cabinet. If the door is or is about to be opened during a measuring process, the robot will immediately stop any movement.

Due to benefiting from real-time reactions, this safety system is directly connected into the robot instead of the LabMS.

### 4.1.3 Safety Fence

After the measurement cabinet and the robot have been moved to a more secure room with limited access, a machine protecting fence is installed to separate the robot and the measuring chamber into a safe area (Figure 3). This machine guard complies with European and international standards: EN ISO 14120, EN ISO 13857, EN ISO 14119, EN ISO 10218-2.



*Figure 3. The Cobot and RFID Measuring chamber are behind safety fences*

For additional safety, a safety lock is installed on the door of the fence, which can be locked from the outside but can still be opened from the insi-

de at any time. So, if a person is in the safety area, they can leave anytime. The fence helps to avoid unintended safety stops caused by passing people. This fence is not connected into the LabMS. Mainly it is used to prevent unauthorized persons from accessing the robot working area at laboratory.

#### 4.1.4 Surveillance Camera

In order to be able to monitor the course of the experiment even while the laboratory is being operated remotely, a surveillance camera is installed in the laboratory in such a way that the room inside the protective fence, in which no people may be present during the measurement, is imaged. IP-Cameras, mainly providing an URL, can be used to get the current snapshot of the environment. By inserting this URL as the “IPCAM\_IMG\_URL” parameter into the LabMS configuration file, you will be able to retrieve the current laboratory image from your developed remote experiment user interface. The LabMS will provide it for you if the endpoint “/getVideoCamImage” of your API is called up. By calling up this API periodically, the remote user can see what is happening during the experiment. As far as security, privacy, and bandwidth management are concerned, the live view feature of the LabMS is only available during the measurement.

#### 4.2 Integrating with Moodle and Booking

The open-source Moodle plug-in, named Scheduler, is used to organize the appointments offered to students and researchers. With this plug-in, teachers can open time slots for students, which can then be booked by them. It is possible to determine whether an appointment can only be booked by one student or by several ones. It is also possible to allocate the appointments. Since the plug-in can be installed very easily in every Moodle course, it is convenient for both teachers and students to use.

## 5 Conclusion and Future Works

Designing and developing a Laboratory Management System is a complex task. Different infrastructures, university guidelines, safety and security issues, as well as recent developments and synergies concerning the Industrial Internet of Things (IIoT) need to be considered. However, the LabMS developed has shown that it is flexible enough to be adjusted to current and future needs. Now, educational laboratories can implement a LabMS with reasonable effort. Implementing a LabMS improves the development of

remote experiments and simplifies the integration of laboratories into the DigiLab4U platform.

We have also discussed digitalizing the RFID laboratory with a LabMS while considering safety issues. The effort to automate experiments with robots should not be underestimated.

A LabMS, as it is, can manage remote laboratories and remote experiments. As part of its next steps, it could be improved to coordinate multiple laboratories as a central cloud-based service. In this case, a central LabMS will be developed and run in DigiLab4U servers to serve and manage interactions between DigiLab4U-shared services and remote laboratories.

Moreover, through improvement of its user interfaces, manipulating experiments (adding, removing, and editing them) could be done in a simple, user-friendly manner.

Providing mechanisms for a LabMS to enable it to interact with other digital laboratory platforms can be mentioned as another future plan.

## Acknowledgements

The DigiLab4U project, on which this paper is based, was funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112. The responsibility for the content of this publication lies with the authors.

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## **Comparing Service-Oriented System Management Solutions in Remote and Virtual Laboratory Environments**

### Abstract

Digitalized laboratories are gaining importance in the higher education sector. Students are being provided with remote access to physical laboratory infrastructures as well as online access to virtual labs. Due to the complexity of systems in digital laboratory environments, it is often difficult to manage the applications efficiently. Moreover, there can be multiple types of laboratories with different system configurations. These laboratories need different management solutions based on the heterogeneity of lab systems. Therefore, different approaches are needed to create deployable software units which support multiple architectures.

We compare a microservices approach and monolithic architectures. As regards production deployment, virtualization and containerization along with their benefits and disadvantages are considered. In our research, we compared Docker solutions as well as the main Kubernetes tools like Minikube, Kubeadm, K3S, and Microk8s. Our goal is to identify solutions that are easy to manage even in heterogeneous hardware environments. Security, high availability, and compatibility with digitalized laboratories are also considered.

### Keywords

Remote Laboratories, Digitalization, Microservices

### **1 Introduction**

Digitalization is rapidly changing the world and many sectors are benefiting from it (Rodriguez-Andina et al., 2010). Digitalization in education is also being adopted in this wave. In lab-based education, digitalized laboratories, like remote laboratories and virtual laboratories are gaining more and

more importance. Corresponding applications vary from basic web-based dashboards to highly domain-specific software (Taivalsaari & Mikkonen, 2018). Those applications can be designed based on monolithic architectures or microservices approaches.

University labs are using a wide variety of hardware components. Some of the laboratories are specially designed for specific requirement. Unfortunately, hardware heterogeneity increases the complexity of system design and management. However, modern system management solutions can handle different hardware architectures, e.g., servers with Intel or AMD processors or IoT-compatible devices such as Raspberry PI with ARM architecture.

Considering monolithic architectures as well as microservices approaches in homogeneous and heterogeneous environments, the aim of this research is to come up with a suitable solution based on the system requirements in remote and virtual laboratories. Our findings will be beneficial for other digital laboratories.

As part of the Open Digital Lab 4 You (DigiLab4U) project (Pfeiffer & Uckelmann, 2019) and the concept of research based education, the requirements mentioned here have been researched by senior and student researchers (Kharade, 2021) at the University of Applied Sciences Stuttgart (HFT Stuttgart).

## 2 Background

Various architectures ranging from monolithic to microservices are compared along with their benefits in this research. The benefit of monolithic architecture is that its development can be faster in the initial phases (Kalske et al., 2017). However, the complexity of hardware architecture and problems arising due to an increase in codebase size could be mentioned as two major challenges with monolithic architecture. This poses challenges in the updating and scaling of application. On the other hand, microservices are small software units that run independently and have a single responsibility. Since microservices are loosely coupled, application scaling and deployments can be carried out independently (Kalske et al., 2017).

Traditionally, the deployment of the application used to be done directly on the underlying infrastructure, the host OS. Virtualization enables the creation of isolated virtual machines on a single hardware system. In contrast, containers virtualize only the file system, whereas VMs virtualize the entire operating system. A container engine is basically a software piece that takes requests from users, including options from the command line,

pulls images, and executes the container from the perspective of the end user (McCarty, 2018). Compared to other container engines (e.g., RKT, CRIO and LXD), Docker provides additional features such as building the images and signing (Baker, 2020). Therefore, in this research for a laboratory environment, Docker is used as one of the use cases for container runtime. By taking advantage of Docker's methodologies for shipping, testing, and deploying code quickly, the delay between writing code and running it in production can be significantly reduced (Official Docker Documentation).

Docker Swarm, Apache Mesos, and Kubernetes are some of the popular Container Orchestration Tools. Jawarneh et al. (Al Jawarneh et al., 2019) has done a comprehensive comparison of these tools based on major functionality groups such as resource management, scheduling, and service management.

Kubernetes (Kubernetes.io, 2020) is an open-source, extendable, portable platform for managing containerized workloads and services, aiding both automation and declarative configuration. It has a vast and rapidly evolving ecosystem. Kubernetes services, support, and tools are commonly obtainable. For this research, Kubernetes is further evaluated in terms of managing applications in a laboratory environment, and the recent container orchestration tools are compared and evaluated.

### 3 Software Systems in a laboratory environment

There are different architectures for a software system, from traditional monolithic architectures to the modern microservices architecture. Laboratory environments can be different in terms of hardware and software complexity and number of devices. So, each laboratory environment can have different requirements in terms of system architecture.

Similarly, based on laboratory requirements, system environments can also differ. There can be traditional servers or virtual machines or use of containerization.

#### 3.1 System Architecture

A typical software system consists of various components such as web user interface, back end, and database application.

Traditionally, software systems were designed using a Monolithic architecture. It provides a unified model in context to software design.

### 3.1.1 *Monolithic Architecture and its Challenges*

Monolithic software is constructed as one unit. Monolithic software is structured to be self-contained; elements of the package are connected and are dependent on each other. These packages have a high coupling between them. To execute the code, all components must be always available in a tightly coupled system. The benefit of monolithic architectures is that their development can be faster in their initial phases (Kalske et al., 2017). Monolithic architectures are best suited for laboratories which have very few hardware and software components and do not need frequent upgrades.

Even though monolithic types of software are simple and straightforward to develop, they have some downsides. There are two major categories of challenges with monolithic architecture which are relevant for the software systems in a complex laboratory or IoT setup.

#### a. Challenges with Hardware Architecture Complexity

Laboratory environments may consist of different devices which have various applications. These applications can be independent of each other and are distributed throughout the infrastructure. For example, a digital laboratory can have some applications which enable robotic movements using a Raspberry Pi, while the UI application and database applications run on high-end servers. Moreover, suppose that a lab needs to run other applications requiring high performance computing, virtual reality, artificial intelligence, or machine learning algorithms as well as data processing on GPUs. Since monolithic architectures are tightly coupled in nature, they are not particularly useful in IoT environments, where multiple applications run independently.

Also, different devices in an IoT infrastructure need different programming languages based on the functionality they need to achieve. This makes monolithic architectures unsuitable for deployment in complex laboratory environments as they are mostly based on the same programming context. For example, monolithic software based on tomcat server hosts user interface, business logic as well database access in the same environment.

#### b. Challenges posed by the Software Development Process

The challenges with monolithic architectures escalate as the codebase increases in size. It is more difficult to incorporate new features and improvements to existing features as the developer must find the right place to apply changes (Kalske et al., 2017).

Along with that, whenever a change is required in the software, the whole software is affected and needs to be redeployed, which increases the downtime of software even though it is not required for other functionalities.

### 3.1.2 Microservices Approach

Microservices are small software units that run independently and have a single responsibility, as shown in Figure 1. Microservices are loosely coupled in nature and focus on one utility. Loose coupling enables developers to make individual changes to microservices without impacting the rest of the codebase. Since microservices are not connected to each other, application scaling and deployments can be carried out independently (Kalske et al., 2017).

Complex laboratory environments can benefit by incorporating microservices architecture. Complex laboratory systems consist of independent software units which have varied purposes, such as data collections from sensors, actuation, data processing, and user interface. These functionalities work independently. Also, platform-dependent microservices can be developed based on hardware architecture, for example software based on ARM architecture for Raspberry Pi and AMD for software based on intel servers. Development and scaling of these applications can be done independently without affecting other applications. This enables the development of IoT systems with wide availability.

## 3.2 System Environment

Traditionally, the deployment of the applications used to be done directly on the underlying infrastructure. In this approach, the applications are deployed directly on the host Operating System (OS) and access the system resources directly via host OS processes. Multiple applications are installed on an OS. These applications are exposed using ports on the host operating system.

### 3.2.1 Virtualization

Virtualization enables the creation of isolated Virtual Machines (VMs) on a single hardware system. These virtual machines have their own operating systems, also referred to as guest operating systems. This approach isolates software applications inside VM and limits resource usage per application.

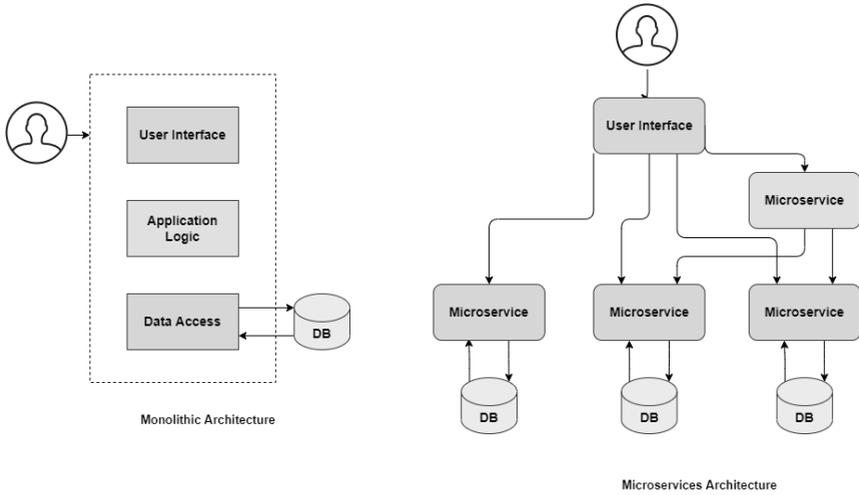


Figure 1: Monolithic vs. Microservices architectures

System encompassing virtualization has components such as Host OS, hypervisor, and VM, as displayed in Figure 2.

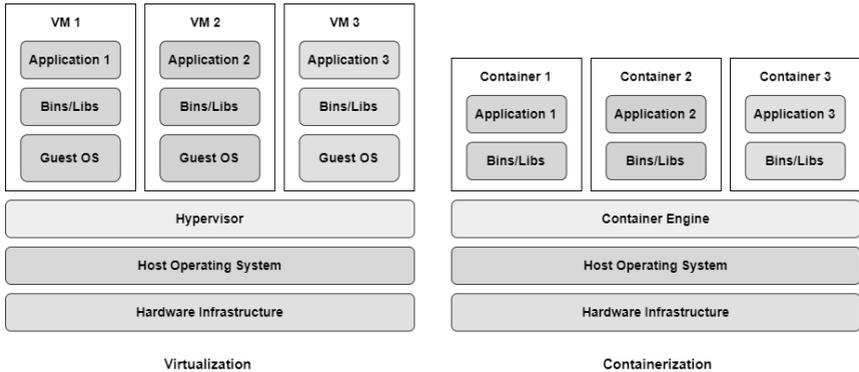


Figure 2: Virtualization and Containerization

The benefit of VMs is that, in a laboratory environment, virtualized deployments can be done on servers with greater processing power and memory.

So VMs are suitable for applications that are resource-intensive. Also, VMs are more secure because applications are deployed in the Guest OS.

The challenge with virtualization is that it is not suitable on edge devices as the guest OS on VM is itself heavyweight and a large chunk of the resources must be assigned to VMs. So VMs are not suitable in labs with low-end servers and applications needing few resources.

### 3.2.2 Containerization

The term containerization originates from shipping containers, where all goods are packaged within containers and shipped across the world. Software containers are used to pack software along with its dependencies. Software containers provide an isolated environment for an application which also contains the required packages, dependencies, and libraries, as displayed in Figure 2.

Software containers are platform independent. Containers try to solve the dev-ops problem through abstraction and platform independence in various environments such as ‘development’ and ‘production’.

A container is a runtime instance of an image. The image is a blueprint of a container which is never running. An image contains file systems and source codes. Many containers can be spawned from the same image.

### 3.2.3 Containers vs. VMs

Containers virtualize only the file system, whereas VMs virtualize entire operating systems. Containers share the kernel with the host OS. VMs create a new virtual kernel. Containers require a lower amount of storage, are lightweight, and take less time to boot up. On the other hand, VMs need more storage as the OS and programs are not only installed and run, but are also heavyweight and even take more time to boot.

In a complex laboratory environment with multiple edge devices, containers are a better option than VMs as edge devices require fewer system resources.

### 3.2.4 Container engines

A container engine is basically a software piece that takes requests from users, including options from the command line, pulls images, and executes the container from the perspective of the end user (McCarty, 2018).

Many container engines are available for running containers, such as Docker, RKT, CRI-O, and LXN. Along with that, various cloud providers such as Google GCP, Microsoft Azure, and Amazon AWS have their own

container engines, which utilize container images compliant with Docker or the open container initiative (McCarty, 2018).

Compared to other container engines, Docker provides additional features such as building the images and signing (Baker, 2020). Therefore, in this paper for a laboratory environment we used Docker as one of the use cases for container runtime.

### 3.2.5 Docker

Docker is a popular container technology provider. Using Docker, it is easier to create, deploy, and run applications. Docker is an open platform for developing, shipping, and running applications. Docker enables separation of applications from infrastructure, so software can be delivered fast. By taking advantage of Docker's methodologies for shipping, testing, and deploying code quickly, the delay between writing code and running it in production can be significantly reduced.

### 3.3 Container Orchestration

Automatic container deployments, management, scaling, and networking are achieved through the Container Orchestration process. It is feasible to deploy the same application in different environments and without any architecture modifications (RedHat, 2019). Along with managing a container's life cycle, container orchestration tools also support the integration of continuous integration and continuous deployment workflows.

A container orchestration tool's major tasks are the management of system resources, scheduling of applications, and management of services (Al Jawarneh et al., 2019). Container orchestration tools manage the underlying infrastructure for setting up the applications and provisions communications between them even though they are distributed.

Although containers are a better solution, it gets difficult to manage applications when there are many servers distributed in a laboratory environment, where there are distributed servers. Managing and networking challenges can be overcome using container orchestration.

#### 3.3.1 Container Orchestration Tools

Over the last few years, many container orchestration platforms have been developed in the industry. Although they all perform the same simple container automation task, they run in various ways and have been developed

for various usage scenarios. The most popular tools are Kubernetes (k8s), Docker Swarm, and Apache Mesos.

These tools are compared by Jawarneh et al. (Al Jawarneh et al., 2019), as shown in Table 1 and Table 2, and we found out that Kubernetes is best suited to a laboratory environment.

Table 1: Comparison of container orchestration tools based on resource utilization (Al Jawarneh et al., 2019)

Functionality	Docker Swarm	Apache Mesos	Kubernetes
Memory	yes	yes	yes
CPU	yes	yes	yes
GPU	no	partial	no
Disk Space	no	yes	no
Volume	yes	yes	yes
Persistent Volume	no	partial	partial
Port	yes	yes	yes
IP	partial	partial	partial

Table 2: Comparison of container orchestration tools based on features (Al Jawarneh et al., 2019)

Functionality	Docker Swarm	Apache Mesos	Kubernetes
Memory	yes	yes	yes
CPU	yes	yes	yes
GPU	no	partial	no
Disk Space	no	yes	no
Volume	yes	yes	yes
Persistent Volume	no	partial	partial
Port	yes	yes	yes
IP	partial	partial	partial

### 3.3.2 Kubernetes

Kubernetes is an open-source, extendable, portable platform for managing containerized workloads and services, aiding both automation and declarative configuration. It has a vast, speedily evolving ecosystem. Kubernetes' services, support, and tools are commonly obtainable.

The platform generally referred to as K8s or Kube has started taking the place of Development and Operations (DevOps) in recent years by helping developers to speed up the coding along with best practices, also to speed up deployments, automated testing, and updates. Moreover, working on Kube helps developers to manage apps as well as services with almost zero downtime. Also providing self-healing abilities, Kubernetes has the ability to detect and restart services if a process fails inside a container (Kubernetes.io, 2020).

To develop scalable and portable application deployments that can be managed, scheduled, and maintained easily, it's easy to notice why it's becoming the go-to technology of preference. Kubernetes can be integrated with all of the top free cloud offerings and can be used on-site in a corporate data hub. Its features, like cross-functionality and heterogeneous cloud support, are the reason behind making this platform standard in container orchestration (Kubernetes.io, 2020).

### 3.3.3 Microk8s

Microk8s is Kubernetes distribution developed by Canonical. Microk8s supports a single node as well as a multi-node Kubernetes cluster in the production environment. Microk8s is also a minimal version of Kubernetes and is suited to all kinds of servers, such as high-end workstations to IoT devices. Microk8s' installation is simple. Microk8s supports all popular add-ons, which are disabled initially and can be enabled when required. This makes Microk8s lightweight and suitable for any environment.

### 3.3.4 Suitable Kubernetes for a Laboratory Environment

The laboratory environment is a combination of multiple devices with different architectures, such as ARM and AMD. Also, there are varying resources per device. For example, devices such as Raspberry Pi have less storage, memory, and CPU than high-end workstations such as Intel based CPUs. Due to these parameters, it becomes challenging to come up with proper tools in such a heterogeneous environment. Also, ease of setup and available features are important parameters.

Based on the comparison of the tools, Microk8s and K3S are best suited for the laboratory environment and support multiple architectures.

#### **4 Discussion and Sample Scenarios**

Each digital laboratory has its own requirements and criteria as well as different hardware and software configurations. Some of them are used for performing experiments by accessing hardware remotely, while others are purely virtual ones. Based on these features the preferred solution for each laboratory can be chosen. These solutions could be adopted with personal computers, high-end servers or even lower-end Single-Board Computers (SBC) such as Raspberry PIs. Although there is no unique solution for all digital laboratories, this paper can help them to find the suitable solution. For example, here are some scenarios and solutions.

Scenario 1: To digitalize the RFID laboratory at the University of Applied Sciences Stuttgart (HFT Stuttgart) in order to enable remote experiments, as discussed in (Pfeiffer et al., 2022), there is a RFID measuring device which is designed to be operated remotely. The device controller software needs to be run during the remote experiment runtime and part of its Graphical User Interface (GUI) is intended to be shared with remote users. Thus, we could only run this program on a real or virtualized Microsoft Windows operating system, because this GUI dependency makes it too sophisticated to be containerized.

Scenario 2: In the second scenario, we found that the DigiLab4U Laboratory Management System (LabMS) (Adineh et al., 2022) is fully compatible with containerization. A LabMS is an application with which to manage laboratory instruments, as well as enhance remote operation while cooperating with DigiLab4U shared services. LabMS applications have been mainly developed based on DigiLab4U LabMS libraries and are potentially adoptable in dockerization scenarios.

Scenario 3: Consider that there is a virtual laboratory through which to execute and evaluate Artificial Intelligence (AI), Machine Learning (ML), or data analytics algorithms. These algorithms consume high performance computing resources as well as Graphical Processing Units (GPUs) on the server's side. As shown in other research, like that by Xu et al. (2017), by dockerizing part of GPUs' computation, not only could the benefits of containerization be significantly minimized, but in some cases so could the overheads.

## 5 Conclusions and Future works

In this paper, we prepared different solutions for system management in digital laboratories (remote and virtual laboratories) which have a different hardware and software complexity. The results show that when there is one application or service to be run, it is suitable for deployment on a single computing machine (e.g., PC, server, Raspberry Pi) as a normal running application. If there are multiple services to be run in one machine, implementing the Docker solution enables us to have more control over application management. Moreover, with the help of Kubernetes, laboratories with multiple machines in a distributed system can be managed more efficiently. Based on our findings, Kubernetes distribution Microk8s can handle multiple applications gracefully in laboratory environments with heterogeneous computing machines (PCs and Raspberry PIs). Microk8s is also easy to use in a laboratory environment as compared to other Kubernetes distributions.

As regards future work, evaluating the results of this research in a purely virtual laboratory as well as a virtual reality provider is considered. Moreover, this research could be continued by providing a Kubernetes-based solution with which to manage all DigiLab4U services. Finally, we want to evaluate the architecture mentioned in a real laboratory and compare the results in terms of deployment speed, failure recovery, and security.

## Acknowledgements

The DigiLab4U project, on which this paper is based, was funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112. The responsibility for the content of this publication lies with the authors.

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# **Enhancing Serious Game-Based Teaching and Learning through Learning Analytics**

## **Abstract**

In modern business management, the topic of the Internet of Things (IoT) is connected with Supply Chain Management (SCM). To teach the necessary business and personal skills, methods like serious games and simulations are often used. The skills that students can acquire are manifold but difficult to verify. In this article, we show methods and visualizations for supporting educators and students with learning analytics that are specifically designed for collaborative SCM serious games. The results and visualizations of the specific learning objectives of the application were aggregated and presented in a dashboard, which was evaluated in a usability study with guiding questions by six teams of two players and interviews with learning technology experts.

## **Key Words**

Learning Analytics, Lab-based Learning, Supply Chain Management, Serious Game

## **1 Introduction**

Supply Chain Management (SCM), controlling, and logistics are topics in study programs like engineering and management (Johnson & Pyke, 2000). In 2015, Loh et al. defined serious games as “digital games and simulation tools that are created for non-entertainment use, but with the primary purpose to improve skills and performance of play-learners through training and instruction” (Loh et al., 2015). Serious games are one way to teach topics like SCM and its respective related skills (Willems, 2020). There are various serious games dealing with linked topics in different simulation levels (Riedel & Hauge, 2011), (Tobail et al., 2011), (Hauge et al., 2016), (Willems, 2020), and (Galli et al., 2021). Ibarra et al., 2020 conducted a quantitative review which showed that serious games are recent research subjects, and the interest in them is increasing.

The other core topic of this paper is learning analytics, which “is the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs” (as cited in Siemens et al., 2011, Learning Analytics section, para. 2). The approach to gaining knowledge out of data could be used to create an interesting view on learning with simulation games. But besides the opportunities are some challenges, like data protection. An important step in the learning analytics process is to bring all stakeholders together. Students especially should be part of the process (Ifenthaler & Schumacher, 2016).

In this paper, we will connect learning analytics data with business game teaching SCM. We show visualizations for teachers and students, which were tested in a pandemic compliant study. The visualizations were presented in a dashboard, which was designed to connect the results with the specific learning objectives of the SCM serious game. The results of an evaluation with the players will conclude the contribution. We show insights from the usability study with the players, which was done based on some pre-arranged guiding questions, and from interviews with experts.

## 2 SCM Serious Game Research Prototype

For this research, we used a special variant of a business game named TransAction, which was developed at the RWTH Aachen University in 2013 and has been continuously improved since then<sup>1</sup>. The web-based business game deals with the supply chain. Students act as managers of a virtual company and increase their game success by applying knowledge obtained in the lecture during the semester. Originally a single-player game, we transferred the game mechanics into a collaborative multiplayer game which works on a simplified set of rules compared to the original game (Schablow sky, 2020). The resulting game mechanics and the basic gameplay are comparable to the games linked in the introduction (for a detailed explanation, see Schablow sky, 2020).

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1 <https://blog.rwth-aachen.de/lehre/2013/06/25/transaction/> and <https://www.medien.rwth-aachen.de/transaction/>

### 3 Learning objectives

A general learning goal at university is to help students to develop good *self-management* skills. Business and serious games are one way to teach students how to learn for themselves (Nissen, 2006).

The main learning objectives of the multiplayer variant of TransAction are reduced in comparison to the variant that accompanies the semester. In contrast to the nuanced learning objectives of the lecture-based variant of the game, they are limited to *understanding the complexity of the supply chain*. This point is interesting because a key limitation of simulations like TransAction is that we need to didactically reduce reality. Games like that are not feasible without the reduction of complexity (Goldmann et al., 2020). Our goal of understanding complexity is therefore confronted with the fact that in simulation games we are forced to reduce the complexity of reality.

Another learning objective is the *development of strategies to deal with uncertainties* and how these change over the course of the game, e.g. through increasing and decreasing demand for virtual products. And here we come to the most serious difference between the game's versions. The component of *collaboration* is an important learning objective and research subject, which is also related to the other learning objectives. The strategy is developed and discussed together with the other players. Two very fundamental learning objectives are that the students should *understand the functionality of the learning game* and be able to *comprehend its possibilities and limitations*.

The subject-specific learning objectives that are not on a basic level (e.g., understanding the function of the serious game) are typical learning objectives for engineers and economists. For example, the Accreditation Board for Engineering and Technology (ABET) lists *problem-solving* as a criterion in the curriculum of engineering technology programs (ABET, 2021), naming *identifying and solving problems* as important skills for graduates. Likewise, the World Economic Forum named *complex problem-solving* and *analytical thinking* as two of the Top 15 skills for 2025 (WEF, 2020). An example of a similar serious game in this context is SHORTFALL (Hauge et al., 2016). Willems, 2020 used the serious game "The Fresh Connection" to research cooperation development.

### 4 Dashboard

"The Learning Analytics Dashboard (LAD) is an application to show students' online behavior patterns in a virtual learning environment" (Park

& Jo, 2015). The Dashboards display visualizations designed to present the results of learning data collection to teachers and students in a way that is as easy to understand as possible. Specific calculations and associated visualizations are often assigned to the various questions (Dyckhoff et al., 2012). An example of such a question is "Do students who have practiced with the SCM serious game outperform students who do not use it?". The questions used for this research lead back to the different learning objectives described in the section before. The goal was to find indicators of concepts that are hard to operationalize like collaboration and the process of building a strategy. One big challenge is to design such results in an understandable format, because they should be understandable without expert knowledge (Dyckhoff et al., 2012).

As in Alonso-Fernández et al., 2021 data was collected in the xAPI data format and stored in a data warehouse. Preliminary work and decisions on this can be read in Ehlenz, et al., 2020 and Lukarov et al., 2020. For the current version, only logging data from the multi-touch devices was used without an extension to include other sensors. A possible extension for post-pandemic research, which is implemented in the underlying framework but not yet used in the current investigation setting, is eye tracking (Heinemann et al., 2020) and others, like motion tracking (Ehlenz, et al., 2020). Praharaj et al., 2018 were able to show that eye tracking data could be used as an indicator of collaboration quality. One way is to calculate the joint visual attention (looking at the same area), which could predict the quality of collaboration. This sort of data could be integrated into a later version of the experimental setting. We collected data comparable with that of Alonso-Fernández et al., 2021, who used the serious game profile of xAPI vocabulary (Serrano-Laguna et al., 2017). The set of definitions used is openly available (<https://xapi.elearn.rwth-aachen.de/>). The following set summarizes the types of collected interactions: Started (game or period is started), Finished (game or period is finished), Synchronized (stage is synchronized), Asked (question for next period), Answered (answer to question), Selected (module chosen by player), Stopped (stopped working on module), Changed (value of a slider is changed), Pressed (button was pressed), and the collected activities are Game, Level, Stage, Question, Answer, Draggable, and Button.

The dashboard for the SCM game contains four sections. Schulz, 2021 developed the visualizations shown in this paper in his master's thesis. Each section shows up to nine graphs with increasing complexity. Each of these can be assigned to at least one of the learning objectives, with a focus on the section in which it is displayed. Each visualization and indicator is designed

using best practices and guidelines, see Abela, 2013 and Iliinsky & Steele, 2011.

The first section shows general information about the sessions. It is designed in line with other dashboards, especially the ideas of T-Mon, “a monitor of traces for the xAPI-SG standard” (Alonso-Fernández et al., 2021). They implemented a set of visualizations with aggregated data for each player.

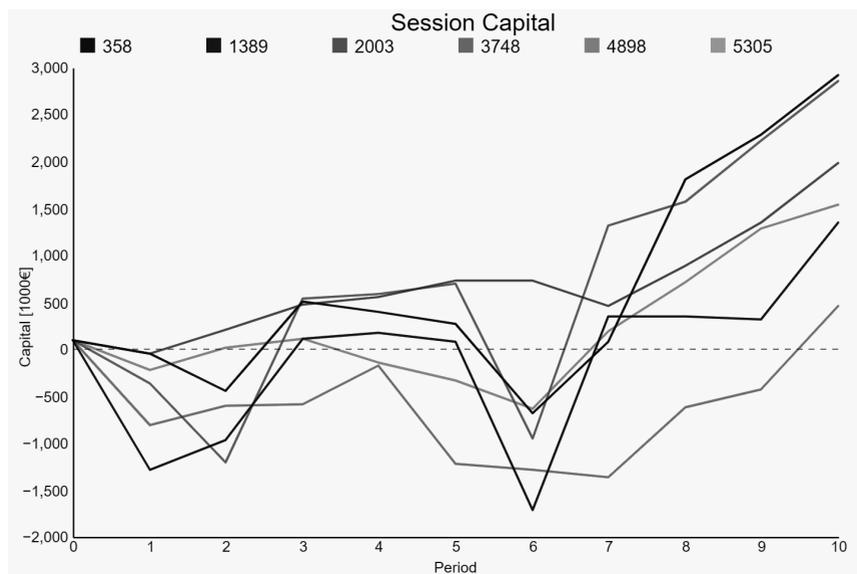


Fig. 1 Example visualization from the general section. The teacher could compare the overall capital of the 6 different groups at first sight.

The second section shows data about the usage of different functionalities of the serious game. Fig. 2 shows two visualizations about the handling of the game. For example, two groups were able to pay back the loan in the middle of the gameplay and took out new loans for the later periods.

Fig. 3 shows a visualization which could be used to compare different groups with regard to the production components used to build cars. With these visualizations, the teacher could learn about the management of materials that was done by each group. On the y axis, the distribution of the different materials is plotted; a solid color-filled period would therefore mean that only one material was present with the group, while no data shows

that the players had no materials in the period (as group 2003 in period 5/6). An even distribution shows that the players had the same amount of all materials, like the same group at the beginning of the game.

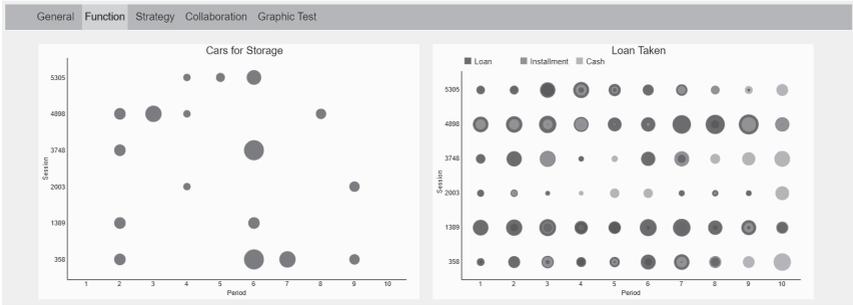


Fig. 2 Example visualizations from the function section. The left graphic answers the question of if the students used the storage function, how and in which game period. The right graphic shows if the learners used loans and how often. This also relates to the first graph shown in this paper.

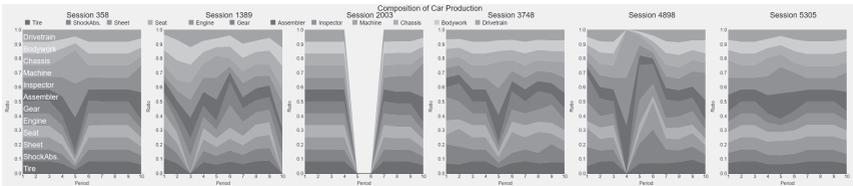


Fig. 3 A more complex visualization from the functions section showing the material management of all groups. The y axis shows the relative distribution of materials; the x axis represents the time periods.

**For the third section**, indicators were derived which are connected to strategy development. Here it is possible to determine the inherent difference between group strategies. For example, the evaluation showed that there are typical mistakes connected to strategy development, which occur at different stages in the game. Especially in the first cycles (rounds) of the game, it is hard for some players to deal with their uncertainty, which is visible in the data on the dashboard. Fig. 4 shows some results of the dashboard concept for SCM serious games. The upper right graph shows the results of the actual group and the mean from the other groups. Together with the

capital allocation, the graphs could be used to analyze the strategy of the learners with regard to the finances of the team.



Fig. 4 Example visualizations from the strategy section. The four graphics show the results for group 5305, which can be used individually or jointly.

The fourth section of the dashboard deals with group behavior; this last part of the dashboard gives insights into collaboration: Division of tasks is the most obvious indicator; other more detailed insights like interaction distribution and attribution of period conclusion allow educators to get a deeper look into the behavior of students learning in teams. Fig. 5 shows the basic visualizations, which are accompanied by others. From these very basic visualizations, the teacher can first see how the students have assigned themselves the individual tasks. However, this type of visualization has led to reconsideration of the decision to let the players pass the module selection. This is because unfavorable distributions show that one player has significantly fewer interactions than the other player.

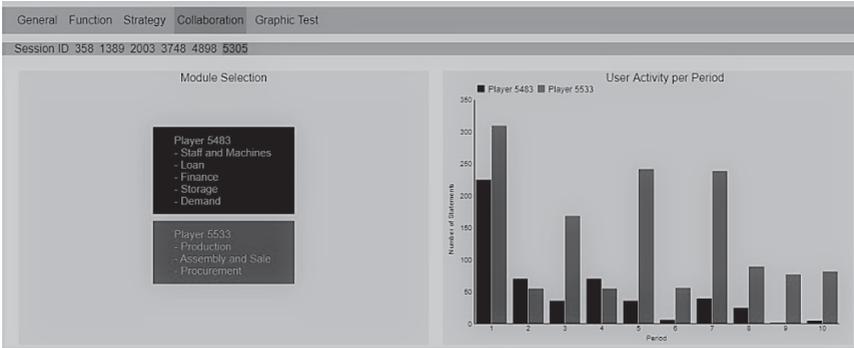


Fig. 5 Example visualizations from the collaboration section. The left graphic shows how the players distributed the modules, which was a decision taken by the groups themselves. The right graphic shows the number of interactions recognized by the system assigned to the players.

### 5 Evaluation

One obstacle in designing dashboards is the need to evaluate them. Jivet et al., 2018 analyzed how researchers evaluated learning analytics dashboards in a systematic review of 26 papers. We tested their usability and the understanding of them in a small-scale study.

A possible next step regarding dashboard evaluation could be to investigate if and how the dashboard is able to change the behavior of the learners in certain respects. For example, it could have an effect on the balance of the workload, forms of collaboration (i.e. division of labor), or a deviation in the observed communication strategies. For now, data about usability and understanding was collected and has yielded promising results, as the *System Usability Scale* (Brooke, 1995) reaches an average score of 85.25. Though the scores are 0–100 and 85.25 is in the official range of “excellent” results, it still leaves room for improvement.

The evaluation of the specific understanding of the dashboard and the indicators employed is done mostly qualitatively and described in more detail in Schulz, 2021.

## 6 Conclusion & Outlook

The work presented here is the aggregate of the efforts of multiple groups from different disciplines. It shows the evolution of curricular content to a serious game, then to a collaborative game, and then further on to a powerful instrument for obtaining deep insights into the understanding process of the complex interdependencies in the supply chain.

While the first evaluations had to focus on the usability and understanding of certain aspects due to the pandemic situation, the results look quite promising: The indicators allow instructors and supervisors to understand their students to a higher degree and yield information inaccessible before. Furthermore, they enable students to reflect on their behavior regarding decision-making as well as collaboration, discuss it in group and with their instructor, and have constructive feedback to improve in upcoming iterations.

The next step should be a larger-scale study to evaluate the current prototype with a larger audience, to test if the learning goal of *self-management* could be improved with a dashboard for students and compare the results to different modalities, i.e. single-user or remote collaboration. Provided the results justify further pursuit of this avenue of research, the prototype will be enhanced to reflect the current complexity of the single-user serious game.

## Acknowledgements

This work has been funded by the German Federal Ministry of Education and Research (BMBF) through the project DigiLab4U (No. 16DH2114).

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# **Information Sources and their Potential for Multimodal Learning Analytics in Laboratory-based Learning**

Abstract

Multimodal learning analytics offer opportunities to understand learning processes more precisely and to use these insights to improve or even individualize learning environments for everyone.

Educational lab environments are usually shared spaces: Learners come and go at regular intervals, engage with prescribed learning activities, and—hopefully—gain practical knowledge on the way to add real-world relevance to the theoretical knowledge they have obtained in traditional lecture halls. Digital means can help to transform those shared spaces into personal learning environments catering to individual needs in the learning process. This contribution aims to explore the potential of various enhancements to laboratories as data sources for these improvement cycles. It introduces several approaches and device categories and provides experiences and guidelines on real-world integration for the early integration of sustainable data collection and usage in lab-based research projects.

Keywords

Lab-based Learning, Learning Analytics, Data Sources

## **1 Introduction**

The key to successful adaptiveness in learning experiences is a deep, thorough understanding of the underlying cognitive and social processes. Based on this fundamental knowledge, prototypes can be designed and tested, further hypotheses formulated and evaluated, and additional insights generated. The discipline dedicated to the generation of the required data and the investigation of it as well as its analysis and transfer into workable guidelines and recommendations is Learning Analytics. Since traditional Learning Analytics usually focuses on personal knowledge construction processes happening in similar traditional methods of operation and institutio-

nal settings, the field of Multi-Modal Learning Analytics (MMLA) evolved. MMLA strives for an even more complete understanding of learning by incorporating data from a broad range of additional data sources (Chejara, 2020 ; Kitto et al., 2015).

Worsley, 2018 provides an overview of the current state of research in this respect but does not yet address specific learning settings. Laboratory learning environments seem a natural fit for MMLA, as existing equipment might be facilitated as a data source for learning analytics and the environment usually offers a suitable infrastructure to add additional means of observation.

Still, a thorough reflection on possible data sources and their potential field of application in the research process of lab-based learning is mandatory, as are pre-planned strategies for sustainable data acquisition, storage, and processing.

## 2 MMLA in Lab Environments

Laboratory-based learning offers an ideal breeding ground to apply the set of MMLA tools to a holistic analysis of the educational processes happening there. The defined environment provides two major benefits over traditional learning in general:

First, the actual objects of interest themselves can be considered a reliable source of data if sufficiently integrated. Second, the laboratory environment, be it physical or virtual, can be augmented with sensors and other IoT capabilities to provide additional information to account for previously hidden variables in the learning process.

### 2.1 *The domain-specific learning process*

The former benefit, the “connected” subject of the students learning process, is of utmost relevance from a plethora of perspectives, as it provides insights into the usability of the tools employed, the didactical approach of teaching the matter, and the students’ method of operation regarding a certain object of interest.

An example could be the comparison of various RFID chips within a measuring chamber. The learning process here includes the operation of the equipment, the handling of the chips, and the proper documentation of the measurement’s results (Pfeiffer et al., 2020).

The actual behavior of the students within the lab can be employed to evaluate the student's understanding of the matter. The occurring interaction can be mapped to an idealized expected sequence of events. A matching pattern can indicate a deep understanding, proper preparation, or (in some cases) just a solid imitation of previously observed behavior—which might suffice depending on the context. Deviations from the intended sequence can be interpreted by a skilled tutor in multiple ways (Herdig, 2013): Any differences can be either unintentional, indicating a lack of understanding and proper preparation, or intentional, which could be caused either by malice or scientific curiosity. While the differentiation of such nuances often requires classification by trained observation staff, the “human-in-the-loop” approach comes with three significant downsides:

a. It binds a serious share of resources, which could be deployed elsewhere in the learning process. Full observation processes, if done correctly, require at least one observer per participant. Furthermore, this work cannot be assigned to untrained auxiliaries. Often, several aspects must be regarded in parallel and documented accordingly, requiring both experience in scientific observation as well as deep knowledge of the experiment conducted to produce the necessary anticipated results.

b. Relying mainly on personnel in supervision and observation is prone to human error. I.e., in security-aware experimental contexts and lab environments, human intervention might prove too slow to avoid dangers to life, health, or expensive equipment.

c. Technical systems can be superior in terms of pattern detection and allow for downstream analysis.

Still, there might be edge cases where different strategies employed by the learner might lead to the intended result. But usually, when it comes to handling lab equipment, there is a set of prescribed rules and protocols to follow. So often, deviation from protocol is not intended, as it might invalidate the results even if the outcome is similar. A thorough approach to data collection still provides the means for post-factum discussion of such processes: MMLA is explicitly not intended as a replacement for (human) supervision but as a means of deeper inspection of the learning process.

## 2.2 *Environmental conditions*

Beyond the previously explained specifics of content-related process definition and supervision, the second benefit is often neglected, as it is much harder to achieve generalizable results from the laboratory in its entirety than to work out success factors in a specific setting. The controlled environ-

ment of laboratory learning may provide many insights that, if analyzed and reported, can have a sustainable impact on teaching and learning.

To provide examples for this category as well: Groups of students within a lab will communicate with each other, both verbally and non-verbally. Even a total lack of communication can be considered a special form of communication and thereby interpreted (Breazeal et al., 2005). Students have certain physiological reactions, i.e. to stress, which might be recorded via electrodermal activity, pulse, or close observation of eye movements (Fadeev et al., 2020 ; Moacdieh & Sarter, 2017). While many such factors might play a role, lab-based analytics offer better possibilities in this regard than other domains of application for MMLA such as mobile learning, where there are far more potentially undetected dependent variables like background noise (learning in a train) or significant temperature differences might, for example, impact concentration and thereby alter observed behavior. Thus, a controlled environment ensures, to some degree, comparability between subjects (Field & Hole, 2003).

As a content-related approach is usually highly domain-specific and requires conception and analysis by didactical researchers from the respective field, the remainder of this publication focuses on these more generic aspects: What data can be collected in most lab-based learning environments, what hardware and software requirements does this mandate, and what should be considered in terms of maintaining good scientific practice?

### 3 Possibilities & Potential of Lab-Based Learning

This contribution focuses on the overarching possibilities of multimodal learning analytics in lab-based learning: data sources for a holistic understanding of collaborative learning processes in controlled environments. Thus, different approaches are examined and analyzed.

#### 3.1 *Observing Group Behaviour*

For example, learning in groups in such settings is, in contrast to purely online scenarios, not purely mediated by digital systems: Verbal communication as well as non-verbal communication play an important role and are hard to capture (Sturm et al., 2007), (Echeverria et al., 2019), (Martínez et al., 2011). The usage of microphone arrays empowers researchers to determine the individual shares in conversations on a purely technical level, which thereby delivers an important indicator of the productivity of the group.

Furthermore, the same data can be analyzed on a semantic level and provide information on role distribution, on-topic vs. off-topic discussions, and work attitudes. Such microphone arrays can be obtained relatively inexpensively and coupled with an open-source software stack like the ReSpeaker product line or as proprietary solutions by various vendors, all of which come with specific pros and cons, but can be fitted to nearly every lab environment.

The same is true for “visual data sources”: A broad range of possible solutions cater to the needs of every potential use case. Even the most basic approach of placing a cheap webcam in a corner will open the option of later post-processing and qualitative analysis, i.e., of a sequence of interactions. Using action cams or other wide-angle equipment will enhance the level of information packed into a single data stream, but the real leap might come—depending on the use case—by obtaining additional depth information by using Kinect systems or Intel’s RealSense devices.

Still, recent developments in machine learning have significantly improved the potential gain in this respect, even from different hardware solutions. Modern open-source software enables researchers to extract information like posture, body language, and group formations from recorded video streams (Schneider et al., 2021). Some approaches even raise expectations of reliable detection of facial expressions or stress levels from those recordings<sup>1</sup> (Hassan et al., 2021). Advancements in hardware promote the idea of even integrating those approaches into real-time feedback processes instead of only using them for post-processing.

### 3.2 *The Individual in Focus*

Those somehow generic data sources just scratch the surface of what multimodal learning analytics can deliver as a foundation for a deep understanding of educational endeavors (Worsley, 2018). Beyond that, a lot of media provide additional information beyond the obvious for the respective application. For example, VR headsets provide movement data of participants, which can enhance the research process in the emerging area of virtual and hybrid labs (Wiepke et al., 2021), touch surfaces deliver information on traces or concurrency, and additional sensors like electrodermal activity wristbands or heartbeat monitors let the researcher draw conclusions on stress levels and, thereby, introduced cognitive load, for example (Huang et al., 2021).

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1 <https://lit.gse.harvard.edu/ez-mmla-toolkit>

The challenge of multimodal learning analytics is the farsighted extent to which data sources might be of value in the retrospective analysis of learning situations, the construction of a comprehensive understanding of the behavior observed, and the meaningful combination of those sources. Often, many single streams of data generate less valuable information than thought through combinations of two thoroughly selected sources. This contribution aims to guide researchers in the process of planning lab-based learning research: It sheds light on its potential, forewarns potential caveats, and advises on strategies for information collection, e.g., synchronization.

### 3.3 Contextual Factors

The data sources described so far merely help to record user behavior, i.e., human reactions to external stimuli. To fully understand learning and to optimize the process, it is essential to try to find and record as many of those stimuli as possible. Beyond the obvious impulses provided by experiments and accompanying instruction and documentation, there are a vast number of other impacts on human behavior. Not all of those can always be fully accounted for, like the proband skipping breakfast that day, but others are well within the control of the researcher. It is open to discussion if and which of those factors might contribute and be worth recording. But for some of them, it usually suffices to eliminate change as much as possible, so differences in behavior can be attributed to the intended variations in the setup, e.g., different instruction sets or tools, instead of a hidden variable such as a forgotten open window. Those environmental factors might include temperature or ambient light, and even the weather. While in most lab-based setups, it is possible to keep those constant, as regards others, like background noise and its effects on attention, it might be worth recording, if the opportunity arises. Furthermore, the research methods selected might mandate close monitoring of environmental factors, as variations in temperature for example might tamper with the results of EDA recordings.

There are more possibilities related to factors and corresponding sensors than can be accounted for in this contribution. As mentioned, usually it suffices to keep the factors constant, but if that is not possible, there are different ways to collect the data. They can either be sampled and recorded in fixed intervals of time, added as metadata to (interaction) events as they occur, or be monitored and recorded either in terms of change or when passing certain (pre-defined) thresholds.

## 4 Lab-based MMLA in practice

As presented before, there is a broad variety of potential data sources and a lot of reasons to record them. Still, just acquiring the respective sensors or logging all user interactions within the system is often not enough to enable a sense-making post-processing analysis.

### 4.1 Considering fundamental decisions

There are several intriguing, practical questions each researcher planning to employ MMLA within their laboratory learning processes should ask themselves to avoid trouble at later stages:

1. Do I need to synchronize the data streams to be able to draw any retrospective conclusions? If so, which resolution is required?  
For example, if eye tracking is involved, reactions to stimuli occur almost immediately, but often last only for a short period, calling for a resolution in a millisecond scale, while vocal interaction in a multilateral communication process can often be assessed when recorded to the second. Electrodermal activity is even slower, given that the body usually takes minutes to produce this reaction to elongated periods of cognitive stress. If synchronization is required, the question of how remains. Using individual, source-specific tools, a simultaneous, multimodal trigger event can mark a common timestamp, and orchestration tools can assist in a timed start of recording. Using a centralized instance like a learning record store omits the problem completely but requires thorough planning to incorporate all the data in a common format like xAPI.
2. Is there any benefit to making the data available in real-time?  
Providing real-time data is a challenge and usually requires a larger effort. Curiosity should not be the sole justification. But there are reasons: Building adaptive systems, monitoring expensive equipment, or coordinating remote collaboration are just some to mention. If the decision for real-time transmission is made, the circumstances usually dictate the follow-up questions: Where to stream the data, how, and using which media? Is a proprietary system the way to go or are open, extensible solutions available? Is data to be streamed just locally? If so, serial interfaces might be an option, otherwise, an internet connection is usually the way to go. Here, various follow-up questions arise beyond the boundaries of this paper, e.g. as discussed in Adineh et al., 2022. Which protocol fits best? Is acknowledged receipt or low latency more important?

Didactically, whether the teacher aims for process assessment with the support of learning analytics or whether the students should learn in an ungraded space is also an interesting question.

3. Most of those questions can also be applied to the next aspect: Where, when, and how to record. A modern setup in a lab should not require the researcher to manually collect recorded data with a flash drive from individual machines after the participants have left. So, the data should be automatically transferred, but this can be done in time (synchronous or asynchronous) or be buffered and flushed in batches as the opportunity arises. Potential factors to be considered are resources (storage, memory, CPU) and bandwidth.
4. Finally, it should be considered early on which disciplines are involved. Traditionally, Learning Analytics unites multiple domains, such as computer science, pedagogy, and psychology among others. Thus, the data captured is of interest to all of them, even though some of them not as tech-savvy as the engineering disciplines. A valid precaution is that proper planning and prepared data processing strategies will save time and effort and prevent miscommunication between all the scientists involved. They encourage more autonomous and self-dependent execution of the experiments and enable long-term cooperation.

Fortunately, researchers interested in implementing multimodal learning analytics methods within their educational lab environment do not have to be concerned too much about starting from scratch, as there are previous works to build upon, to use to get accustomed to the topic and to kickstart their projects, as referenced in section 4.3.

#### 4.2 *Maintaining Good Scientific Practice*

Data collection is usually a necessary evil for many practicing scientists, as it often feels like a dangerous balancing act. Privacy by design is a principle that demands being as scarce in data collection as possible, while researchers always dread the situation in which the analysis shows that the data collected is insufficient. To stay within the boundaries set by policies like GDPR as well as community conventions usually referred to as “Good Scientific Practice”, transparency is key and of utmost importance: Participants must be asked for their informed consent, with the researcher stating clearly what data is recorded and why. Furthermore, privacy by design also mandates the use of means of anonymization and pseudonymization as often as possible, admittedly a challenging task when it comes to learning analytics. Lastly, the Open Science community provides great tools and guidelines. Participating

in Open Data might, in the long term, enhance the quality of research, published metadata will help to understand related work, and open-source tools make the research process accessible, transparent, and reproducible.

### 4.3 *Open-Source Approaches*

There are different approaches and tools for multimodal learning analytics in laboratory environments, and a thorough discussion would be beyond the scope of this contribution. There are two projects focusing on different stages of the process to be mentioned here as examples and vantage points for explorations of this area: First, there is the set of tools implemented by Ehlenz et al., 2017 and 2021, used in research projects concerning collaborative learning with interactive tabletop displays. While there has been no explicit publication on the tools, they are available open-source and focus mainly on the orchestration of multi-device setups in lab-based learning, including camera recordings and screen captures.

The efforts presented by Praharaj et al., 2018 aim at the data-receiving end of the research pipeline: The identification of possible data sources, the aggregation of said data, and approaches to holistic analysis are discussed in great detail.

Both projects are works in progress and might well be interfaced with each other at some point in the future.

## 5 **Conclusion & Outlook**

This paper provided a brief, structured introduction to the field of multimodal learning analytics and its application in the context of laboratory-based learning. As shown, there is great potential in this discipline to enhance learning across many scientific domains and in various areas of institutional learning. Some reviews already show the huge potential of learning analytics, e.g. (Worsley, 2018) and (Samuelsen et al., 2019). They show the most frequent modalities, but alone are not a solution to the task of integrating learning analytics into complex settings like lab-based learning.

By structuring and categorizing that potential and those fields of use, and by introducing a set of further considerations to be taken, experts from other disciplines are guided to a possible starting point to try and incorporate MMLA into their teaching strategy. Technical challenges in this respect are described by Shankar et al., 2018, Mu et al., 2020, and Adineh et al., 2022.

Furthermore, the first glimpse into scientific practice and existing open-source solutions can guide the way to both improving scientific processes as well as enhancing these works by leveraging future contributions.

## Acknowledgements

This work has been funded by the German Federal Ministry of Education and Research (BMBF) through the project DigiLab4U (No. 16DH2114).

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## 1.3 Didactical Considerations



*Massimo Bertolini and Mattia Neroni*

## **Online Labs in Engineering Education: the Experience of SimuLOPS Lab**

### Abstract

During the pandemic crisis related to the severe acute respiratory Covid-19 syndrome (SARS-CoV-2), we had to redesign the education system at all levels, from primary schools to undergraduate and postgraduate academic courses. Because of the emergency, we, therefore, realized that traditional teaching models, at least in a university environment, can greatly benefit from the intelligent use of the latest advantages in the Information and Communication Technologies (ICT) sectors.

This paper describes the development and testing of a new teaching and learning system that integrates traditional with virtual approaches to undergraduate education in the field of industrial engineering. The approach was specially designed and developed for undergraduate students in mechanical and automotive engineering with poor, or no, knowledge of the optimization of complex production and logistics systems. The basic idea of the approach is to integrate more traditional university training methodologies, although provided through a virtual learning platform, with Experiential and Laboratory Learning (ELL) provided in both virtual and traditional ways.

We believe that it is time to innovate and implement a holistic educational system, which allows the integration of traditional classroom educational experiences, with new and more modern experiences obtainable through the virtualization of educational activities, in an intelligent way and in such a way as to allow students to autonomously initiate self-assessment processes.

### Keywords

Virtual Lab, Digilab4U, Industrial Logistics, Operations Management, Experiences.

## 1 Introduction

Over the past two years, the pandemic crisis linked to the severe acute respiratory Covid-19 syndrome (SARS-CoV-2) has profoundly challenged many of the established habits of our world, including how we teach. Universities and other educational institutions were forced to replace traditional teaching approaches (e.g. face-to-face lectures or teaching in physical laboratories) with distance teaching. Taking advantage of this opportunity, many universities modified their courses, both laboratory-based and theoretical, including in the STEM (Science, Technologies, Engineering, and Mathematics) disciplines, in line with the recommendations of the National Research Council (2006).

Making engineering education available online is considered by many researchers to be one of the biggest revolutions in the modern education system (De Jong *et al.*, 2013 ; Waldrop, 2013). Online labs, and with them all teaching activities, can now be optimally used thanks to currently available technologies such as ICT, virtual reality, augmented reality, cybersecurity, and others.

Our experiment concerns the transition of a traditional laboratory into a virtual one for mechanical and vehicle engineering students. The laboratory aims to teach students how to optimize logistics and production processes in industrial plants. Engineering students who have to learn these topics often face several problems in understanding the algorithms behind the optimization logic and translating them into computer programs. Many researchers claim that this is a complex and difficult learning process (Arias *et al.*, 2007 ; Lahtinen, 2010). Students are required to understand the issues related to logistics and production processes and, at the same time, to understand the optimization algorithms; moreover, they frequently have to make additional efforts to learn horizontal topics such as probability, statistics, operations research, and simulation and translate them into a computer program.

To overcome these difficulties, many STEM education initiatives that make use of the virtualization of educational laboratories have been developed all over the world in recent years (Zhu *et al.*, 2016). These include the Malaysian Smart School Implementation Plan (Malaysia), Intelligent Nation Master Plan (Singapore), Smart, the multi-disciplinary student-centric education system (Australia), SMART (South Korea), New York's Smart School (United States), SysTec (Finland) or Mohammed Bin Rashid Smart Learning Program (United Arab Emirates). These initiatives, mostly conducted with small-scale pilots, provide useful guidelines and considerations for

the design and provision of virtualized intelligent learning environments for STEM disciplines.

Drawing inspiration from these experiences, this paper reports the results of a pilot project conducted at the “Enzo Ferrari” Engineering Department (DIEF) at the University of Modena and Reggio Emilia. The experiment consists of virtualizing the SIMUlate Logistics Operation and Supply chain Lab (SimuLOPS): the idea of the SimuLOPS Virtual Lab is to integrate more traditional university training methodologies with virtualized Experiential and Laboratory Learning (ELL).

By adopting the proposed approach in two university classes of mechanical engineers, excellent learning results were achieved in a learning-by-doing approach, even for students with poor or no knowledge of the subject in question. The test, carried out on 66 students randomly divided into two equal groups, showed that the group that attended the blended learning model achieved better results in the final test. Furthermore, the students who took part in the test, answering a simple satisfaction questionnaire, showed higher satisfaction than the others.

## **2 The SimuLOPS Lab**

The “Enzo Ferrari” Engineering Department (DIEF) at the University of Modena and Reggio Emilia has a wide range of teaching and research labs, where students of master’s and Ph.D. courses carry out experimental activities, exercises, projects, and theses. Lab activities reinforce the skills acquired through studying and allow the balanced development of engineering education through the individual and/or group execution of experiments and projects.

Among these labs, a new one has recently been set up that allows students to deepen their knowledge in Operation, Intralogistics, and Supply Chain processes optimization. The SimuLOPS Lab was designed for master’s degree students in Mechanical and Vehicle Engineering who have little or no knowledge of the above topics.

The Lab was organized in a traditional way, that is, students were grouped in small teams, with a maximum of three students per team, and the activities were provided through a mixture of lectures, classroom exercises, and computer-based exercises. The activities were carried out independently by the students in a classroom under the supervision of the lab tutor. When the students knew enough about the subject, they were assigned specific tasks (both individual and group) concerning (i) solving one or more pro-

blems using Excel and VBA, and (ii) analyzing articles/problems provided by the tutor, replicating the solution in Excel and VBA.

The Lab is organized as a classic computer lab, whose goal is not to teach students how to program but to know how to solve industrial engineering problems through the development and application of multi-criteria techniques such as discrete event simulations and algorithms through the use of ICT tools.

With the pandemic, the laboratory was virtualized and linked to traditional teaching. This required a radical redesign, not in terms of the specific contents (still linked to the optimization of logistical and production projects in industrial plants), but in terms of how students can use the lab.

The laboratory activities were organized by combining active learning methods (i.e., providing didactic support, but leaving the learner the task of learning through his or her autonomous activity) and permissive learning methods (i.e., providing materials to the learner, who has the task of working his/her way through the learning unit). Then the exercises were rethought, creating a mix of individual exercises and group work. All the infrastructure was created and shared using the open-source Moodle course management system.

First, a compulsory placement test was created for all students. The self-assessment test, a mix of closed-ended questions and small exercises, is designed to check whether a student has the necessary prerequisites to successfully follow the laboratory activities, namely (i) Excel programming skills at beginner level, (ii) good reasoning/analysis skills, and (iii) basic knowledge of applied optimization and simulation, probability statistics, and operations research.

If the self-assessment test is not passed, the system warns the student that he/she should bridge the gaps in his/her knowledge.

Subsequently, the workshop is organized into 3 modules, each of which includes:

- recorded video lessons with teaching materials, mainly for in-depth study of the theoretical part;
- exercises to be carried out individually, uploading the results online and independently verifying that the exercise has been passed; the exercises must be uploaded onto a specific portal that is visible to the tutor for any evaluations/corrections;
- analysis of the data obtained by carrying out a small simulation on a specific problem created by the tutor; the analyses must be carried out individually and uploaded onto the portal; at the end of the upload,

comparative templates are provided to understand whether the analyses have been carried out correctly;

- learning self-assessment tests, which are accessible directly from the platform, that provide the students with the correct answers.

After the initial self-assessment, the student has access to the first module only after having (i) watched all the video lessons, (ii) performed all the exercises by uploading the results and the required documents, (iii) completed the data analysis, and (iv) passed the self-assessment before going on to the next module.

Students who complete the three modules are put together in a team of 3 people and each group is assigned a task to do together. The work will be presented to the tutor; only when the tutor gives a positive evaluation of the work will the students be able to sit the final examination.

### 3 Preliminary experiences

The activities of the SimuLOPS Lab were integrated into two lectures given for the Mechanical Engineering MSc courses, held in the teaching periods *March–June 2021* and *October–November 2021*. The two classes were randomly divided in half: half of the students attended only the classroom lectures (we call this set of students *Cluster0*) and the other half attended the virtual laboratory as well (we call this set of students *Cluster1*). The total number of lecture hours for the two groups of students was the same, but the way a part of the teaching program was used for a total of 3 European Credit Transfer and Accumulation System (ECTS) changed.

The analysis of the grades obtained by the students, as reported in Figure 1, shows that students in *Cluster1* obtained a higher average grade than those in *Cluster0* (26.0 compared to 24.4 out of 30). What is interesting is the variability of the grades: with a slightly higher average grade, almost all the students in *Cluster1* have grades close to the average (e.g., lower variance) than those in *Cluster0*, which show a higher dispersion of the grades compared to the average.

All the *Cluster0* students, those who did not attend the lab, were given the chance to repeat the test after attending the virtual lab. The interesting fact, even if this was limited to only 13 students, is that after attending the virtual lab and repeating the test, all the students significantly improved their evaluation (obtaining an average grade of 26.3 out of 30).

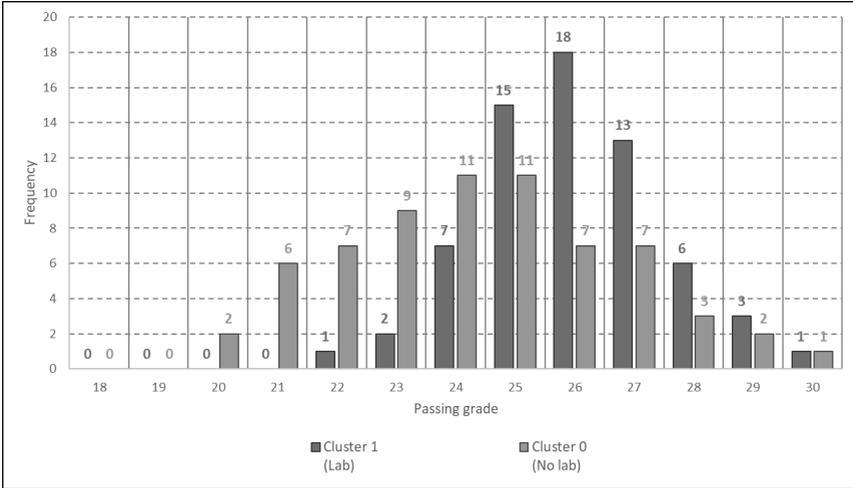


Figure 1: student grades for the two clusters (Cluster0 and Cluster1).

To confirm the students’ interest in the lab activities and to indirectly assess the quality of the proposed solution, the 66 students of *Cluster1* were given (at the end of the course and before taking the exam) an extremely simple questionnaire. The first three questions, the answers to which are shown in Figure 2, reveal a generally high level of satisfaction; the students considered it very useful (or essential) to integrate the laboratory activities, including virtual ones, with more traditional teaching activities.

The analysis of the answers to the following questions (shown in Figure 3) suggests some lines of development/improvement of the workshop. On the one hand, it appears that, although the lab activities were not considered too complex, the students engaged in them complained about their lack of previous knowledge preventing them from following the activities effectively. These responses may suggest that the lab should be supplemented with additional optional modules that can be taken freely by students to fill in the gaps in their knowledge (essentially related to probability, statistics, operations research, and programming).

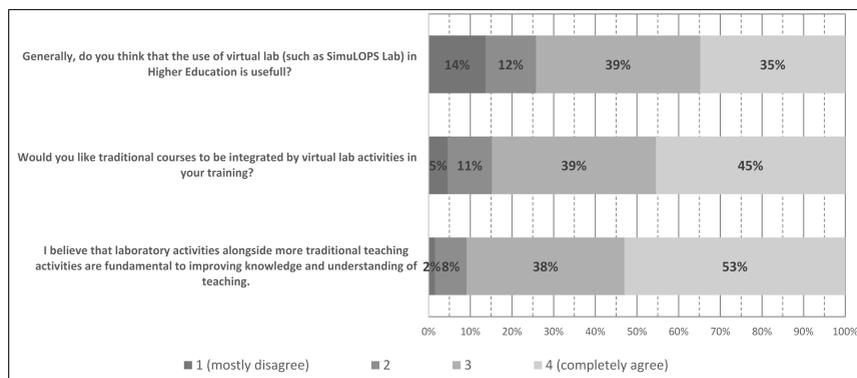


Figure 2: Students' general interest in the lab's activities.

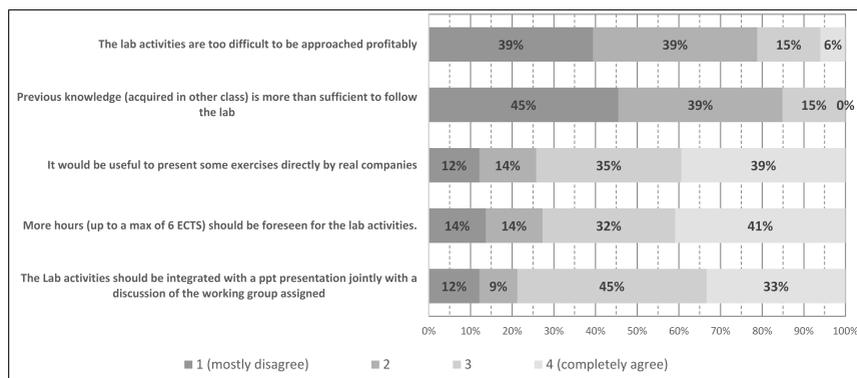


Figure 3: some suggestions collected from the questionnaire for improving the workshop.

Two other interesting conclusions that can be drawn from the analysis of the answers concern, on the one hand, the possibility of presenting some problems from companies and, on the other hand, having collegial moments of discussion of the group projects assigned.

The workshop could then be supplemented by some companies presenting real problems that the students in groups could face and solve. The resolution could be discussed publicly (both with the companies and with the other students) and part of the final evaluation could be attributed to considering the students' ability to manage the presentation of the results.

#### **4 Conclusions and future developments**

This paper describes an innovative approach to teaching industrial engineering topics (i.e. optimization of complex logistics and production systems). The innovation consists of the development and integration of a virtual environment (i.e. a virtual lab) with teaching and lab experiences, specifically designed and developed for engineering students.

The model and the virtual environment were built so that a holistic teaching and training approach was possible. Different training approaches, such as traditional teaching lessons, guided exercises, online lessons, virtual laboratories, teamwork, and intermediate and self-learning tests, were combined.

The model was developed in a rudimentary way and the first tests were carried out to confirm the quality of the solution and to collect appraisals for its improvement. Two classes of about sixty master's degree students each attended the lessons. For each class, half of the students had a traditional teaching method and the remaining half made full use of the virtual resources of the lab. The overall teaching hours were the same for the two groups of students.

The results of the final exam show that there was significantly better preparation on the part of students who made full use of the virtual resources on offer than those who had a traditional teaching approach. Moreover, from a feedback questionnaire given to the students, a greater degree of satisfaction on the part of the students attending the lab emerges.

For the future, the system will have to be extended and tested in a larger classroom, integrating the online teaching modules with cyclical self-tests for the students on past topics as the program progresses. Similarly, more group tests/experiences will have to be integrated (which were lacking in the first test conducted) to facilitate study and preparation activities in groups. Finally, it would be appropriate to develop a proficiency-level entrance exam

that allows teachers to evaluate the students' starting skills level and to profile the correct lab path—to be combined with traditional teaching activities—based not only on any gaps but also on students' personal attitudes.

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*Peter Treffinger, Michael Canz and Jens Glembin*

# **Opportunities and Shortcomings of Model-based Online Laboratories in Mechanical Engineering – Findings from a Guided Laboratory Study**

## Abstract

During the coronavirus crisis, labs had to be offered in digital form in mechanical engineering at short notice. For this purpose, digital twins of more complex test benches in the field of fluid energy machines were used in the mechanical engineering course, with which the students were able to interact remotely to obtain measurement data. The concept of the respective lab was revised with regard to its implementation as a remote laboratory. Fortunately, real-world labs were able to be fully replaced by remote labs. Student perceptions of remote labs were mostly positive. This paper explains the concept and design of the digital twins and the lab as well as the layout, procedure, and finally the results of the accompanying evaluation. However, the implementation of the digital twins to date does not yet include features that address the tactile experience of working in real-world labs.

## Keywords

Remote, Model-Based Laboratory; Digital Twin; Evaluation Survey

## **1 Introduction**

In the summer semester of 2020, due to the coronavirus pandemic, key teaching labs in courses such as mechanical engineering could not be held as face-to-face labs. This also affected multifaceted labs offered in advanced study programs. The complexity of these laboratories also stems from the combination of several disciplines. This results in students having to become familiar with test benches which, alone in terms of the number of components used, go beyond laboratory test benches as used in basic studies. In addition to subject-specific skills, personal skills are also addressed— for example, communication skills and coping with tasks in group work.

The face-to-face laboratory “Fluid Machinery” in the bachelor's degree program in mechanical engineering at Offenburg University of Applied

Sciences also had to be replaced by a virtual laboratory. The implementation of the laboratory experiment was solved via a so-called digital twin. The corresponding technical concept is explained in detail below. The question now arose as to what extent the virtual laboratory offered the same impetus for students to acquire skills—perhaps even opening up new perspectives—or whether important incentives were simply lacking. The main focus in the summer semester of 2020 was on ensuring that the virtual lab was available in the first place; the above questions were then investigated in the winter semester of 2020/2021 by researchers conducting extensive surveys to accompany the course.

## 2 General concept of the laboratory

It has already been mentioned above that the concept of the course is multifaceted.

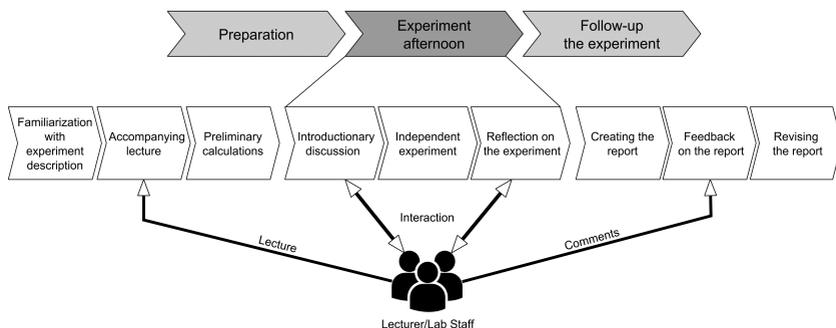


Figure 1: Follow-up of the different phases of the Laboratory from preparation to revision of lab reports.

On the timeline, there is a sweep from the preparation of the experiments to the feedback to be given on the experimental reports which have to be compiled about the experiments.

In principle, these elements were able to be retained in the implementation of the virtual lab. However, the discussion on the test benches could not take place in the real laboratory. Therefore, presentations were prepared with photographs, flow diagrams, and schematic diagrams in order to provide the students with a link to the real systems.

The lecturers had the impression that, also with this format, cognitive activation of theoretical prior knowledge was possible through a classroom discussion, as is also carried out in a real laboratory. Student perceptions were asked for in the surveys discussed below. An obvious deficiency of the virtual laboratory is that the students do not have tactile access to the test rigs. In the further course of the laboratory afternoon, however, the students succeeded in understanding the digital twins of the laboratory experiments with the result that they were able to carry out the laboratory experiments independently. As in a real laboratory, the lecturers follow the students during the implementation of the virtual lab and provide ideas through interim questions by encouraging the students to reflect on and explain their strategies and decisions during their actions. In addition, these questions stimulate the linking of the work in the laboratory to the theoretical basis discussed in the lecture. In this phase, the students work actively together in laboratory groups of two to three participants. The students have to organize themselves in carrying out the laboratory test. For example, they have to agree on who will use which strategy to set the parameters in the virtual test facility, who will document the values measured, and who will be responsible for ensuring the plausibility of the measurement results.

In addition, they have to agree on who in the group will respond to the lecturer's questions and, if necessary, support each other in answering them. After the experiments, a joint discussion on the results takes place. This has the particular goal of cementing the knowledge gained with regard to the theoretical foundation from the lecture. At the end of the afternoon in the laboratory, this discussion leads to a conversation about the expected content and form of the report. When creating the report, additional skills such as the evaluation of data, theoretical modeling, and the presentation of results are addressed. The students have several weeks to prepare the reports. As a rule, these are created based on a division of labor. The students receive critical comments from the lecturers on the content and form of the reports. If necessary, the reports must be corrected until a minimum standard is reached, which is sufficient for the laboratory certificate. From the lecturer's point of view, this last section (the creation of the reports and their critical discussion) is independent of whether a real laboratory or a virtual laboratory is used.

### 3 Digital twin as a means to a virtual laboratory

#### 3.1 Digital Twin concept

Besides classical hands-on laboratories, other lab types have been established in recent years, such as purely virtual labs and remote labs, in which lab installations are remotely controlled by students (Ortelt et al., 2021). In addition, a mixture of these elements is possible, which can be labeled as hybrid laboratories (Zapata-Rivera and Larrondo-Petrie, 2016).

The digital twin concept is a relatively new development originating from product lifecycle management (Grieves and Vickers, 2017) and is often described as a crucial element in the context of digitization/industry 4.0. (Jones et al., 2020). Such a digital twin is a digital representation of an object in the real world including all its properties, information, and behaviour (Haag and Anderl, 2018 ; Adamenko et al., 2020). The main difference from usual digital models is the data exchange between the physical object and model in both directions (Kritzinger et al., 2018). Due to this direct physical-to-virtual connection, the application of digital twins is also advantageous within a modern lab concept.

#### 3.2 Design of the Digital Twin in the machine lab

In the machine lab, the implementation process starts with the first prototype dealing with the radial fan test rig of the machine lab (García, 2019). Figure 2 gives an overview of the digital twin concept, including the main data streams occurring during its operation.

The digital twin itself was created by using the multidisciplinary modeling language "Modelica" within the commercial environment "Dymola". The communication between the digital model and the data acquisition (DAQ-) software of the rig ("LabVIEW") was the main obstacle in the development but was finally realized by using the Middleware TISC Simulation Server (Kossel et al., 2006). By comparing model results and values measured, the developers continuously improved the digital twin until the model and test rig showed almost the same operating characteristics and reproduced process values in high agreement.

As can be seen in Figure 2, the digital twin may be operated in two ways using different graphical user interfaces (GUI). On-site in the machine lab, the digital twin and real test rig may be operated in parallel, exchanging the necessary information in real time. In contrast, the digital laboratory events are carried out solely with the model using the GUI of the simulation

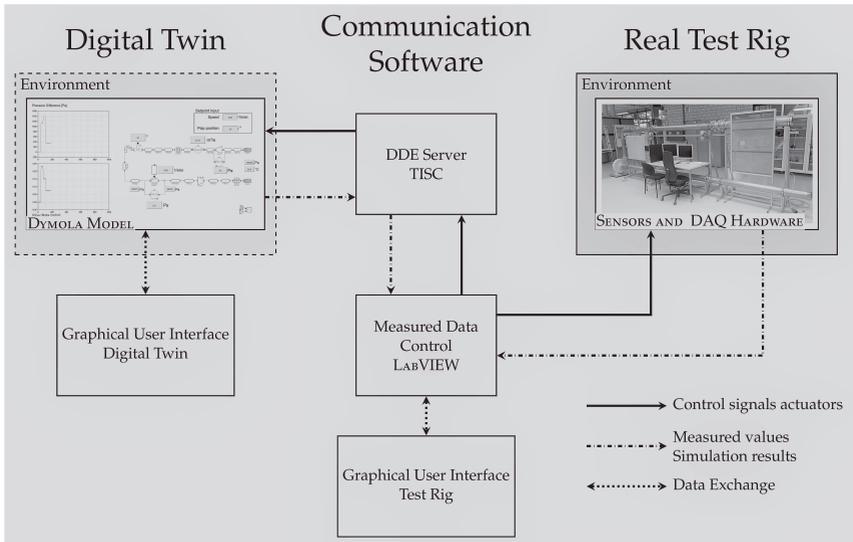


Figure 2: Basic scheme of the digital twin radial ventilator test rig in the fluid machinery lab at Offenburg University

environment. The design of the GUI allows the digital twin to be operated in the same manner and produces the same results as the facilities in the real laboratory. In this way, the students are able to concentrate on the experiment itself without being disturbed by other technical details of the model's environment.

The virtual lab is conducted via an online conference system with groups of 2–3 students. The digital model is opened within the simulation program on the computer of a lab assistant, who shares his/her screen. Through the assistant transferring control of their keyboard and mouse, the other participants are able to use the GUI on their screens and conduct experiments. This procedure prevents the students from installing the appropriate program and getting familiar with its handling. However, the lab's future development focuses on an autonomous operation by the students, e.g. by transferring the model in an executable program or by providing the model via a Web platform.

## 4 Design of a survey for evaluation of the laboratory

### 4.1 Overview

The combination of theoretical lectures, in which technical skills are developed, and application-oriented laboratories, in which these skills are transferred and thus methodological competence is refined, are traditionally an integral part of engineering degree programs. A particular characteristic of universities of applied sciences is the significantly higher proportion of application references in the curricula. As already mentioned, this connection is also a determinant in the laboratory's Fluid Machinery, which is offered in the sixth semester of the bachelor's program in Mechanical Engineering at Offenburg University of Applied Sciences. With the help of digital twins, a total of three experiments are carried out, the results of which are interpreted by the students in reports. Normally, experiments are conducted both in the laboratory on site and then supplemented by the capabilities of virtual digital twins. Due to the limitations of the COVID-19 pandemic, this was not possible during the study period.

### 4.2 Didactic structure

The didactic structure of the course is based on the approach of situated learning, and here, especially on the concept of the Cognitive Apprenticeship Model (CAM), which can be divided into four to six phases: first, the demonstration of expert knowledge by the lecturer; second, a scaffolding of student activities; third, decreasing support from teaching staff while increasing the students' sense of competence; and fourth, continued support in the learning process during independent experimentation as needed (García-Cabrero et al., 2018). Whereas the first phase relates to the theoretical lecture, all further phases are applied in the laboratory. The laboratory experiments are introduced by discussions between the lecturer, assistant, and two students to ensure the theoretical classification of the practical laboratory test. In the process, both declarative and procedural knowledge are transferred to practical problems within the three laboratory experiments, whereby methodological, social, and personal skills are stimulated and developed in addition to technical ones. By writing down the practical experiences, students have the chance to reflect on their learning progress and establish connections with other module contents during their discussions with their fellow students.

If we focus on the perspective of classroom research, the following connections can be noted: Determinants in terms of lecturer and student behavior in connection with the context of the course influence teaching or learning success. Lecturer behavior is characterized by the ability to structure and by clarity, rhetorical competence, motivation, activation, processing depth, communication, and leading discussions. In addition, there are variables on the student side that affect the success of a course: prior knowledge, diligence, and participation during the class. In addition, contextual factors such as the topic, the requirements (in our case mainly related to the structure and design of the digital twins), and the existence of performance certificates influence the teaching/learning success of a course (Rindermann, 2003).

### *4.3 Description of surveys*

In order to analyze the effects of the didactic concept and its practical implementation, two surveys were conducted to contrast the direct observations and assessments of the lecturers with the student evaluations and views. The first was conducted after the first laboratory experiment in order to use the results to potentially modify and optimize the course. The second survey was conducted at the end of the course to reflect on and balance the overall growth in competence. Both surveys were composed of quantitative single-choice questions and qualitative open-ended questions to give students the opportunity to elaborate on additional aspects that they felt were necessary to describe the course and its impact on learning. Limited participation, interaction, and communication opportunities due to the COVID-19 pandemic were also considered in the second survey.

After the first laboratory experiment was conducted in mid-November 2020, 1 in 2 students were asked to answer the seven-question survey created in the learning management system. Participation was voluntary and thus not an integral part of the experiment or of the credit to be earned. Of 35 students enrolled in the course, 29 participated, a rate of nearly 83 percent. In the second survey, which was much more comprehensive with 25 questions and was conducted two months later in mid-January 2021, 26 out of 35 students participated, corresponding to a rate of 74 percent.

The questions in the two surveys, which are formulated in combination with different 5-point Likert scales, and the results are summarized in Table 1. The second column indicates which questions were raised in the respective surveys. As statistical parameters, the average and the standard deviations are given. Three further questions allowed the students to express their views in free text responses.

The questions can be grouped into different categories. Group 1, the construct of teaching behaviour with the variables of structuring and clarity, rhetorical competence, activation, depth of processing, communication, and leading discussions was mapped by questions 1–3, 6.

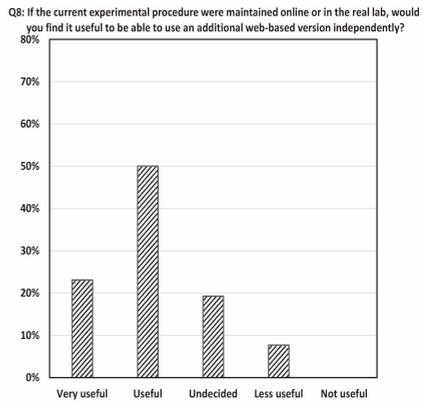
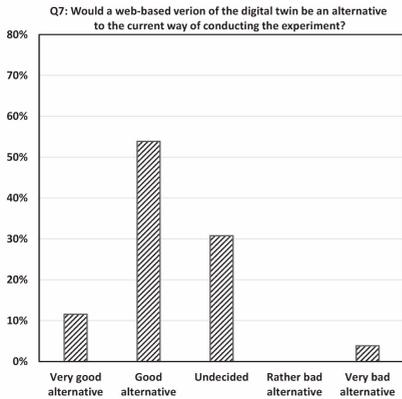
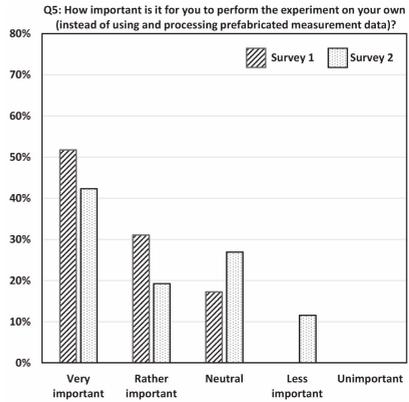
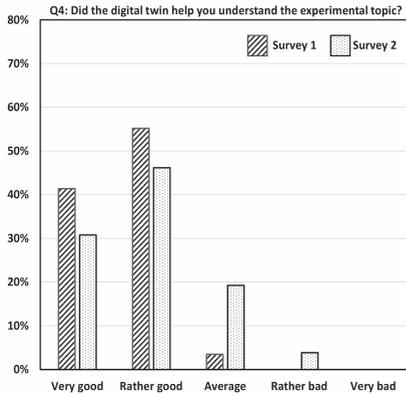
Group 2, the impact of interacting and engaging with the digital twins, as it relates to the current situation and possible future developments, was mapped in questions 4–5, 7–9.

Group 3, questions 12–13 addressed the specific constraints caused by the COVID-19 pandemic. The social, methodological, and personal contextual conditions and their impact on perceived skill development were mapped by group 4 questions 14–15, 17–22.

Table 1. Question and results of survey [Sur.] 1 and 2

No.	Sur.	Question	Quantity					Percentage					$\mu^{12}$	$\sigma^{13}$	
			1	2	3	4	5	1	2	3	4	5			
1	1	Did the materials help you prepare for the lab?	12	14	2	1	0	41%	48%	7%	3%	0%	0%	1.7	0.74
2	1	Did the discussion at the beginning of the lab help you relate to the lecture?	11	10	5	0	0	42%	38%	19%	0%	0%	1.8	0.75	
2	1	Did the discussion at the beginning of the lab help you understand the experiment?	12	13	3	1	0	41%	45%	10%	3%	0%	1.8	0.77	
3	1	Did the discussion at the beginning of the lab help you understand the experiment?	11	9	6	0	0	42%	35%	23%	0%	0%	1.8	0.79	
3	2	Did the discussion at the beginning of the lab help you understand the experimental topic?	18	10	4	0	0	52%	34%	3%	0%	0%	1.4	0.58	
4	1	Did the digital twin help you understand the experimental topic?	11	10	4	0	0	41%	41%	16%	0%	0%	1.6	0.64	
4	2	Did the digital twin help you understand the experimental topic?	12	16	1	0	0	41%	55%	3%	0%	0%	1.6	0.55	
5	1	How important is it for you to perform the experiment on your own (instead of using and processing prefabricated measurement data)?	8	12	5	0	0	31%	46%	19%	4%	0%	2.0	0.81	
5	2	How important is it for you to perform the experiment on your own (instead of using and processing prefabricated measurement data)?	15	9	5	0	0	52%	31%	17%	0%	0%	1.7	0.76	
6	1	How balanced did you find the proportions of theory/discussion and practical activities?	11	5	7	3	0	42%	19%	27%	12%	0%	2.1	1.07	
6	2	How balanced did you find the proportions of theory/discussion and practical activities?	0	8	21	0	0	0%	28%	72%	0%	0%	2.7	0.45	
7	1	Suppose a web-based version of the digital twin existed which you could access independently in terms of time. If you used this way of conducting the experiment be an alternative to the current way of conducting the experiment. If the materials were maintained online or in the real lab, would you find it useful to be able to use an additional web-based version independently?	2	12	12	0	0	8%	46%	46%	0%	0%	2.4	0.62	
7	2	Suppose a web-based version of the digital twin existed which you could access independently in terms of time. If you used this way of conducting the experiment be an alternative to the current way of conducting the experiment. If the materials were maintained online or in the real lab, would you find it useful to be able to use an additional web-based version independently?	3	14	8	0	1	12%	54%	31%	0%	4%	2.3	0.82	
8	1	Would working independently with a web-based version allow for a better understanding of the experiment content?	6	13	5	2	0	23%	50%	19%	8%	0%	2.1	0.85	
9	1	Which of the experiments contributed most to your understanding of the lecture content in fluid machinery?	3	12	5	6	0	12%	46%	19%	23%	0%	2.5	0.97	
10	1	Which of the experiments contributed most to your understanding of the lecture content in fluid machinery?	6	3	6	1	10	23%	12%	23%	4%	38%	0%	2.5	0.97
11	1	In the context of online teaching, have you had more or fewer professional and personal interactions with other students than before?	2	3	4	17	0	8%	12%	15%	65%	0%	0%	0%	
12	1	In the context of online teaching, have you had more or fewer professional and personal interactions with other students than before?	1	1	5	4	15	4%	4%	19%	15%	58%	4.2	1.11	
13	1	With fewer face-to-face interactions between instructors and students, is it more difficult for you to effectively absorb knowledge?	13	6	5	1	1	50%	23%	19%	4%	4%	1.9	1.09	
14	1	How important is group work in the context of labs to you?	12	5	8	1	0	46%	19%	31%	4%	0%	1.9	0.96	
15	1	Would you appreciate if lab reports were no longer carried out as group work, so that the responsibility for results is clear?	4	22	-	-	-	15%	85%	-	-	-	1.8	0.36	
16	1	Do you believe the requirements placed on laboratories in the mechanical engineering course (preparation, lab reports) as for before?	21	5	-	-	-	81%	19%	-	-	-	1.2	0.39	
17	1	Are expressive and communication skills as well as oral and written presentation techniques on specialized topics encouraged in the mechanical engineering course?	1	12	7	6	0	4%	46%	27%	23%	0%	2.7	0.87	
18	1	Should a course on (technical) communication be included in the curriculum?	16	10	-	-	-	62%	38%	-	-	-	1.4	0.49	
19	1	Does this course make it easier for you to ask questions when you do not understand something?	1	5	11	7	2	4%	19%	42%	27%	8%	3.2	0.95	
20	1	Did you learn to formulate your spoken contributions more comprehensively in this course?	1	5	13	4	3	4%	19%	50%	15%	12%	3.1	0.97	
21	1	Does this course make it easier for you to get to the heart of what you are saying?	0	4	16	5	1	0%	15%	62%	19%	4%	3.1	0.70	
22	1	Are you better able to assess where you stand professionally as a result of this course?	0	9	12	2	3	0%	35%	46%	8%	12%	3.0	0.94	

<sup>1</sup> Scale: 1 = Very good; 2 = Good; 3 = Satisfactory; 4 = Neutral; 5 = Unimportant  
<sup>2</sup> Scale: 1 = Fair too much theory; 2 = Too much theory; 3 = Balanced; 4 = Fair too much practice; 5 = Fair too much practice  
<sup>3</sup> Scale: 1 = Very good alternative; 2 = good alternative; 3 = undecided; 4 = rather bad alternative; 5 = very bad alternative  
<sup>4</sup> Scale: 1 = Very useful; 2 = useful; 3 = less useful; 4 = Not useful  
<sup>5</sup> Scale: 1 = Significantly better understanding; 2 = Better understanding; 3 = No change; 4 = Worse understanding; 5 = Significantly worse understanding  
<sup>6</sup> Scale: 1 = Significantly more; 2 = More; 3 = Equal; 4 = Less; 5 = Significantly less  
<sup>7</sup> Scale: 1 = Much more difficult; 2 = More difficult; 3 = Equal; 4 = Less difficult; 5 = Much less difficult  
<sup>8</sup> Scale: 1 = Much more easier; 2 = Easier; 3 = No change; 4 = More difficult; 5 = Much more difficult  
<sup>9</sup> Average value  $\mu = \frac{\sum_{i=1}^5 (x_i \cdot N_i)}{N_{total}}$  with  $x =$  Scale factor;  $M =$  Quantity  
<sup>10</sup> Standard deviation  $\sigma = \sqrt{\frac{\sum_{i=1}^5 (x_i - \mu)^2 \cdot N_i}{N_{total}}}$



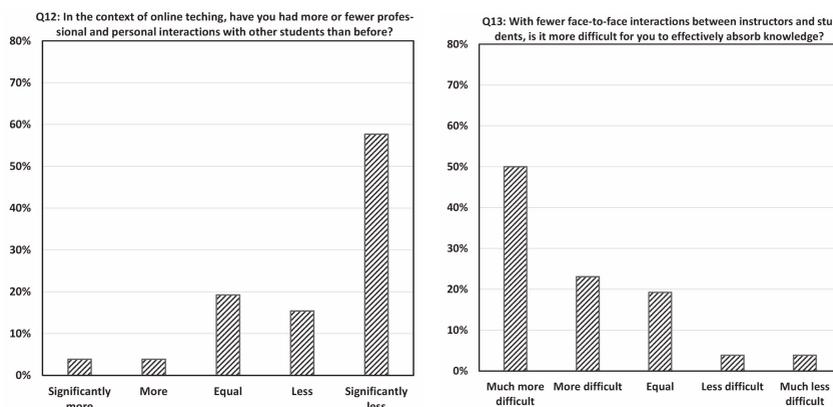


Figure 3: Selected survey results: Questions 4, 5, 7, 8, 12 and 13

## 5 Discussion of results

### 5.1 Digital lab experience

The usefulness of the digital twin experiment was addressed by questions 4 and 5 (see upper diagrams in Figure 3). It was rated between very good and good (1.6/1.7) in the first survey after the first experiment was conducted. In the second survey, at the end of the semester, the mean shifted towards good. Also, the distribution of responses widened. Overall, then, the virtual lab appears to be useful to the majority of students. However, the slight deterioration in the ratings and thus the change in perception of the lab could also be due to external factors: first, the special coronavirus situation, which particularly limited the opportunities for contact and exchange among students; and additionally, the special study situation in the sixth semester with several complex labs and correspondingly time-intensive requirements. These factors are indicated by the free text answers.

The preparation concept of the laboratory was addressed in questions 1 to 3. It was also rated between very good and good (1.4 – 1.8). The evaluation shifted only slightly over the semester. Only the evaluation of the dialogue/discussion as an introduction to the experiment was slightly weaker in the second survey. The supplemental free texts hint at limiting the amount of theory to the essentials at the beginning of the afternoon of the experiment. Again, perceived stress seems to apply as an explanatory pattern.

## 5.2 *Communication and group work*

The aspects of group work and communication were especially targeted in questions 12 to 14 (see lower diagrams in Figure 3). Communication is perceived as limited and impaired in online teaching. Interestingly, the lower level of habitual direct exchange between students and lecturers leads to a more difficult absorption of knowledge and thus to the reduced acquisition of skills. To compensate for this effect, students predominantly state that their engagement with the digital twins and the subsequent elaboration of the reports in groups provides a framework that is conducive to learning (1.9). Moreover, it can be assumed that the perceived communication problem exacerbates the effect of technical overload in the sixth semester.

## 5.3 *Web-based digital twin*

Questions 7 to 9 (see diagrams in the middle of Figure 3) asked for perceived opportunities offered by web-based experiments. These questions venture a prospective look into the future and focus on the intended more independent engagement with the digital twin experiments. The students evaluate the prospective web-based experiment as a good alternative to the current execution (2.3); the accompanying higher degree of independence is assessed slightly more positively (2.1). However, the students are somewhat more skeptical about whether this form of conducting the experiment, with a lack of guidance and support from the lecturers, will lead to a better understanding of the content (2.5). It should be kept in mind that previous student experiences are based exclusively on the guided variant.

## 5.4 *Curriculum in Mechanical Engineering*

Questions 16 to 18 explored the context of the laboratory with respect to the total lectures and laboratories in the sixth semester. The highest score (1.2) was obtained for a question whose subject matter goes beyond the narrow scope of the course under study. Students rated the expectations of all laboratory courses in the sixth semester as highly inconsistent. This results in a substantial cognitive and time burden, which is clearly evident from the extensive free text responses. First, the desire for harmonization can hardly be met due to subject-specific differences; second, dealing with heterogeneous requirements appears to be a goal of academic education. Nevertheless, supporting students in achieving this competence-oriented

goal seems reasonable. Students would very much welcome the inclusion of a course on "Professional Communication" in the curriculum (1.4).

### *5.5 Personal skills*

Questions 19 to 22 asked about how the laboratory contributed to the development of personal skills. The improvement of communication skills and personal and methodological competence intended by the concept and implementation of the laboratory course is rated most inconsistently by the students. One reason could be the concrete implementation of the individual seminars; another reason could be that students have not yet had enough experience with competence-oriented course concepts to recognize their advantages.

### *5.6 Summary*

In summary, our key findings can be mentioned on three levels: First, it seems reasonable and appropriate to implement further experiments using digital twins. The concept of introductory theoretical discussions, subsequent independent data collection, and joint interpretation of the results in groups with feedback conducive to learning is viewed positively by the students overall. Nevertheless, the perceived excessive demands in terms of subject matter and time in the sixth semester counteract learning success and the competence-oriented development of the students. Second, these findings should be discussed within the faculty by staff and students. The legitimate question of why this workload overload is not identified in the course evaluations conducted by the central quality management body can be explained in part by the fact that the sample size of such evaluations is predominantly less representative than the surveys conducted in this lab. Third, based on the results at the course level, the discussion about competence-based teaching could be intensified.

In order to be able to make further, detailed statements about the lab concept, in the next step the examination of the digital twins could be compared with that in a real lab. In terms of methodology, a mixed-methods approach could be used in addition to quantitative questionnaires, including participant observations.

## 6 Conclusion

The coronavirus crisis has highlighted the flexibility of maintaining lab teaching formats if digital lab twins can be accessed. Without this tool, it simply would not have been possible to conduct the lab, which is conceptually designed as a Cognitive Apprenticeship Model, appropriately. The accompanying study showed that it was widely successful in realizing the intended content-related competence goals. The students largely accepted the format as a fully acceptable laboratory event.

The implementation of the digital twins to date does not yet include features that address the tactile experience of working in real-world labs. It is currently still unclear what influence this has on the students' acquisition of skills. There may also be considerable differences in perception between students on this issue, depending on whether they acquire knowledge more by theoretical means or are inspired by tactile experiences.

An important aspect that the study again revealed is the importance of face-to-face communication and interaction between lecturers and students, as well as between the students themselves. In the lab format with the digital twin, it was possible to maintain communication between the lecturers and the students. However, there were breaks in the communication between students. This was solely due to the fact that they could not meet in person in one location but had to communicate via media. Thus, important informal get-togethers in which information is exchanged are probably lacking. As with many online teaching formats, the question here is how this informal communication can be adequately supported. The importance of communication from the students' point of view may also be one reason why online formats without feedback to lecturers were rated unfavorably by the students in the study. This aspect should be strongly considered in the elaboration of virtual laboratories, for which there are enormous opportunities based on virtual twins.

In the study, it was again found that the perception of a course is strongly influenced by the current context of the students' overall situation. Such influences are likely to be even stronger in the extraordinary situation of studying under coronavirus conditions. We, therefore, intend to repeat the study in the future for comparative analysis.

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## Acknowledgements

This work is partly funded within the frame of the project SHELLS (SHELLS—Shared Excellence—Laboratory Learning Spaces 4.0). The authors thank the “Stiftung Innovation in der Hochschullehre” for funding and support.

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## **OpenAPETutorial – A Problem-Based Learning Unit for the Personalization of Smart Home Applications**

### Abstract

This paper describes the creation of a problem-based learning unit. The aim is to help students to learn how to make applications more accessible through aspects of personalization. In addition, a basic understanding of smarthome interfaces will be given. For this purpose, the personalization framework OpenAPE and the smarthome interface OpenHAB will be used. A java OpenAPEClient will be created for OpenAPE. The client will then be used in a tutorial application. This tutorial application is to be integrated as a kind of cloze text in the learning unit as a practical exercise. It implements a lamp control and a personalizable user interface. Final user tests showed that the learning unit is executable as planned. Some problems and inconsistencies were already identified and eliminated during the user tests.

### Keywords

personalization, learning analytics, problem-based learning

### **1 Introduction**

A problem-based learning unit design is described in this paper, which is supposed to introduce students to concepts of personalization and the area of Smarthome. For this purpose, a learning unit with a practical exercise is to be created. In the area of personalization, the personalization framework OpenAPE will be taught. This can be used to store personalizable settings in contexts in an account and synchronize them across multiple applications and devices. For the smarthome domain, OpenHAB is used. This interface is used in smarthomes and offers to connect, control and automate different areas in smarthomes.

In the research part of the work, three topics will be addressed. First, the field of personalization needs to be looked at in more detail. In the second topic, the concept of problem-based learning is to be further explored. The third topic is about learning analytics, which is a possible extension of the learning unit.

For OpenAPE a Java client is developed, which can be used in Java and Android applications. The client should reduce the complexity of these applications since the use of the client replaces direct communication with the rest interface of OpenAPE.

In the learning unit, a final exercise will be performed. For this purpose, the so-called OpenAPETutorial application has been developed. This application implements a simple lamp control via OpenHAB and basic personalization, which can be synchronized using OpenAPE. In the application, the functionalities concerning OpenAPE and OpenHAB are outsourced to services. The methods in these services are left empty for the task, the students should complete these functionalities.

### *1.1 Motivation*

More and more people are dependent on barrier-free applications. 15% of people live with at least a moderate disability, a large number of whom require some level of accessibility. (World Health Organization, 2011) Accessibility can also play a major role in older ages, as eyesight or motor skills may decline. In addition, the population is getting older; from 2008 to 2018, the number of people over 60 increased by 3%. (Bevölkerungspyramide: Altersstruktur Deutschlands Von 1950 - 2060)

Politicians also see the need for accessibility. Therefore, guidelines and laws are written, which make accessibility mandatory for public authorities. (EUR-Lex - 32016L2102 - EN - EUR-Lex, 2016)

For these reasons, it is important that students learn early which methods can be used to increase accessibility in applications.

A lot is also happening in the area of the smarthome. More and more devices in the home can be networked and some even enforce this networking. 3.3 million people in Germany were already using connected household appliances at the beginning of 2021. The number has increased by 5% within the last 10 years. In the area of heating, lights and electricity, about 5 million use systems in the smart home. (Statistisches Bundesamt) A central management instance in your own smarthome, which brings together various devices or technologies, is therefore becoming increasingly relevant.

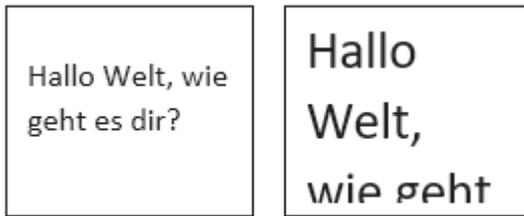


Figure 1 Example of two fields with different font-sizes

## 2 Personalization

is an aspect of accessibility in which the software can be adapted in such a personalized way that, in the case of various limitations, the software can still be used without any problems?

A distinction is often made between personalization and auto-personalization. Personalization is about possible changes to the interface according to the needs of the user. Auto-personalization allows this to be done automatically, i.e., without knowledge of exactly how this works in the system being used. (Vanderheiden & Jordan, 2019)

Many different ways can be used to increase accessibility in applications with personalization.

Many available tools simply try to customize different parts of the user interface. On the web, for example, this can happen by customizing CSS files. These tools are mostly installed on the client side. On the web, these tools are often included as toolbars. Predefined toolbars can be used, but also user-defined toolbars with the desired functionalities can be created. (AT-bar ; Wald et al., 2011 ; Web Developer) Another possibility is to intervene in the network traffic of the browser in order to apply the corresponding transformations there. This works via a proxy. (Iaccarino et al., 2006) Outside the web, operating system extensions can be used, which can directly access the operating system's functionalities. (Vanderheiden & Jordan, 2019)

If changes are made to the user interface where the application itself is not the initiator, some problems can arise. For example, increasing the font size could cause the font to become larger than the displaying area, making it unreadable. Figure 1 shows how this could look like.

In addition to client-side tools, there are also tools that are used on the server side. The adaptations of these tools are then mostly more deeply

anchored and equally available for every user of the website or application. (OpenAPE) But even here there are possibilities to focus only on surface changes. These are easier to implement, but may have the problem described in Figure 1 again. However, since it is integrated by the providers, it can be assumed that the functionalities have already been tested. (Cloud Based Accessibility Assistive Technology Toolbar | Products | Recite Me)

In operating systems there are many functionalities to personalize a device. These include colors, contrasts, font size or size of elements. But also, ScreenReader, voice control, zoom or the reduction of animations is mostly offered.

For developers, it seems relatively difficult to write a cross-operating system application that uses the corresponding personalization of each operating system to the full extent. This is due to the different interfaces of the operating systems. A possible solution would be a uniform interface, which addresses the appropriate functionalities depending on the operating system. (Gonzalez & Reid, 2005)

### **3 Problem-based Learning**

In the design of the learning unit, aspects from the field of problem-based learning are used.

Problem-based learning originated in the medical context and was used to teach students content through real-world problems. After it had much success in the medical context, it was transferred to other areas as well. (Jonassen & Hung, 2012)

In problem-based learning, mostly small groups of learners should tackle the real-world problem together. In many cases, no further information about the problem is provided. But often information about the fundamentals is provided. (Ellis et al., 1998)

It usually starts with some kind of analysis of the problem. The aim is to find out exactly what the problem is and what the learners already know about it.

This is followed by an attempt to enhance the missing knowledge through research in order to get closer to the solution. The problem is then discussed again in the group and analyzed once more. This process can then be repeated until the solution is found. (Jonassen & Hung, 2012) This is only one possible process. Depending on the requirements and use case, the process can also be different.

(Ellis et al., 1998) differs into three different approaches within problem-based learning:

- problem-based approach
- guided problem-based learning
- full problem-based learning

While in the first approach the necessary information regarding the problem is already provided, in the second approach the information is only partially described. In the third approach the independence of the learners is highlighted. Here almost no information is given, this must be searched for in the process of finding a solution. Moreover, the way in which the problems are presented may vary. The problems to be addressed may be fully known and described by the teacher. So, the learners only have to look for a solution to the problem. On the other hand, the problems can also be completely unknown. In this case they have to be identified first. In between there is a mixture with partially described problems. (Ellis et al., 1998)

In the context of computer science and programming, problem-based approaches can be particularly effective. In this field, the competence to solve problems is needed every day and is therefore very important. This competence is also strengthened by problem-based learning. (Learning Programming: Enhancing Quality Through Problem-Based Learning, 2003)

Problem-based learning can increase the complexity of the learning process, as students need to have skills in problem solving and possibly also in communication and teamwork, in addition to technical skills. This can be a potential weakness. Another weakness is the teaching of fundamentals via the problem-based approach. (Learning Programming: Enhancing Quality Through Problem-Based Learning, 2003)

While problem-based learning engages learners deeply in the subject matter and thus develops a concrete understanding of that problem, it can create a gap in the learners' broader knowledge. The students are very focused on this one-use case, a transfer to another use case in the future could still bring problems despite a good understanding during the learning unit. To counteract this problem, learners must be offered sufficient information, which can then be accessed as needed. (Kolmos & de Graaff, 2003)

## 4 Learning Analytics

(Clow, 2012) describes learning analytics as a cycle consisting of four steps. The starting point in the cycle is the learners. During learning, the second

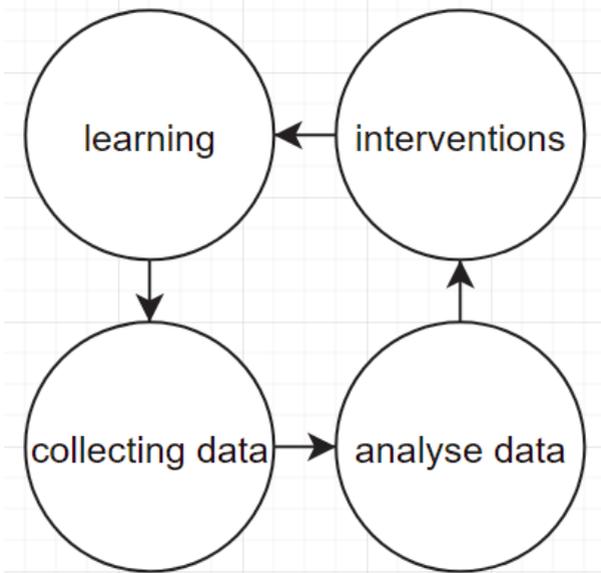


Figure 2 Simplified representation of the learning analytics cycle

step is to collect data. This can be either from learners or about learners. This data is then processed in the third step, for example through analysis. After the data has been processed, the results of this processing can be used to influence the learners in the final step. This step completes the cycle. The Figure 2 visualizes this approach.

In order to implement learning analytics, various methods and tools are required. First of all, it must be clarified which data needs to be collected. This can be done on different levels. For example, in programming exercises, the number of compilations or the exceptions thrown during an execution of the application can be collected. If this data is not sufficient, more detailed data can be collected. Here you might log every keystroke the learner makes. Additionally, data can be collected on a social level by using discussion forums for the tasks. There, the learners can exchange information about the problems in the tasks and the teachers gain information about which problems occur during the execution. (Ihantola et al., 2015)

Since the data often contains person-related data, ethical aspects and privacy should not be neglected. However, according to (Ihantola et al., 2015), this is not addressed enough in many studies.

To integrate learning analytics various ways can be chosen. For example, plugins in the development environment can help to collect data and provide a direct forum for communication inside of the development environment. (Olivares & Hundhausen, 2017)

Furthermore, interfaces can be used, which can receive data from different tools and applications. The data can then be analyzed on an appropriate platform. (Ihantola et al., 2015)

## 5 Introduction OpenAPE

OpenAPE is an open-source framework that offers a way for developers to implement personalization in their own application.

The biggest difference between OpenAPE and many other tools for personalization is that OpenAPE must be integrated into the architecture of the application. Here the integration of a plugin or a toolbar is not sufficient. The personalization functions must be implemented in the source code and must be retrievable from OpenAPE or stored in OpenAPE. However, once it is integrated into the architecture, properties can be synchronized across multiple devices and multiple applications that have implemented OpenAPE. This will then work without any further installations on the user side.

In OpenAPE everyone can create an account, in which he can store so-called contexts. These contexts can contain different data. In OpenAPE, there are the following four context types:

- User-Contexts: can be used to assign specific properties to a user.
- Task-Contexts: intended for various tasks, e.g. properties for surfing on the Internet or writing e-mails.
- Equipment-Contexts: represents the properties for a specific device, e.g. desktop PC or a laptop.
- Environment-Contexts: for specific environments, e.g. a daytime or nighttime use.

In this work only, the user contexts are relevant, therefore the other contexts are not described in more detail. If a context is mentioned, the user context is always meant here.

Each user can have several user contexts, where he can store different preferences. For example, font size, colors, language or other information about applications can be stored here. This stored information can then be accessed by any application after logging in via the Rest interface.

The Listing 1 shows such a context. Line 2 contains the unique name or ID of the context. There can be multiple of these objects behind line 2, they are identified by the ID. Line 3-6 shows the stored preferences of the context. In this case a font size of 60 was stored in the context with the name "default".

```
1 {
2   "default": {
3     "preferences":
4     {
5       "..fontSize": "60"
6     }
7   }
8 }
```

*Listing 1 Simple OpenAPE user context*

The entries in the preferences are simple key-value pairs, where the value can be a string, boolean or a number. To make the preferences consistent across multiple applications, the OpenAPE Registry Service should be used. (OpenAPE Registry Service - HdM) This is available at "<https://terms.gpii.eu>" and already contains several publicly available entries. Here an id, a description of the data type to be selected and other information is stored. Additionally, a json schema can be defined, which describes the format of the value. All developers can access this database, so that the data is saved in a uniform way. However, this is not controlled, so there is no control whether the data is really stored according to the given specification.

### *5.1 OpenAPE Focus Group*

In a focus group with students from the Computer Science and Media bachelor's degree course at the Hochschule der Medien, the goal was to gather information about what the students think of the idea and implementation of OpenAPE. In addition, the aim was to find out how such a framework could be integrated into a learning unit.

As part of a lecture in which students are required to program an application with OpenAPE connectivity, 9 students participated in the focus group. The focus group took place online, which may have led to reduced activity in the discussions.

Only one student had already used the interface, all others had only the introduction to the topic. Nevertheless, some points could be discussed.

Especially important for the students was a type safety for the preferences. The types of the entries can be described by a second service, but a control mechanism, which then also checks whether the correct values were entered, does not exist. Another point was lists. In the current implementation it is not possible to store lists in OpenAPE.

Furthermore, it was mentioned by the students that it would be helpful to have direct examples of the use of OpenAPE in order to learn OpenAPE. For example, a "Hello World!" application that implements the benefits of OpenAPE could help to understand how exactly OpenAPE should be used.

## 6 Introduction OpenHAB

The open-source project OpenHAB stands for open Home Automation Bus. It is used in Smarthomes, where it can do different jobs. Many devices, systems or technologies can be connected to the OpenHAB system and OpenHAB can become the centre of a smart home. Moreover, with OpenHAB automation can be achieved in the Smarthome area. A cloud connection is not necessary with OpenHAB, but if desired, it can be connected to common cloud-based systems. You can host OpenHAB on your own local system or via a cloud connector directly in the cloud. (OpenHAB Documentation) Several keywords are relevant for OpenHAB: Bindings, Things, Items, Rules.

To connect OpenHAB with other devices, you can install Bindings in your OpenHAB system. These Bindings create a connection to the devices and then create so-called Things. These Things are the corresponding representations of the devices. Things can then be used to generate items. Items represent functionalities of the things. They have a status which can be changed if necessary. For example, there is the item type "Switch", which can represent an on/off switch of a lamp. (OpenHAB Documentation)

For automation, rules can be created that can execute different commands in different situations. To be able to use OpenHAB from everywhere, a rest interface is offered. (OpenHAB Documentation)

## 7 Java OpenAPEClient

In addition to the learning unit, a Java client for OpenAPE was also implemented. This client will also be discussed in the learning unit and used in the tutorial application of the learning unit. The aim of this client is that

```
1 OpenAPEClient openAPEClient = new OpenAPEClient();
2 openAPEClient.login("username", "password");
3 UserContextMapDTO contextMap = new UserContextMapDTO();
4 UserContextDTO context = contextMap.getOrCreateContext("default");
5 context.addOrUpdatePreference("http://terms.gpii.eu/common_fontSize", "60");
6 context.addOrUpdatePreference("http://terms.gpii.eu/common_language", "de");
7 String id = openAPEClient.createUserContext(contextMap);
```

### *Listing 2 OpenAPE Client - codesample create context*

it can be used in any Java and Android application in order to reduce the complexity of these applications.

In the client, an http client is implemented, which makes the appropriate calls to the Rest interface. The client then offers the corresponding calls as methods.

So far, only the methods for user contexts are available in the client. However, it is built in such a way that the other context types can be added without a major modification of its structure.

The OpenAPEClient is close to the Rest interface. Listing 2 shows how a context containing two preferences can be created using the client. Lines 1 and 2 initialize the client and log in the user. Lines 3-6 show how to create the structure of the context and insert the appropriate data. In line 7 the context is then created. What happens with the returned ID must be decided depending on the use case.

## 8 Learning Unit

The goal of the learning unit "Universal Design & Personalization for Smarthomes - Implementation" is to get a technical understanding of how to implement accessibility through personalization already during the development of applications. The personalization framework OpenAPE will be used for this purpose.

In addition, basic knowledge in the area of Smarthomes will be taught; this will be implemented with the help of the Smarthome framework OpenHAB. After the learning unit has been completed, the students should be able to implement and use both interfaces in applications. Especially the personalization with OpenAPE should be kept in mind as an option to improve accessibility in applications.

The learning unit is aimed at students who already have experience in the field of programming. In addition, the students must have already com-

pleted another course unit before this learning unit, which is the learning unit "Universal Design & Personalization for Smarthomes - Concepts".

The course is intended to be carried out by each student alone, so no group work is foreseen. The learning unit is also well suited as an online course since the students should work alone either way. Nevertheless, a lecturer should be available at any time for questions. However, this could also be solved via a forum in which the students can exchange information with each other.

In the subdivision of (Ellis et al., 1998), the learning unit falls between the first and second approach. Students get most of the information they need through the learning unit. However, with the help of various documentations about interfaces and tools, the students should read more in depth and thus gain more information. As the problem of the learning unit, it is described to the students how people with a visual impairment operate applications and what problems can arise. More concretely, the programmed application should be operated by different people, therefore it should be made usable in a personalize way with OpenAPE.

Through the information about the interfaces in the learning unit, it attempts to counteract the problem that problem-based learning is less suited to fundamentals. By providing additional links to documentation and further information, students will also have the opportunity to know where to find this information at any time in the future. (Learning Programming: Enhancing Quality Through Problem-Based Learning, 2003)

The verification of the tasks can be designed dynamically. If no verification is provided, the students can verify themselves by checking the functionalities they implemented. Otherwise, the tasks could be checked by handing in the programmed source code.

### 8.1 Content

The content of the learning unit can be divided into two parts.

Part one covers the theory of the unit. The learning unit is introduced by trying to give the learners an understanding of why personalization can be useful in an application. For this purpose, four images of a seat selection in a movie theater are shown. Reserved seats are marked in red and free seats in green. On three of the images a filter is applied, where the seat selection is shown with different visual impairments. The learner sees the selection as a person with a visual impairment would see it. On two of the images no differences in color can be seen through these filters, on another one the colors are no longer the original colors. The fourth image shows the

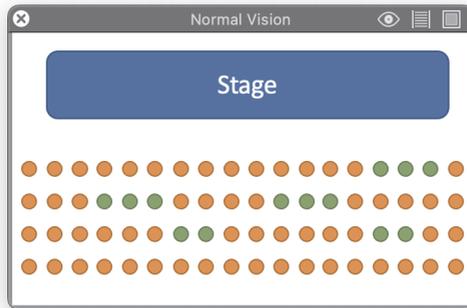


Figure 3 Seat selection without any filter

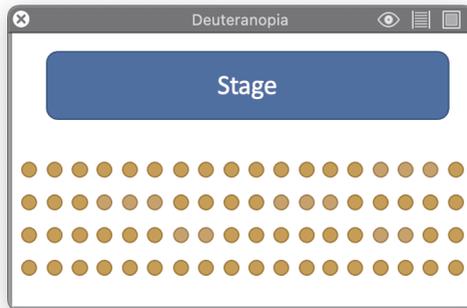


Figure 4 Seat selection with red-green filter

selection without the filter. The Figure 3 and Figure 4 show examples of the used use case.

Chapter two describes OpenAPE. The basic information about it is already explained in the preceding learning unit. The possibilities of the rest interface are described, and the individual calls are explained in more detail. Afterwards the usage of the programmed Java OpenAPEClient is explained. Here the available methods and Exceptions are presented. In addition, an illustrative use is demonstrated in a sequence diagram and parts of the data structure used within the client are shown in a UML diagram. In the third chapter OpenHAB is introduced. In addition to background information, the required calls of the rest interface are described in more

detail. In the fourth and fifth chapter, the OpenAPETutorial application and the assignment for this application are presented. Necessary information about the implementation of this application is also given. More about the application and the task will be described in the next chapter, chapter 8.2. The second part of the learning unit is the practical exercise. The exercise is a fully programmed application with parts of the source code removed. The removed content relates to the implementation of the OpenHAB and OpenAPE interfaces. So, it becomes a kind of cloze. As already mentioned, the application is described in the following chapter 8.2.

The description of the functionalities of both interfaces are all technical. For example, the rest calls describe all the technically required data. This leads to the fact that it might be difficult to imagine the execution. Therefore, there is a short video in the learning unit for each rest and method call, which has a length of about 30-60 seconds. In these videos the corresponding call is executed using an example and in addition it is explained. These videos have the additional advantage that the students can watch individual videos about the problematic functionalities at later stages if they have problems with these certain functionalities. In addition to the videos, a file is provided that can be imported into the rest interface tool insomnia. It can be used to perform the rest calls described in the videos themselves. The focus group from chapter 5.1 showed that students find practical examples useful for learning the interface. Since a complete example application would simplify the tasks in the OpenAPETutorial application too much, only the videos and the exported file are given here as examples.

## 8.2 *OpenAPETutorial Application*

In the learning unit, basic knowledge about the implementation of the OpenHAB and OpenAPE interface will be acquired. This basic knowledge will be tested and deepened in the OpenAPETutorial application.

For this purpose, a simple Smarthome application was programmed, which shows a simple lamp control on the first page. The items retrieved via OpenHAB are displayed. In addition to the status of the item, there is also the option to change the status. When switching to the settings page, possible settings for personalizing this application are offered. These are the following settings:

- language
- font size
- font color
- background color

- font color of controls
- background color of controls

These settings are integrated in the application and can be changed, depending on the needs of the user. Through this page, the user can get to a login page for OpenAPE. After a login, the settings stored in a user's context are retrieved and applied in the application. If no settings have been saved there yet, nothing will happen. In addition, after the successful login, all changes to the settings in the application are also saved in the context in OpenAPE. If necessary, a context is created for this purpose.

In order to integrate the application into a learning unit, the functionalities of OpenHAB and OpenAPE were outsourced to services, which are called from the rest of the source code. For the assignment, the contents of the methods implemented in these services are removed. What remains are empty methods, which the students then must fill.

The following empty methods remain for the OpenAPEService:

- constructor
- login()
- isLoggedIn()
- saveSettingsInOpenAPE()
- loadSettingsFromOpenAPE()

In addition, a method remains which returns an object of the global settings. This object must be used if settings are to be read from the application or applied.

The following empty methods remain in the OpenHABService:

- constructor
- getItems()
- sendCommand()

For OpenHAB one more class remains: OpenHABRest. Here an interface is implemented, which is needed by retrofit. It contains wrapper methods with information regarding the rest calls to be executed. These must also be filled in by the students. The methods that are included there are the same.

The possibility to personalize the application has already been implemented and is not relevant for the learning unit. If the students have to implement these aspects additionally when doing the learning unit, another big topic would need to be opened up. By keeping this content out, no knowledge about the framework in which the application is written needs to be taught.

## 9 Usertests

In order to check whether the designed learning unit can be carried out as planned, final qualitative user tests are executed.

### 9.1 Preperation

For the user tests, students from the target group, i.e., with experience in programming, are recruited. The problem here is that the students who are recruited have not done learning unit 1, so they do not have the prior knowledge. In addition, the user tests should not last longer than one hour.

For these reasons, the learning unit is only carried out in sections. Parts of the learning unit will only be discussed orally. For some content, assistance will be provided so that the content can be processed more quickly. In addition, not everything will be completely programmed in the programming exercise; comments or pseudocode are usually sufficient. This procedure is intended to validate the learning unit in terms of content and still not exceed the time frame of the user tests.

In the individual user tests, different priorities are set in each case, so that each area is carried out as planned at least once. The focus is set depending on previous user tests, depending on what worked well or poorly there.

During the user tests, the users were asked to think aloud and try to explain how they understood the subject at hand. This leads to the identification of whether the described content conveys what it is supposed to.

### 9.2 Evaluation

A total of 5 user tests were carried out. Many weaknesses that were noticed by the users could be fixed directly, in the following some points for such problems are described.

In general, many small logical or syntactical errors have been fixed. But also the structure of how the information is provided was adjusted according to the findings of the users.

Some subjects were unclear about the data structure of the OpenAPE client. As a result, corresponding UML diagrams were added for the most important classes in the data structure.

In the chapter about OpenAPE, a sequence diagram was shown, which is intended to reflect a possible flow of the OpenAPEClient in a real application. Here the steps of the initialization of the OpenAPEClient were skipped

and the return value `void` was not described. This led to students missing the initialization step in the programming exercise and the `void` return value causing confusion.

In one user test, the test person described that he first had to orient himself in the task and especially in the `OpenAPETutorial` application. He found this relatively difficult. To help students orient themselves better, the tasks could be broken down and described in more detail. In addition, code comments could be added, which describe again what must be done at the respective locations in the source code. This is probably a problem in time-limited user tests. In real-life situations, however, students should deal with the topics more intensively and not be given exact instructions for the tasks. This should lead to students learning the knowledge better as it is not a simple fill in the blanks. This issue should nevertheless still be noted in possible pilot tests.

The videos were rated as particularly positive. The demonstration of the functionalities with real data made it possible to understand the contents very well. Three test participants had little to no experience with the use of rest interfaces, but after a brief introduction to the basics and watching the videos, they were able to complete the learning unit without any problems. The videos were rated particularly well by these test participants, as they were able to help very well in understanding the calls to the rest interface.

In the tasks regarding `OpenHAB`, `retrofit` (`Retrofit`) is used as http client. For this topic, little information is described in the learning unit. The learners must read the documentation of the tool to understand the functionalities. After a user had problems with it, the section of the explanation about `retrofit` was filled with additional information. In a subsequent user test, there were still unclear points. These were not corrected in the following, because here again the assumption is that in a real situation there is enough time to read the documentation. This assumption is strengthened by the fact that the users could understand the functionalities well afterwards.

## 10 Conclusion and future work

The `OpenAPEClient` implements only basic functionalities so far. The further development of this client can go into many areas. Probably the most important further development would be the support of all context types, the client is designed to implement this extension. Moreover, type safety or lists in the preferences could be implemented via the client. These are the functionalities that stood out through the focus group. The functionalities

should first be implemented in the OpenAPE interface itself, so that everyone can access them via the rest interface.

The execution of the learning unit could be validated by the user tests. The tests showed that the learning unit is understandable and the tasks can be performed with the knowledge taught. In addition, some weaknesses could be identified, most of them could also be fixed directly. Some issues were intentionally not fixed, as they may have occurred only under the circumstances of the user test.

Through the focus group, it became clear that students liked having hands-on examples like a Hello World application to learn from. Although a Hello World application was not provided, the explanatory videos of the individual calls to the interfaces provided practical examples with sample data, which were very popular during the user tests.

Despite the successful user tests, a pilot test under real conditions should be done in the future. In the conducted user tests different aspects of the learning unit were reviewed, but due to the way it was conducted, e.g. the time needed for the theory part and the tasks could not be checked. In addition, this pilot phase could further monitor the vulnerabilities encountered in the user tests and identify additional issues. Especially the problems that were not fixed due to the circumstances of the test should be monitored further.

Regarding learning analytics for the application, it must be decided which data can be relevant for a possible analysis. From this, it can then be decided at which level the data must be collected. In order to then embed this in the learning unit, it may need to be integrated into a development environment that has been designed for this purpose. Another possibility would be an interface which collects the data.

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## **Didactical Concepts and Evaluation of a Supply Chain Management Serious Game**

### Abstract

It's a couple of decades since Serious Games (SGs) started to be implemented for both educational and professional purposes, especially in the engineering sector. The interest in virtual SGs has risen even more in the last few years due to their ability to be used from anywhere, apply theoretical knowledge, and involve users in a challenging way. Since the beginning of the project Open Digital Laboratory For You (DigiLab4U) in October 2018, the University of Parma started to develop a brand new SG with a strong focus on Supply Chain Management (SCM). This paper presents the didactical background and the feedback received that led the University of Parma staff to the creation and improvement of the SCM SG scenario.

### Keywords

Serious Game, Operation Management, Didactical Evaluation

### **1 Introduction**

Nowadays, enterprises increasingly need to add to their organic new resources with enough skills to cover many functions. Among these functions, production, logistics, suppliers, and customer management are the most requested. The knowledge required for these functions is taught in Operation Management and Supply Chain Management (SCM), which are courses held in bachelor's and master's degrees in Management Engineering. Up until 2019, at the University of Parma the courses were held as a combination of theoretical teaching and practical exercises carried out on sheets of paper or with informatic support like MS Excel. However, it highlighted a gap in the acquisition of practical, technological, and soft skills. So, in 2018, corresponding to the beginning of DigiLab4U, the University of Parma started the design and development of a Supply Chain Management Serious Game (SCM SG). The SCM SG has been designed as a multiplayer

cooperative/competitive game in which players are divided into different companies competing in the production of e-bikes. Students individually play at conducting day-to-day operations and collaborate with others to take strategic decisions. The rest of the paper is structured as follows: Section 2 presents an overview of the state of the art in the SCM SG; section 3 presents the methodology adopted to design and refine the SCM SG. Section 4 presents the didactical scenario created for the serious game. Section 5 presents the beta testing evaluations performed and the summative evaluation carried out after the alpha release. The results are discussed in section 6, with conclusions and future works in section 7.

## 2 Serious Games in Supply Chain Management

The definition of SG can be expressed as games that provide both entertainment and learning, by making the users deal with complex problems, dilemmas, and challenges combined with the fun resulting from gameplay (Burghardt, Ferdinand, Pfeiffer, Reverberi, & Romagnoli, 2020). With the rise of virtual laboratories, distance learning, and online services, this tool has been reconsidered and implemented in the education and training of engineering students and professionals (Galli et al., 2021). Also, the fact that SGs are based on learning by doing represents a significant advantage as it is considered one of the most effective teaching styles by numerous teachers and it allows learners to operate in a real-world environment. This characteristic of SGs enables students to make mistakes without causing real damage, thus making SGs ideal tools for the teaching of Operation and Supply Chain Management (Reese, 2011). As already existing examples of SCM SG, it is possible to find the Beer Game (Kaminsky & Levi, 1998), which is card-based and probably the most known and used. AUSUM (Crowe, 2011) is a game focused on the dynamics of supply chain management in the automobile sector. Also, the Fresh Connection (De Leeuw et al., 2015) is based on strategic decisions to be taken and highlights how these decisions influence different functions within a company. On the other hand, among the operation management SGs, Learn2Work represents one of the main examples by making available three different scenarios in which the user has to lead the company to success. Practice Operation<sup>1</sup> is the last example: here, the users face a 3D game where they have to manage a

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1 [https://www.mhpractice.com/products/Practice\\_Operations](https://www.mhpractice.com/products/Practice_Operations)

clothing company by managing orders, resources, and the procurement of raw materials to complete different production orders and sell clothes.

### 3 Methodology

With the SCM SG being a brand new tool, and a totally new technology at the University of Parma, its development started with a phase involving the definition of Learning Objectives (LOs) and Research Questions (RQs). The definition of LOs was driven by two different requirements, namely (i) the targets of the Operation Management course, and (ii) the knowledge required in the day-to-day actions carried out in the company's functioning. These are defined as (a) the ability to schedule a production order with different shops, (b) the connection between quality, quantity, price, and due date in a deal with customers and suppliers, and (c) the ability to design a replenishment plan for resources. Nonetheless, the LOs are also connected to soft skills like teamwork, the ability to achieve common goals, and problem-solving, to face unexpected events and react in the proper way considering significant KPIs. Similarly, RQs were formulated to evaluate the design of the serious game. With its creators having the objective clearly in mind, the design and development of the game started with the first beta testing run internally in June 2020. This first session represented the initial step in an iterative approach composed of testing and feedback collection and repeated for different months and different test groups. The first official version of the game was released to coincide with the courses in Operation Management held at the University of Parma and the University of San Marino in the summer semester of 2021. In order to test the alpha release of the game, a pre-test and a post-test were conducted, on the first and on the last day of lessons.

#### 3.1 *Game development and testing*

The first working implementation of the SCM SG, released in spring 2019, was not optimized at that time; to solve any problems that arose, a beta testing phase was conducted. This phase was composed of two different iterative approaches (Figure 1) to test the effectiveness of the game and the right combination of parameters. In the first, lecturers and researchers played the SCM SG to prepare it for student testing; this first iteration was repeated twice.

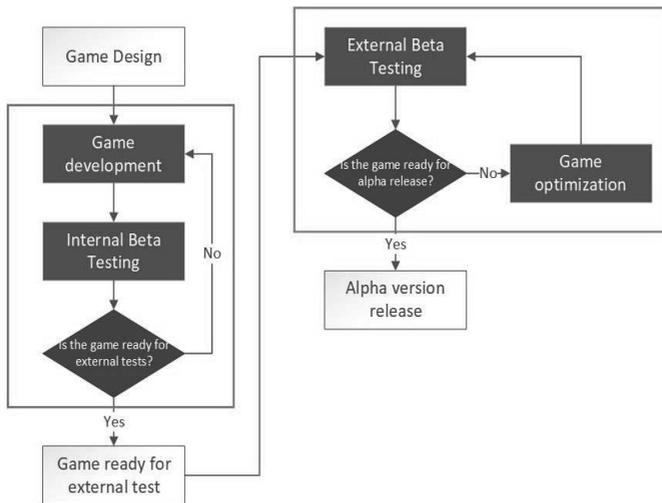


Figure 1: Beta testing process

These contributions led to the detection of major glitches and bugs in the first iteration, and the proposals for the optimization of parameters the second time. Subsequently, the game was evaluated as ready to be submitted to students. The second phase was replicated twice with two different groups of students. Once these two iterations had finished, the game was evaluated as ready to be released as an alpha version. The first users of the game were the students enrolled in the two bachelor's degree courses in Operation Management at the University of Parma and the University of San Marino. In order to best evaluate the SCM SG and the students' willingness to use it, two tests were conducted. Pre-tests aimed to investigate the perceived usefulness of SGs, the willingness to use them, and the perceived added value of this type of learning tool. The post-test was structured by using a framework validated by Iten and Petko (Iten & Petko, 2016), which is based on a Likert scale and aims to investigate characteristics of the game like (i) usefulness, (ii) simplicity, (iii) fun/enjoyment, (iv) personal ability, (v) fear of use, (vi) intention to use, (vii) clarity of the goal of the game, (viii) strategic approach, (ix) use of prior knowledge, (x) flow, (xi) feedback, (xii) help/assistance, (xiii) enjoyment of the game, and (xiv) competition.

## **4 SCM SG Scenario**

The scenario is structured as a universe comprising different companies competing in the e-bike market. This universe simulates a semi-real-life scenario in which every company is an e-bike manufacturer buying raw materials from the suppliers, using these materials to produce final products, and selling them to customers. This design of the game, which reproduces manufacturers' day-to-day actions, enables the users to deal with real-life and real-time dilemmas, developing hard skills required in Operation Management and in manufacturing companies. Also, SCM SG has been designed as a multiplayer game where companies are composed by two to three students playing different roles and cooperating in order to achieve a common goal. The three roles are: purchasing manager (PM), operations manager (OM), and sales manager (SM). The PM role is in charge of managing inbound operations, the OM manages the scheduling of production, and the SM runs outbound operations, as described by Galli et al. (Galli et al., 2021). The collaborations and cooperation between these functions are fundamental to achieving optimal company management. To do so, the users have to share their function information and decide altogether on the strategy to follow. Indeed, the serious game does not foresee a common way of achieving optimal management; it is up to the players to decide if producing with a make to order (MTO) strategy, a make to stock (MTS) strategy, or a hybrid combination of them is most effective. To take such decisions, coordinate each function to achieve the common objective, and maintain the strategy chosen, communication and coordination are a fundamental part of the game. Another peculiar characteristic of the SCM SG is its high level of customizability, which enables the players to create different levels of difficulty and different scenarios to be played. An important parameter to be considered is the duration of the game in order for the players to benefit from mistakes-driven learning and change their roles.

## **5 SCM SG Evaluation**

In the beta testing phase, two different types of feedback were gathered. Firstly, the observations made by lecturers and researchers were managed with open discussions due to the limited number of participants and the diverse number of bugs, glitches, and parameters to be fixed and balanced. Once the testing passed from the professionals to students, feedback was enhanced with a questionnaire with the scope to investigate the perception of different parameters. For all the parameters investigated from here on

a Likert scale 1 to 5 (1 = very low, 5 = very high) was used. This survey revealed that the overall difficulty level of the game is perceived as medium; among the roles played, OM was perceived as having a slightly higher level of difficulty (Galli et al., 2021). Also, the user interface (UI) was evaluated as well designed, and game practice was adjudged to be in line with theoretical lessons. The perceived competition was high: 90% of the students reported a grade higher or equal to 4, and the game was evaluated as enjoyable. However, the discussion highlighted the possible benefits of an integrated chat system, which was not provided by the game itself at that time. A summative evaluation was carried out by submitting a pre- and post-test in the two courses. As result, the pre-test was submitted to 176 students and the post-test to 102 students; 37 of them participated as players; the rest represent the control group. The pre-test highlighted the high perception of added value that SGs can bring to the teaching methods used, with 80% of the interviewees voting higher or equal to 4 in response to that sentence, and more than 70% of the students expressing their feedback in the same way in terms of their willingness to use the game and of its perceived usefulness. On the other hand, the post-test investigated all the parameters which characterize the serious game in more depth. The test is composed of 46 different sentences, divided into the 14 parameters which students can evaluate. In Figure 2, the average evaluation of every parameter is divided into the two groups, University of Parma (UNIPR) and University of San Marino (UNIRSM), and the average value given by all the players. In general, the parameters with a score higher than 3 can be considered evaluated positively, around 3 as neutral, and lower than 3 as negative (Iten & Petko, 2016).

The feedback received in the post-test can be considered generally positive. Important results were the vote received in terms of Usefulness (4.42), Fun/Enjoyment (4.57), Intention to use (4.2), Clarity of the goal of the game (4.31), Enjoyment of the game (4.53), and Competition (4.25), which all ranked highly. The only parameter with a low evaluation was Fear of usage (1.66), which cannot be considered a negative evaluation due to the purpose of the game in which students are afraid to make mistakes. Having no fear would represent a self-defeating attribute in the usage of mistakes-driven learning.

## 6 Discussion of the results

The beta test results outlined a good evaluation of the SCM SG and its design, which peaked in terms of the relevance between practice and theory

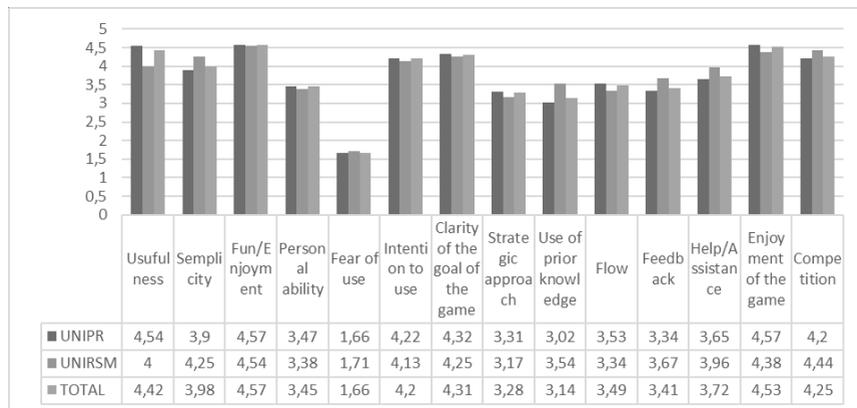


Figure 2: Post test evaluation

taught, and perceived competitiveness. The game’s UI and playability achieved good grades. In the pre-test, the willingness to use SGs and their perceived usefulness achieved positive feedback, which was confirmed later by the post-test. The beta test results were confirmed by the post-test, in which the game was evaluated as a good give-and-take between usefulness and fun, in which competition and the clarity of the objective represent key aspects of success. However, personal ability, the use of prior knowledge, and strategic approach received a neutral vote in contrast to the mark received for the relevance between practical aspects and theory. The perceived difficulty of the roles in the game was in line with the results of the beta test, with the OM function being considered more challenging than the SM and PM.

## 7 Conclusions and future works

In conclusion, the feedback received on the SCM SG was positive. The data indicates that the aspects of competitiveness, enjoyment, and usefulness were achieved, which indicated that the participants highly intended to use the game. Plus, the students who played the game gave on average 12.5% marks higher than the students who saw only the introductory video. This last statistic can be interpreted as an excellent result which confirms that the game surpassed the expectations of the students. Also, the difference in the evaluation of the roles’ difficulty underlines the need for the learners playing in the same company to change roles during the game. In contrast

to these positive outcomes, the game has to be improved in the usage of skills taught in the Operation Management and Supply Chain Management courses. As a next step, pre-set scenarios will be defined in order to address both long game sessions and short game sessions in an appropriate way.

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## **Development of Hybrid Lab-based Learning Environments with a Design-based Research Approach**

### Abstract

This paper deals with the complete process of didactic concept development for hybrid laboratory-based learning environments in engineering sciences using the design-based research approach. This includes all stages, starting with the research problem and the research questions, a requirements analysis, the first concept development including sub-concepts (self-directed learning, collaboration, virtual reality), implementation and a formative evaluation with subsequent concept refinement, and a final summative evaluation.

### Keywords

Lab-based learning, Design-based research, Hybrid learning

### **1 Educational problem and research questions**

The Internet of Things (IoT) has enormous economic potential with the largest share in the industrial sector. The core element of the economy will be smart networking (BMW, 2017). Engineering education at universities and colleges is called upon to impart the new requirements to their students, not only theoretically but also practically and close to industry. This requires future-oriented digitization and networking of industrial and logistical systems in the university environment as suitable places to learn and work. It also requires didactical reflection on digitization in engineering teaching and the adaption and design of the methods and digital tools, based on the current state of research in order to support the development of (IoT)-relevant skills (Feisel & Rosa, 2005) among students. A particular challenge here is in the area of digitized laboratory-based research and teaching: Real laboratory infrastructures include personnel, are cost-intensive, and are

generally only available to the respective research institution. In contrast, purely virtual laboratories offer advantages in terms of security, scalability, remote access, and cost efficiency, but cannot replace the success of real laboratory environments, as these require and promote different knowledge. One approach to meeting these challenges and at the same time exploiting the potential of digitization for the training and competence-oriented learning of prospective engineers is to digitally integrate real laboratories and virtual learning locations into a hybrid learning and working environment, which additionally links different laboratories with each other via a learning platform and makes them globally available. That is precisely what is investigated in the research project presented here.

This requires a methodological didactic concept that is tailored to the requirements of the target groups and participating institutions and makes profitable use of the available technology and media options for learning. Both methods of collaborative and self-directed learning are relevant here (Kerres, 2018). Research in this respect focuses on the cross-location collaboration of multiple remote users, interaction with real and virtual objects via the Internet, and ways to promote self-directed learning in such complex environments. The availability and performance of smartphones, tablets, as well as AR/VR glasses, have increased massively in recent years. This has made the use of mixed reality (MR) practicable for learning. Thus, the potential of MR to support such learning methods in hybrid environments needs to be explored and exploited.

The central research question here is how such a methodological didactic concept must be designed so that effective learning can succeed in such a hybrid and distributed environment. More specifically, it is about the design of self-directed learning and the possibility of support by means of digital open badges, of collaborative learning and suitable forms of interaction between learners and with remote or virtual learning objects as well as ways of using MR to support these forms of interaction for learning.

In order to derive valid didactical design recommendations, several learning and teaching scenarios were developed, evaluated, and improved upon.

## **2 Didactical development (DBR approach)**

In this project, we developed several lab-based learning scenarios that span several different didactical categories. While all of them have to teach an engineering topic in a lab-based, hybrid learning environment at heart, parts like learning methods, media, or organization can differ widely.

The didactic concepts in the project were created on the basis of Kerres' model for media didactic design (Kerres, 2018). In order to be able to implement this model, a needs and requirements analysis was first carried out, with which relevant information for the didactic design of the teaching-learning scenarios was collected. The focus here was on identifying the prerequisites, wishes, and possible problems on the part of the groups of actors associated with the learning scenarios (teachers, learners, laboratory staff, etc.) as well as on working out the institutional and organizational circumstances at the respective laboratory locations. Five types of information sources were used for this purpose: State of research and theoretical background on laboratory-based learning and the teaching-learning methods used in the project, intentions, and goals from the project proposal, interviews with teachers and researchers from the subject areas relevant to the project, interviews with students from the field of engineering, and so-called scenario surveys that provided information on the structure and framework conditions of the teaching-learning scenarios used. The results of this work were then used to derive more than 175 requirements for the development of the overall methodological didactic concept and the sub-concepts associated with it. For example, it was formulated here that sufficient opportunities for communication between teachers and learners should be provided within the learning management system or that the limited experience of many students in this area must be considered when using serious game applications.

Using the information and requirements obtained in the requirements analysis (fields of didactic analysis: actor conditions, environmental conditions, teaching content, and teaching objectives) as well as knowledge gathered from specialist literature, the researchers were able to start the development of the didactic concepts. Creating these concepts represented the beginning of the design-based research process used in the project and contained concrete didactic recommendations, which were examined scenario-specifically for their meaningfulness and feasibility and then, if possible, implemented in the scenarios. Thus, it was considered which teaching-learning methods, which media and tools, and which forms of a learning organization are most suitable in each respective context to convey teaching content and thus achieve the teaching objectives. In this way, the first prototypes of the project scenarios were created, which, if all the concepts are added together, resulted from more than 110 didactic recommendations. Of these, 17 alone were taken from the overall concept, such as "When designing media, display information in a way that uses both coding channels (e.g. image and text), use visual symbols to display processes (e.g. images, videos, animation), avoid merging coding channels of the same type (e.g. text and audio), and give options on how to represent information".

The learning scenarios redesigned in this way were then formatively evaluated with the help of interviews with students, teachers, and relevant experts from research and laboratory practice. In the next step, the results were used to discuss problems identified and wishes and ideas expressed in the evaluation and, if sensible and possible, to integrate them into the concepts and design recommendations so that they were then partially incorporated into the scenarios. This iterative sequence of tasks was repeated as often as time allowed per scenario and concept in order to optimize them for teaching and learning. In this way, for example, about 75 new didactic decisions were generated for the scenarios at the HFT Stuttgart, including the rejected ideas or suggestions that were not implemented. This involved topics such as task links between different learning phases, the clear communication of learning objectives, stronger referencing of the scenarios to everyday work in companies, or the inclusion and structure of a short introduction at the beginning of the scenario.

### **3 Collaborative learning**

Collaborative learning and working are generally important parts of engineering education (Feisel et al, 2002 ; Tekkaya et al, 2016). Thus, the use of collaborative learning as a method is also of substantial interest in this context. However, one of the major educational problems in this joint learning is that students in the subject often lack team skills (as emerged from the requirements analysis). These include (IoT-)relevant skills, for example, communication, negotiation, and leadership skills. Therefore, to address this problem, these skills were often identified as learning objectives in the original project scenarios and the learning events associated with them. However, these learning objectives had not been optimally formulated and implemented in terms of methodology and media. So, this was exactly the starting point for the sub-research questions and improvement plans for the collaboration concept in the project, which focused on finding out with which methods of learning support social learning processes and interactions in hybrid lab-based learning spaces and with which forms of direct or technically mediated interaction learning and collaboration in such learning environments succeed. Or in short: How can collaborative learning be supported there?

In order to stimulate learning and working together, appropriate didactic decisions were made to promote social presence (and its perception: "awareness") and interaction in the learning environments, so that a feeling of togetherness was created among the participants. Thus, especially in the

digital project labs, the perception of other learners was supposed to be prevented from suffering due to a lack of facial expressions, gestures, and spatial proximity. Therefore, an attempt was made to create a feeling of not being alone, for example, by making questioning, chats, emojis, wikis, FAQs, and a generally dynamic feedback system important components of the learning scenarios (Brandon & Hollingshead, 1999). Such feedback and support mechanisms were intended to make it clear to learners that other people are involved and that teachers and tutors are available to provide support, especially in terms of the learning management system. Further design recommendations of the didactic concept refer to the fact that, as can be seen from the requirements analysis at the beginning of the project, the learners in the project scenarios have very heterogeneous prerequisites in terms of previous technical experience. Accordingly, system introductions, for example, were recommended and implemented. Additional recommendations concern the areas of optimal group size—which was set at approximately three to four people in order to keep the benefits of collaboration high in relation to the communication costs—appropriate group composition (according to professional knowledge, gender, previous experience with collaboration and technical knowledge) and the transparent presentation of the goals, assessment, benefits, and process of collaborative learning phases (Brandon & Hollingshead 1999).

#### **4 Self-directed learning**

For self-directed learning, too, a didactic concept was created, design proposals were made, some of them were implemented in different project scenarios, and their implementation was evaluated both during the process and at its end. The aim was to create didactic learning environments that are suitable for the application of this learning method and, above all, support learners who primarily work individually, thereby achieving a more effective learning process and gaining (IoT-)relevant skills. Special attention was paid to the extent to which Open Badges and other tools and media are useful for learners in those self-directed learning environments.

In accordance with the didactic procedure outlined above, a total of eleven requirements for the design of self-directed learning spaces were identified with the help of the requirements analysis and were, henceforth, considered mandatory in the further progress of the project. On the one hand, these were requirements that address the prerequisites of the scenario target groups (different skills, etc. of learners and instructors), and on the other hand, a number of requirements for the teaching-learning environments

themselves (ensuring social interactions during learning, etc.), especially also in digital and hybrid learning settings (Ferdinand, 2007 ; Friedrich & Mandl, 1997 ; Faulstich, 2001).

The derived requirements subsequently formed the framework for the creation of the concept and its concrete adaptation in the learning scenarios. With the help of relevant literature, suitable ideas and solutions were then developed for the specific research context of the project, which ultimately resulted in more than 60 design recommendations. Among other things, this included the idea that the laboratory exercises should, if possible, be divided into concrete learning sections with their own intermediate objectives, in order to be able to form learning paths and to simplify the planning of learning—and gladly also with visualizations, for example via Open Badges (Ferdinand, 2007 ; Stauche & Sachse, 2004 ; Cucchiara et al, 2014).

## **5 Mixed Reality**

Traditionally, one would define Mixed Reality in the sense of Milgram et al. (1994) in the context of the Reality Virtuality Continuum. The Continuum spans from the Real Environment on the one hand to the completely Virtual Environment on the other. Mixed Reality in this context includes the complete space between these worlds, such as Augmented Reality and Augmented Virtuality. Nowadays, however, the term Mixed Reality is understood more broadly and is often used as a synonym for all technologies from this area. Speicher et al. (2019) note that it is difficult to find a universal definition for a branch of research that is currently evolving so rapidly. We interpret the Virtual Environment of the continuum as synonymous with Virtual Reality, since the immersion and interaction, as well as the complete isolation, of the user from the real world, are its main foci. For collaboration aspects, we refer to the Time/Space Matrix from Johansen (1988), which classifies collaboration types based on time (Synchronous vs. Asynchronous) and on location modalities (co-located vs. non-co-located or remote). During the project, we developed multiple Virtual and Augmented Reality Applications, both for single users, as well as for collaboration between multiple users, which can be classified via both the RV Continuum and the Time/Space matrix. Based on this and our experiences during development, we created a schematic to show the difficulty of the implementation, extensibility, and maintenance of Mixed Reality applications by combining the RV Continuum and the Time/Space matrix. This way, we determined the dependencies of collaboration modalities with their position on the Reality Virtuality Continuum.

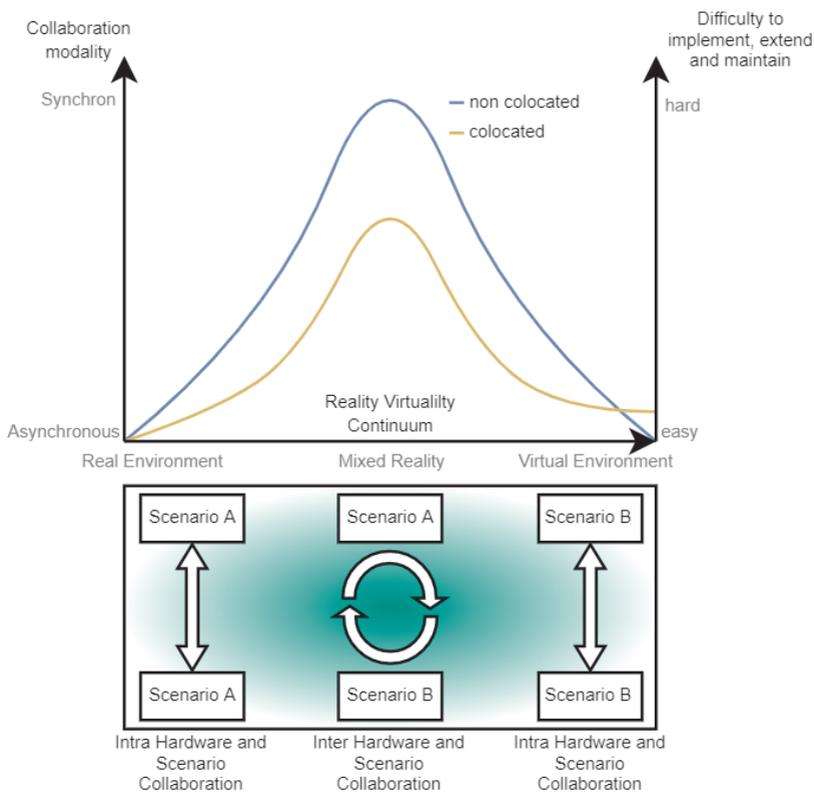


Figure 1: Own illustration (based on Milgram et al (1994) & Johansen (1988))

At the top of Figure 1, the RV Continuum lies on the X-Axis and spans the continuum from Real Environment to Virtual Environment, while the Y-Axis depicts Synchronicity as well as Difficulty. The two graphs, one for co-located and one for non-co-located (remote) collaboration, show that it is typically harder to implement collaborative Mixed Reality applications if the collaboration/communication is synchronous, remote, and placed somewhere in the middle of the RV-Continuum. The reasons for this are briefly summarized below:

Collaboration Synchronicity: The more real-time the collaboration is, the more computing power and network bandwidth is typically needed.

Additionally, one has to deal with filtering incoming positional data if movement is synchronized.

**Reality Virtuality Continuum:** Since most Mixed Reality applications run on portable devices, they offer the least computational power, restricting the options of the programmer. Additionally, the variety of devices (smartphones, head-mounted displays, etc.) has resulted in many new and changing frameworks, as well as programming environments, which makes maintenance over long periods of time difficult. For Augmented Reality applications especially, external influences that might interfere with camera tracking have to be considered.

**Co-located vs non-co-located:** Naturally having all devices in the same location and/or running on the same hardware makes things easier in regard to networking and removes most bandwidth issues. However, one has to keep in mind certain hardware limitations, like security spaces for Virtual Reality or interference of different tracking technology. This is the reason why having multiple co-located users in the same Virtual Reality application is rated harder than the non-co-located alternative.

In contrast to the increased difficulty of implementation, maintenance, and extendibility, applications in the middle of the RV Continuum also offer tremendous opportunities to act as a bridge between the two extremes. Whereas scenarios in the real world and in the virtual world are often strictly separated, the boundary is increasingly blurred in Augmented Reality applications. In terms of collaboration, this enables an inter-hardware approach in which, for example, users of Augmented Reality glasses can communicate with users of Virtual Reality glasses.

As we have successfully shown in the project, spatial boundaries as well as boundaries within the Reality Virtuality Continuum can be overcome in this way to enable students to learn together in a profitable way. We believe that our schematic relationships will help to weigh up whether opportunities for inter-hardware collaboration justify the increased effort. We also provide an overview of potential difficulties that may arise along the Reality Virtuality Continuum or the Space/Time matrix.

## **6 Summative Evaluation**

With a view to answering the project's research questions, data on the effects of the concept recommendations in terms of learning progress, different forms of learning motivation, and acceptance of learning environments (dependent variables) were collected after their implementation. For this purpose, quasi-experimental group studies with repeated measurements we-

re conducted and the test persons were assigned to different groups. The groups first had to complete a pre-test and then prepared for the laboratory exercises, which differed depending on the group classification. While some study subjects went through the original scenario as a control group, other groups had self-direction, collaboration and/ or VR treatment. This had consequences above all in terms of which laboratories the test persons used and also in which social form they worked there and how the digital learning management system was designed in the follow-up and report preparation phases—i.e. which possibilities, media, and tools were available. Finally, after the completion of the whole learning scenario, a post-test was conducted. All the surveys were primarily quantitative and were executed via questionnaires, most of them consisting of already tested and validated items and only slightly adapted to the respective contexts of the scenarios. The knowledge tests, on the other hand, were created in the project itself.

Unfortunately, the samples in some scenarios were not particularly large, especially in the one that was most significant for the concepts presented here ( $n=34$ ). As a result, fewer groups were able to be formed than necessary for a properly conducted treatment study. This circumstance will most likely have an impact on the accuracy of the results.

Currently, the results are not yet available, as the analysis phase has just begun. At present, there is only a brief insight into the mean values of the scenario just mentioned for the dependent variable *amotivation*; in this case, over three measurement points, as there was also an intermediate measurement after the laboratory phases.

Of the study groups, the one in the original scenario actually performs the worst: After the last measurement, it has the highest amotivation (1.92; complete amotivation: 4.00; no amotivation at all: 1.00). Although it was able to reduce this by 4% over the course of the scenario, it also ranks worst in comparison with the other groups. The group in the remote lab with Self-Direction Treatment is in a somewhat better position, with amotivation of 1.85 in the end, but was able to reduce it by 12.32% until then. The VR probands even achieved more than 20.5% and 1.62 here and thus already better values than the average of all test subjects (-16.75% and 1.69). The revised hands-on scenario, in which all forms of treatment (collaboration, self-directed learning, and VR) were implemented simultaneously, took a good second place in this ranking. Despite the highest start motivation (2.22), the second lowest final value of 1.59 was measured here due to a reduction of 28.38%. Only the participants of the remote lab without self-control treatment did better, showing a very low amotivation value of 1.22 in the end, after they had been able to reduce it by more than 31.4%.

The first results thus give slight indications that the scenario revisions made had positive impacts on the extent of amotivation in the exercise. However, the significance of the results remains low for the moment due to the small number of cases, the types of calculations made, and the preliminary exclusion of important control variables, and does not yet permit any meaningful interpretation. More detailed information will follow shortly.

## 7 Conclusion & Outlook

In conclusion, it can be stated that the creation of the overall didactic concept and the sub-concepts of collaborative learning, mixed reality, and self-directed learning has succeeded so far and was extremely complex in terms of content, as there were a large number of design options. It was therefore not always easy to remain goal-oriented and to pass on only those design recommendations that had a very strong presumed benefit for learning in the aforementioned learning environments. This task was made all the more difficult by the inevitably heterogeneous framework conditions and target group prerequisites that prevail in an international project with different partner universities. These circumstances meant that the creation of the concepts was relatively time-consuming, which must be considered when planning such projects.

The implementation of the design recommendations was also largely successful. However, it was necessary to forego the realization of many ideas here because the selected learning scenarios, which were intentionally kept quite simple and short, would otherwise have been overloaded. This development shows that it is important to anticipate the relationship between the research project and its real possibilities as early as possible in order to be able to work accurately. For this purpose, information and findings from the initial phase can and should be used, such as those from the requirements analysis conducted at the beginning of our project.

The iterative process of the design-based research approach that was used, in combination with the qualitative surveys and analyses of the formative evaluation, played a very important part in identifying practical problems and implementable ideas for improvement in the individual learning scenarios. By doing so, they built a bridge between theory and practice, which led to new insights. This approach has hence proved successful overall, but at the same time was quite time and resource-intensive.

With regard to the summative evaluation, there were unfortunately some problems that will affect the quality of the results. For example, the global pandemic situation in the survey year 2021 meant that the number

of probands, which was already tightly calculated in some scenarios, shrank even further, some scenarios could not be tested or could only be tested under different circumstances than planned, and the scheduling and preparations turned out to be extremely difficult.

Nevertheless, it was possible to carry out the data surveys. As described above, it remains to be seen which conclusions will be possible after the analysis due to the data collection problems. The analysis is scheduled to be completed by the end of March 2022. If possible, the types of treatment will then be assessed for their success and conclusions will be drawn on how didactic concepts in hybrid engineering laboratory environments can be designed to improve learning.

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*Karsten Henke, Johannes Nau and Detlef Streitferdt*

## **Hybrid Take-Home Labs Empower Future STEM Education**

### Abstract

The acceptance of digitally supported teaching has increased enormously in recent years, not only because of the coronavirus crisis. Online labs are increasingly being used in STEM subjects to meet the availability, usability, and granularity of what they offer. This ensures the connection of theoretically taught basics to their application and deepening in practical courses in the basic subjects. However, hands-on experimentation and the haptic learning associated with it are being somewhat lost.

The *Hybrid Take-Home Labs* project aims to develop and test the foundations for practical support of learning processes in STEM subjects, enabling students to conduct even complex virtual and remotely controlled laboratory experiments from home using their own resources, combined as needed for student-centered teaching that meets the requirements of future-oriented competency-based learning.

### Keywords

Control education engineering, distance learning, virtual and remote labs.

## **1 Introduction**

Since the beginning of the coronavirus pandemic, e-learning has primarily been able to alleviate the loss of face-to-face teaching at Ilmenau University of Technology—except work in laboratories, which is mostly only possible in person. Soon, however, real experiments will be increasingly feasible from home. To this end, TU Ilmenau is developing a portable online laboratory infrastructure that will enable students of STEM subjects to conduct their own complex "tactile" laboratory experiments remotely using their own control units via the Internet. The Thuringian Ministry of Science is funding the project. It was initiated together with the Association for the Promotion of Science and Humanities in Germany as part of the "Fellowship Program for Innovations in Digital University Teaching" [1].

In recent years, digitally supported teaching has found its way into universities, not just since the coronavirus pandemic. So-called online remote labs are just as powerful as on-site technical facilities, but they are also more flexible, as students can access them virtually from anywhere. Since their subject matter is permanently available remotely in the form of digital, interactive simulations, and video recordings, students can decide when to access it according to their individual work rhythm, schedule, and level of knowledge. Online labs enable remotely controlled experiments through web-based access to real controls and physical systems. This ensures the connection of theoretically taught basics to their application and deepening in practical courses. However, practical experimentation and the "haptic learning" associated with it are being lost, i.e., many problems dealing with real hardware are being "abstracted away". E-learning environments are predominantly based on visual and auditory components. With the advent of haptic technology, we can now simulate/create forces and thus also the sense of touch. This practical side of the learning process will be enabled by the *Hybrid Take-Home Labs* currently being developed at TU Ilmenau.

TU Ilmenau has been using digital laboratory solutions in its STEM students' online and hybrid education for more than ten years. For example, the interactive hybrid online lab GOLDi ("Grid of Online Lab Devices Ilmenau") has been used for courses, practical work, and online demonstrations on a national and international scale [2, 3]. It was not only through the pandemic situation of 2020 and 2021 that the advantages of digital laboratory solutions became clear in terms of performance and flexibility. The preparation of subject matter in digital, interactive simulations, video recordings, or remote access opens up a flexible time allocation corresponding to individual work rhythm and level of knowledge with permanent availability.

Meanwhile, many interested learners have their own hardware at home—be it an Arduino or a Raspberry Pi for software enthusiasts, or now affordable FPGA demo boards and digital logic experiment kits for hardware enthusiasts to independently control interactive objects or interact with software applications. Thus, while they have their own control units, they lack direct access to the complex experimental environment of a professional laboratory. The *Hybrid Take-Home Labs* will allow students to perform complex experiments in an online lab with their hardware flexibly used as their own control unit. For this purpose, they will be provided with a *Take-Home Lab* interface unit. On the one hand, this interface unit connects them to the GOLDi online lab via the Internet. On the other hand, it serves as an interface with all the inputs and outputs of a real technical system, such as an elevator, a 3-axis gantry, or a high-bay warehouse located remotely in the

university's remote lab. Students design the control algorithm and program their own control unit in their residential schoolroom. We believe that "haptic" feedback will increase the immersion of the learners in a distance learning environment and their interaction with other learners using a variety of sensory inputs in addition to text, video, and audio. The opportunity to have richer tactile experiences can improve the way students explore content at a distance. This principle could also be extended to other learning areas, for example, teaching the control of complex chemical plants remotely.

## 2 Planned Innovations in the Teaching Process

Online labs can be divided into remote, virtual, and hybrid labs (see Figure 1).

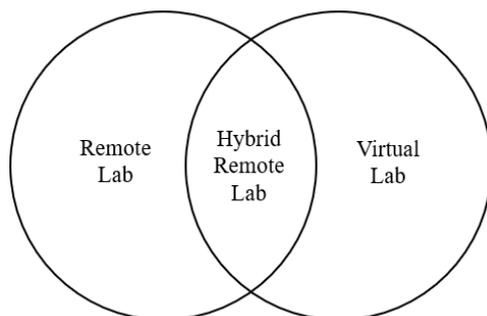


Figure 1: Overview of experiment types in online labs

Remote labs allow experiments to be performed remotely via web-based access to real controls and physical systems (electromechanical hardware models). Virtual labs work exclusively in virtual artificial worlds. In addition to enabling remotely controlled experiments via simulation, hybrid labs combine both approaches by allowing students to work with virtual devices that correspond to real devices in their essential characteristics. This approach follows the idea of digital twins, which is likely to be of great importance for developing Industry 4.0 work environments in the future. The GOLDi online lab implements all variants flexibly. Thus, it is possible to perform all experiments either entirely virtually or on real devices or using a combination of both.

The many different online labs that have been successfully used for many years all have the disadvantage of "abstracting away" many of the problems associated with dealing with real hardware. This fellowship application aims to extend the existing lab concept with the idea of *Hybrid Take-Home Labs* (Figure 2).

The approach of *Take-Home Labs* (or Pocket Labs or Mobile Labs) is not new. It stands for portable mobile labs that can be borrowed by students and, in our discipline, often used in conjunction with a laptop or tablet PC—for example, in lectures, in a seminar, at home, or on the go [4].

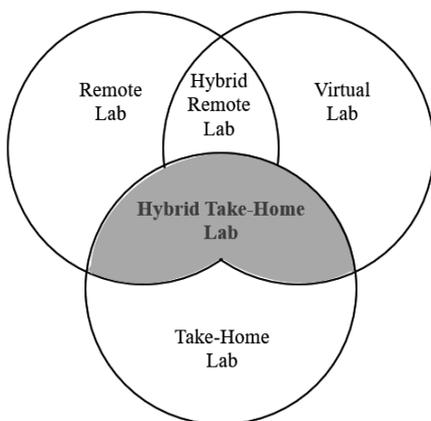


Figure 2: Overview of experiment types in online labs

By now, many interested learners have their own hardware at home—whether it is an Arduino or a Raspberry Pi for software enthusiasts or now affordable FPGA demo boards and digital logic experiment kits for hardware enthusiasts. So, they have their own control devices but no direct access to complex experimental environments. Within the *Hybrid Take-Home Lab*, they can flexibly use their hardware as their own control device to perform complex experiments in conjunction with the GOLDi online lab. Learners can easily connect to this interface with their own control devices and thus can control these complex hardware models (from home).

In the future, the *Take-Home Lab* modules will also be used in the pre-university sector, especially for student recruitment (initial contacts have been made in the STEM Excellence Cluster—an association of high schools

in Germany). But also, in the post-university sector for training and further education.

### 3 Usage of the GOLDi online lab in basic computer science education

In the following, the usage of the GOLDi online lab in fundamental computer science education for students in technical fields will be presented first. Then, how the *Hybrid Take-Home Lab* concept extends these with diverse applications will be shown.

The GOLDi online lab currently supports topics in computer engineering and digital technology as offered in the basic studies of TU Ilmenau for all engineering courses, in which the foundations for the understanding, systematic design, and formal verification of digital systems are laid.

The courses "Computer Engineering" and "Design of Digital Systems" are intended to enable students to design and build digital control systems independently and verify their correctness. Students will acquire the ability to use digital circuits to acquire sensor values and process them so that actuators respond in a manner specified in the assignment, such as controlling an elevator or a simple 3-axis portal.

To achieve this goal, the mathematical basics of Boolean algebra are first taught. This is followed by the systematic, formally verifiable functional description of digital controls, such as the formulation of the dependencies of sensor values in the form of Boolean equations. Another theoretical concept, which is especially important for constructing sequential circuits, is finite state machines (FSM). Based on this, it is shown how these descriptions can be implemented in digital circuits. In order to illustrate the correctness of their behavior, a practical construction through the interconnection of basic elementary circuits, which correspond in their function to the essential elements of Boolean algebra, is necessary, in which haptic learning types are addressed at the same time. This is usually done in a laboratory experiment. This teaching concept can be accompanied by and supported by the help of our hybrid online lab GOLDi and the *Take-Home Lab* extension.

As already mentioned, the GOLDi online lab flexibly supports all variants of remote labs: remote, virtual, and hybrid labs. Thus, it is possible to perform all experiments either entirely virtually or on real devices, or in a combination of both.

The task in an experiment is to control a physical system with a self-designed algorithm to execute a given sequence of movements. The digital-twin concept enables the exploration of side effects that can occur in faulty designs as early as the design phase. In this process, partial concepts of the

control algorithm can be tested on a virtual emulation of a physical system, independently of its later implementation. Once the algorithm works on the digital twin, it will also work in a real environment.

#### 4 Expansion of the lab concept to include Hybrid Take-Home Labs

The beneficial introduction of digital labs from a student perspective is still a technically, didactically, and organizationally complex topic. It is about much more than simply digitizing lab equipment. Instead, it is about the goal-oriented digital transformation and implementation of agile, self-directed, creative, and collaborative research-based learning that promotes competence. The entire GOLDi lab is thus not a "hard-coded" installation, with a firmly defined model of possible learner interaction patterns, but rather the subject of a continuous process of adaptation and evaluation.

For this purpose, the term *Hybrid Take-Home Labs* defines open digital lab objects (interface units) combined in a demand-oriented and interoperable way for student-centered teaching to effectively meet the requirements of future-oriented competence-based learning and working 4.0.

**An Application scenario:** *The following task is given: "The trolley of a gantry crane is to move back and forth between the left and right limit switches. The movement can be stopped and released again with a push button. For this purpose, the two motors for left and right travel are to be controlled."*

*The student will first derive and simulate his/her automaton graph using the Interactive Learning Object GIFT. Then, he/she can derive the equations, which are the starting point for a digital sequential circuit.*

*As regards practical implementation, the student uses his/her private "collection" of essential digital components (AND, OR, NAND, NOR, flip-flops, ...) and his/her plug-in board. After the circuit is built, the student wants to test his/her design on the real hardware model in the Remote Lab and connects his/her circuit to the inputs and outputs of the Take-Home-Lab interface.*

*When starting the experiment, the student notices that the trolley does not stop at the left limit switch, and thus a GOLDi protection mechanism aborted the experiment. He/She gets the error message that the trolley still wants to move to the left when reaching the end position. After a short troubleshooting test, he/she realizes that he/she had misconnected a cable. As a learning experience, he/she understands that meticulous work is advantageous in the construction of digital circuits.*

*During further testing, he/she notices that some signals are set to zero by chance. After some consideration, he/she realizes that he/she has not yet connected the reset pins of the flip-flops. A quick look at the data sheet tells him/her that they*

*have to be switched to zero to prevent a reset, and he/she adds that to his circuit. The student has had his/her first experience with incompletely wired components.*

*Nevertheless, his/her circuit does not reliably trigger the desired stop in the movement when the push button is pressed. In the electrical engineering course, he/she once heard that you have to debounce switches to switch in a defined way. Using a capacitor and resistor as a low-pass circuit, he/she can fix the problem. In this case, the student once experienced live effects as they are theoretically presented in the courses and practically applied the techniques described to fix his/her problems.*

The effects described here are typically not observable with an online experiment, as they cannot occur there. Students who do not have their own control unit assemblies can also borrow them in addition to the *Take-Home Lab* interface units.

The difficulty level of the tasks can be adapted to the respective knowledge level in the semester. For example, at the beginning of the semester, only simple tasks such as working with Boolean constants and variables are possible. However, these can be immediately tested independently in the *Take-Home Lab* with their own simple control units (e.g. switches or push buttons) by setting variables (actuators) to constant values and triggering an immediate reaction to the hardware model GOLDi online lab. In the next training step, tasks on Boolean expressions follow, with the help of which more complex dependencies of sensor signals can be considered when controlling actuators. Finally, to control sequential processes, skills for the design of sequential circuits or digital automata (FSM) are required, which can also be developed with the Interactive Learning Objects described above and exported to the GOLDi Online Lab from home via the *Take-Home Lab* modules.

In higher semesters, microcontrollers or programmable circuits (FPGAs) can then be used as the students' own control devices. As required for programming FPGAs, the necessary knowledge for programming in higher programming languages (e.g., C++) or hardware description languages (e.g., VHDL) is acquired in separate courses. Challenging tasks that can be solved with this knowledge are, for example, parallel control algorithms for elevator control. Also, a comparison between a software solution and a hardware solution via a microcontroller or an FPGA is interesting for higher-semester education. For the editing of source code in the browser and its compilation, the Interactive Learning Object WIDE (Web-Integrated Design Environment) is available, which can be accessed via the Web interface of the GOLDi Online Lab, thus providing a uniform user interface for all programming languages.

The further development of the *Hybrid Take-Home Lab* will always take place with the involvement of students of higher semesters in the context of software projects and annual student research projects and bachelor's and master's theses. In particular, this is intended to develop skills for the challenges that the concept of Industry 4.0 poses to future graduates.

With the individualized use of heterogeneous digital laboratory installations of other GOLDi-Cloud partner institutions with other hardware models, the bandwidth, and the proportion of practical training components in STEM subjects can be significantly increased. This allows universities to balance the heterogeneity of students concerning practical skills in the lab context.

In addition to the benefits for the learners, the applicant also expects a leap in innovation on the part of the teachers through the networking of the respective disciplines at the participating university locations and beyond. While individual staff members design conventional laboratory implementations and didactic concepts, the overarching use of the respective infrastructures increases interaction and reflection. This direct exchange entails an explicit didactic evaluation and thus continuous quality development.

## 5 Conclusion

The *Take-Home Lab* project presented here is an integral part of the new project CrossLab (in German: "Flexibel kombinierbare Cross-Reality Labore in der Hochschullehre: zukunftsfähige Kompetenzentwicklung für ein Lernen und Arbeiten 4.0" [5]—which stands for: flexibly combinable cross-reality laboratories in university teaching: future-proof competence development for learning and working 4.0), which has been running since summer 2021. The partners want to combine the concepts for digitizing the laboratory education that they have developed at their various locations into a cross-university, interdisciplinary network. Thus, the individual CrossLabs, which enable simulations, the creation of virtual lab environments, and remote labs, will be combined into a single learning environment. Currently, new areas of application for online labs are being explored, e.g., automation technology, optics, mechanical engineering, or chemistry.

In addition to the conception and implementation of their technical realization (configuration and linking of the individual *Take-Home Lab* objects) and new use cases in various STEM disciplines, didactic concepts and organizational strategies are to be further developed in parallel to ensure broad integration capability. In the future, the *Take-Home Lab* modules will

also be used in the pre-university sector, especially for student recruitment, but also in the post-university sector e.g., for training and further education.

The Vice President for Studies and Teaching at TU Ilmenau, Professor Anja Geigenmüller, expects the current research activities in this area to provide a boost not only to digital laboratory technology developments but also to innovative didactic concepts: "The further joint development of innovative formats across disciplines and even locations will help to continue to make STEM courses attractive and also to incorporate ubiquitous digitalization into teaching content and teaching methods." [6]

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*Martin Burghardt*

# **Design, Implementation, and Evaluation of Self-Directed Learning in Digital and Hybrid Lab-based Environments**

## Abstract

In order to find out how Self-Directed Learning can best be embedded in a hybrid engineering laboratory environment to make learning there more effective, this paper briefly presents the related workflow within a research project. The procedure is presented from the perspectives of a requirements analysis to an iterative didactic design, from implementation and a formative evaluation as part of a design-based research approach to a survey design, and the first insights into the results of a summative evaluation. In the last section, the experiences and results so far are summarized and evaluated before there is a short outlook on the follow-up tasks of the research plan.

## Keywords

Self-Directed-Learning, Hybrid Learning Labs, Design-Based Research

## **1 Goals, Project Context & Research Question**

This paper will demonstrate the main work steps, research questions, results, and findings from the conceptual work developed for self-directed learning in the context of an ongoing international research project. This is a joint project involving different universities. It addresses, among others, the question of the best way to didactically design teaching and learning environments using different types of media, tools, and didactical methods combined with various kinds of educational labs (digital/virtual, remote, hands-on, hybrid) in engineering sciences which are (partly) interconnected with each other to be able to use them more efficiently and more broadly by doing so. The main goal is to maximize the benefit for students working within these settings in terms of learning progress, learning motivation, and acceptance (dependent variables). Furthermore, this approach applies specifically to self-directed learning, which in the context of the project is understood as a method, especially for learners who predominantly work

individually and, at least temporarily, digitally. The creation, implementation, and evaluation of the self-directed learning concept is the focus here. Thus, the core question is to what extent the use of this concept leads to an increase in the aforementioned dependent variables when tested in practice.

## 2 Self-Directed Learning in digital and hybrid Educational Labs in the field of Engineering Sciences: Theoretical Context

First of all, it should be clarified at this point how self-directed learning, learning labs, engineering sciences, and the project are interrelated. This serves an essential function in allowing us to understand why the use of this learning method is theoretically appropriate in the given context of application and why it was accordingly chosen to be researched in the project.

So, teaching-learning labs are important in the engineering sciences to provide students with initial practical experience, skills, and references that can be linked to the theoretically acquired knowledge from other learning units (e.g. seminars, lectures) (Tekkaya et al, 2016). Those laboratory-based learning environments are characterized by practical tasks and their closeness to reality. In most cases, this circumstance implies an active and constructive role for the learners, which is accompanied by self-direction (Stauche & Sachse, 2004). Furthermore, self-directed learning is also relevant in connection with a second important feature of this research project: hybridity. For example, in many cases, the various learning phases associated with laboratory scenarios (preparation, execution, follow-up, etc.) occur partly in face-to-face form, partly in online phases, partly synchronously, and partly asynchronously (Kerres, 2018). The phases in computer-based asynchronous online learning environments (using a learning management system) especially offer great potential for self-directed learning, since the learners can determine the outcome of important decisions such as learning time, learning pace, or learning location themselves and they have permanent access to important learning materials (Stauche & Sachse, 2004 ; Dreer, 2008). Hence, suitable framework conditions for the successful implementation of self-directed learning as a method arise here, and subsequently the opportunity to benefit from the advantages associated with its use for learning. Among other things, this includes increased motivation and more enjoyment of learning, which in turn can be followed by an improvement in learning success (Stauche & Sachse, 2004).

### **3 Requirement Analysis plus Creation, Implementation, and Formative Evaluation of the SDL-Concept**

Thus, it makes sense to investigate to what extent self-directed learning can positively influence such laboratory-based hybrid learning environments with regard to the variables mentioned above. For this purpose, a didactic concept of self-directed learning was created in the research project. It is based on findings, framework conditions, and needs that were previously identified with a requirements analysis through scenario descriptions, guideline-based expert interviews, literature studies, and project objectives. In this way, eleven requirements were identified for self-directed learning, which had to be obligatorily adhered to for concept development and later for scenario creation. Therefore, attention had to be paid to the anticipated prerequisites of the learners and teachers in the project. On the learner side, for example, the focus was on their self-regulation abilities, and their prior knowledge of or interest in the specific subject matter (Ferdinand, 2007; Friedrich & Mandl, 1997). For instructors and tutors, on the other hand, it was about various skills in areas such as guidance/counseling, planning, or media (Faulstich, 2001). Since the learning environments were intended to foster self-directed learning to ensure meaningful and successful application of the method, it is not surprising that all the other nine requirements had a direct reference to this area. For instance, learning environments must ensure that social interactions are enabled during learning to evoke additional motivation in learners. They must also be designed to demand the use of self-regulated learning as a learning method so that its benefits can be realized (Ferdinand, 2007).

Using these requirements as a starting point, the concept itself was then developed. This primarily had the goal of generating design ideas for the hybrid learning environments consisting of laboratories and learning management systems, by considering relevant specialist literature and deriving project-specific design recommendations from these. The latter were, if possible and reasonable, subsequently transferred to the teaching-learning scenarios available in the research project. They were implemented considering individual circumstances (learner prerequisites, organizational/institutional conditions, etc.), learning objectives, and the learning contents of the learning environments, which all were known through surveying important scenario-specific conditions using the requirement analysis. This procedure refers to Kerres' model of design-oriented media didactics, which served as a basis for all the didactic scenarios of the project and represents a kind of decision grid for the creation of learning scenarios (Kerres 2018). So, this

whole sequence can be thought of as a kind of selection process in which appropriate design recommendations were adopted into scenarios.

Using a formative evaluation for each particular scenario, problems and ways of improving the implementation of the suggestions from the concept were then sought. To this end, semi-standardized guided interviews were conducted with experts from the fields of engineering and didactics as well as with the most important target groups of the learning environments (teachers and learners). The corresponding qualitative results (overall 33 interviews and 321 pages of transcriptions) were discussed within the research group and, subsequently, decisions were made on suitable optimization solutions. The innovations decided on were then embedded in the scenario. In the spirit of the design-based research cycle, this process was repeated as often as possible in each of the three scenarios.

The period of the surveys and refinements was mainly in the spring and summer of 2020. So, the concept itself has now been completed. In its final form, it contains a large number of design recommendations (more than 60), ranging from the use of certain tools and media, such as open badges, learning analytics, assistance systems, or guidelines on relevant topics, to the modularization of learning content or the choice of social form.

While in principle self-regulation elements were included in all the project scenarios—which means that they contain more self-regulation after revision than in their original state—by far the most were implemented in the measuring-chamber scenario. In this regard, the scenarios offered various entry points for the realization of the self-regulation recommendations, since they are hybrid laboratory exercises that alternate between individual and group learning phases and whose preparation and post-processing times take place primarily through working in a learning management system environment, created in the project. For communication and social interaction, which are important in self-directed learning, forums and feedback mechanisms have been built in (Ferdinand, 2007 ; Stauche & Sachse 2004). Furthermore, some of the exercises were divided into different sections with small intermediate targets, where choices were created in the tasks and voluntary extra tasks for practice were introduced. In this way, small learning paths with some intermediate goals were created in such scenarios, which were also made visually comprehensible by linking them to progress bars and Open Badges. Open Badges are digital awards in the form of small pictures that honor achievements and contain all relevant information about them—i.e. who did what, where and when with what goal, etc. They were applied in the project to support self-directed learning because, among other things, they can increase the motivation of learners (for example, through gamification and reward effects), but can also be helpful with

regard to learning planning and learning assessment or reflection (Otto & Hickey, 2014 ; Cucchiara et al, 2014). All these aspects are considered essential for the successful use of the learning method in common self-direction models, such as Zimmermann's model (Zimmermann 2002). To encourage learners to discuss content and to engage with Open Badges, the latter were also awarded for meaningful communication within the forums.

Overall, all these measures are intended to communicate to learners that they have decision-making power in the learning process and to provide opportunities for them to plan and assess their learning better through the transparent presentation of learning objectives, content, and sequences. As a result, learners should perceive their learning as self-directed.

#### **4 Summative Evaluation of the SDL-Concept and the related Scenarios**

The self-directed learning concept is presently undergoing its final summative evaluation. Currently, the task is to find out how its concrete implementation in the various scenarios performs in comparison to the learning environments used before the start of the project. For this purpose, experimental groups (with treatment "SGL concept implementation") and control groups (without treatment "SGL concept implementation") were formed in each relevant scenario, enabling a direct comparison with regard to the above-mentioned dependent variables (learning progress, learning motivation, and acceptance). Pre- and post-measurements, and in some scenarios also intermediate measurements, were conducted in order to infer short-term and medium-term cause-effect relationships and to answer the related research questions, namely to what extent the use of self-directed learning can lead to an increase in the dependent variables. Roughly summarized, it is hypothesized that self-directed learning environments have a slight positive effect on motivation, acceptance of the learning scenarios, and ultimately on learning progress, in terms of knowledge and skill acquisition. These effects should be generally recognizable, but especially in comparison to the groups that did not receive self-direction treatment. These assumptions are justified by the basic suitability of the learning method for such learning spaces, which has already been discussed, and, among other things, by the expected increased satisfaction of the basic need for autonomy from the Self-Determination Theory, which can be expected from the design of the corresponding learning scenarios (Thomas & Müller, 2011; Deci & Ryan, 1993).

The quantitative data collection through written surveys (questionnaires with open and closed questions) has now been completed. In two different

learning scenarios, a total of four modes were fully tested with two student groups each, cumulatively 130 people. However, most of the analysis of these quantitative data and thus the answers to the research questions are still pending and are expected in March 2022. Unfortunately, only descriptive statistics of the progress of learner motivation in the four scenario groups in the measuring-chamber scenario are currently available. This is not yet sufficient to answer the research questions and related hypotheses, especially since there are a lot of other variables to consider in identifying causal relationships between the treatment and the dependent variables, which also cannot currently be included. Nevertheless, the given information shall be utilized here in order to get a first insight into the trends within the study:

In a comparison of mean values, an increase of 9.9% between the first and third (last) measurement time points was recorded with regard to their intrinsic motivation among all participating subjects ( $n=33$ ). With values of 3.03 (first measurement), 3.15 (second measurement), and 3.33 (third measurement), intrinsic motivation (minimum 1.00; maximum 4.00) is at a relatively high level overall. The development of the groups with self-regulation treatment (plus 9.69%;  $n=19$ ) and those without (plus 11.6%;  $n=14$ ) is very similar in this respect and does not show any major differences. This already indicates that the hypotheses can probably not be confirmed and that the self-regulation groups were not able to gain any greater intrinsic motivational advantages from their learning environments. However, it is noticeable that the self-regulation groups were able to make increases in this area above all after completion of the laboratory work phases (time of the second survey) in the post-processing and report preparation phase (plus 0.22 points/ 7.46% vs. plus 0.16 points/ 4.71% (Group without treatment)), while the groups without self-regulation treatment made greater gains during the preparation and laboratory phases (with treatment +2.08%, without treatment +6.58%). Of course, these are minimal differences that are likely to have limited significance due to the general survey situation and the resulting analysis options. They also clearly originate exclusively from the hands-on lab groups and not from those who used remote access.

A second interesting variable was surveyed in terms of amotivation, which declined by a total of 16.75%. It is noticeable that the decrease occurred mainly between the first and second measurements (-20.69%), i.e. during the preparatory tasks and during the various laboratory phases (depending on the study group). Afterward, it increased slightly again with a plus of 4.97% (follow-up work, joint report writing). In relation to the minimum (1.00) and maximum (4.00), its values (2.03 (I), 1.61 (II) and 1.69 (III)) are at a rather low level. The self-control groups were able to benefit

more here, recording a decrease in amotivation of 19.91%. In contrast, the other groups show "only" 14.74% less amotivation.

The differences between the various phases described above can be found in both groups (but to a much greater extent in the control group) and also in all scenario variations. Thus, for this variable, there are at least slight indications that the corresponding motivation hypothesis could be correct. Further and more detailed calculations must follow, though, in order for us to be able to make serious statements here, because this is not yet possible with the present calculations.

## 5 Conclusion & Outlook

In conclusion, it should be noted that the creation of the didactic concept based on the requirements analysis and its continuous improvement through the inclusion of further literature and the formative evaluation results worked as previously planned. Accordingly, it was possible to pass on project-specific design recommendations for implementation to the scenarios.

For various reasons, the implementation of the scenarios could not be completed, and thus many recommendations and also many suggestions for improvement that were obtained from the iterative data surveys could not be considered. Among other things, this was due to a lack of time and human resources, but also because the scenarios did not have the structure (time duration, etc.), framework (learning content, learning objectives, etc.), and extent that it would have taken to implement all the ideas. However, it was probably not realistic to expect this, which is why this work step was nevertheless successful in summa summarum in view of the challenges.

Far more problematic were the multi-factorial developments before and during the data collection phase, which will, unfortunately, have the consequence that the results yet to be calculated will, in all probability, have an overall low significance. The first factor to be mentioned here is the small number of probands in some scenarios. This fundamental problem was intensified by the coronavirus pandemic. In general, the pandemic was extremely disadvantageous in terms of test person recruitment and survey planning. This was compounded by the large number of forms of treatment and variables to be considered in the research project, all of which had to be accounted for. In combination with mostly small numbers of probands, it was not possible to plan the survey designs in such a way that the forms of treatment could be cleanly separated from each other. This will have to be considered in the analysis. Here, it will also be exciting to calculate

how strongly self-directed the learners perceived the opportunities in each scenario to be because this perception is considered crucial for the positive effects of the learning method investigated (Ferdinand 2007). Accordingly, in the preliminary stages of the study, it is expected that groups with a higher perception of self-control will perform better on the dependent variables than those with a low perception.

As mentioned above, the outstanding analyses on self-directed learning are expected to be available in March 2022. In the next steps, they will be interpreted in relation to the research questions and hypotheses. If possible, conclusions will be drawn from them.

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## **Implementing Learning Analytics-based Feedback in Online Laboratories—using the Example of a Remote Laboratory**

### Abstract

Laboratory-based learning in practical, lab-based learning environments forms a central pillar of engineering education, as it promotes the practical application of theoretical knowledge and thus supports theory–practice transfer in a particular way. Over the past 15 years, laboratories for use in teaching and research have undergone a rapid transformation. This transformation is primarily reflected in the numerical increase in labs accessible online, such as remote labs, virtual labs, labs supported with augmented reality, or a combination of the aforementioned, which are also known as hybrid, mixed reality, or cross-reality labs. This opens up a wide range of opportunities for data collection, which in turn enables a wide variety of Learning Analytics (LA) applications. The use of LA-based feedback in a remote laboratory-based learning environment will be illustrated using the RFID measurement chamber laboratory at Hochschule für Technik Stuttgart (HFT).

### Key Words

Learning Analytics, Laboratory-based Learning, Engineering Education

### **1 Introduction**

When we use online labs in Higher Engineering Education, a large amount of learning process data could be generated and opened up for LA and the resulting feedback processes. Using an LA-based method to support teachers in providing meaningful feedback in online lab environments to students is one of the goals being pursued as part of the DigiLab4U project and the ways to do this are illustrated by the remote laboratory RFID measuring chamber in this paper. In general, the core of the data collection in online

laboratory learning environments includes usage data from the online laboratories themselves, i.e. the *experiment operation data (EOD)* such as time, duration, number of experiments or attempts, type of experiments, error reports, results data, process data, and in some cases motion data (VR, AR) (see, e.g., Schardosim Simao, Mellos Carlos, Saliyah-Hassane, Da Silva, & Da Mota Alves, 2018, p. 88; Schwandt, Winzker, & Rhode, 2021, p. 121). Laboratory exercises are often accompanied by *learning management systems (LMS)*, which can also supply a wealth of data. The integration of usage data from the LMS provides LA data such as logs, duration, results of quizzes, downloads, reads, access, and usage of learning resources (videos, templates, scripts), activity data (discussions, forums) etc. (see, e.g., Tobarra et al., 2019, p. 2 ; Wuttke, Hamann, & Henke, 2015) In addition, depending on the laboratory and its desired learning outcome, there is also the possibility of using further data sources for LA. like video data on the respective laboratory usage, eye-tracking data or questionnaires (see, e.g., Gonçalves, Alves, Carlos, da Silva, & Alves, 2018a; Ehlenz et al., 2021 ; Heinemann et al., 2020; Heinemann et al., 2022). This promising mix of data and sources, both sensor-based and event-based, enables the use of LA, which generally describes “*the measurement, collection, analysis and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs*” (Siemens & Long, 2011, p. 34). According to Duval, who describes LA as the collection of “*traces that learners leave behind*”, the DigiLab4U project aims to locate those traces in online lab environments to improve learning and teaching processes (Duval, 2012). To address this concern, the following research questions (RQ) were explored in this contribution.

*RQ 1:* What ways do LA provide to support feedback in remote labs?

*RQ 2:* How and at which point in the teaching/learning process should LA be anchored in hybrid learning environments to support feedback processes using the example of the RFID measuring chamber?

In the first step, the purpose of this contribution is to introduce current theoretical insights into the integration of LA in remote labs and to identify what types of feedback are currently provided in remote labs. In the second step, a didactical concept of a remote laboratory-based learning environment is presented and analyzed, with the aim of defining starting points for the use of LA.

## 2 Supporting Feedback Processes in Online Labs with LA

Feedback is a highly use-oriented and complex communication process in higher education institutions and has been identified as one of the most important factors influencing a student's academic achievement (Hattie, 2015, p. 206). Hattie and Timperley were able to identify four dimensions of feedback commonly used in learning processes, which will serve as an orientation for the provision of LA-based feedback in online labs in this contribution. These dimensions include feedback on tasks, feedback in processes, feedback for self-regulation, and personal feedback (Hattie & Timperley, 2007, p. 90). According to Resch, feedback conducive to learning should be constructive, timely, and future-oriented (Resch, 2019, p. 100).

A classic perspective in higher education describes feedback as a way to provide information that is specific to a task or a learning process and bridges the gap between what has been understood so far and what needs to be understood and thereby helps to identify strengths and weaknesses (Ramaprasad, 1983, p. 4). Feedback in this sense aims to reduce the discrepancy between current understanding and performance on one hand and a learning intention or goal on the other (Hattie, 2015, p. 208). It is assumed that the pure information given via feedback is sufficient to change students' own performance actions and that students receive and understand feedback in the same way as the teacher intended (Boud & Molloy, 2013, p. 701).

In higher education processes, feedback is not a one-way form of communication that informs about a gap between a status quo and possible target states anymore; it is imperative to integrate feedback into dialogical processes to support self-help and self-regulated learning (Hattie, 2009). In contrast to assessment, feedback is intended to show observations, perceptions, and potential for improvement. Furthermore, feedback can address learning needs in a timely manner (Resch, 2019, p. 101). The goal is to use feedback in such a way that students gain confidence and motivation to continue learning. We need evidence that students were affected by the feedback, and it must become clear that they are developing their skills and competence in the desired direction. This means that the feedback loop has been closed only when perceivable effects become apparent (Boud & Molloy, 2013, p. 703). Necessary conditions for feedback are the availability of data providing a reference level for a particular determinant (e. g. learning objective), data on the actual level of achievement of a determinant, and a mechanism for comparing the two to obtain information about the gap between the two levels. There can be no feedback if any of the three (data as a reference level, data on an actual level, and a mechanism for comparison)

is not available (Ramaprasad, 1983, p. 6). In order to integrate feedback into the learning process in a meaningful way, learning activities should build upon each other and pursue similar objectives as far as possible. Enough time between two tasks should be given for teachers to prepare the feedback and for students to receive it and to be able to align their own actions with it (Boud & Molloy, 2013, p. 703).

Boud and Molloy name three key features of a sustainable feedback model in higher education (Boud & Molloy, 2013, 706ff). The first one is *the learners and what they bring*. Instructors often experience that students do not take responsibility for their learning process. For this reason, students should experience themselves proactively as learners who can influence their learning process. Feedback in this sense requires active engagement and the feeling of being responsible for their knowledge. When students receive feedback, they have to engage in self-assessment to use this feedback for the improvement of their performance (Nicol, 2009, p. 339). It is essential for students to learn this evaluative capacity. The second one is *the curriculum and what it promotes*. The authors see feedback as a “*key curriculum space for communicating, for knowing, for judging, for acting*” and recommend implementing certain didactical elements to foster feedback, e.g. implementing calibration systems, that enable learners to check knowledge resources or installing learners as both feedback seekers and providers, so that they can practice giving and receiving feedback among other didactical elements (Boud & Molloy, 2013, p. 708). The third feature is *the learning milieu and what that affords*. This considers how the curriculum, with its learning objectives, assessments, and faculty expectations is ultimately implemented because this is reflected in the daily interactions students have with teachers, with their peers, and within the context, in which they operate. This involvement also plays a central role in feedback processes.

In summary, the classic understanding of feedback is more about bridging the gap between what has been understood so far and what needs to be understood in the future and identifying possible individual strengths and weaknesses. This form of feedback can be helpful for less complex tasks and especially for students whose behavior for self-directed learning is still less pronounced (Nicol & Macfarlane-Dick, 2006, p. 7). Feedback processes in Higher Education should not stop here but should increasingly support processes that allow students to self-assess and interpret their performance as well as actively request feedback if required.

What does this mean for the use of LA-based feedback in online labs? Online laboratory learning environments can provide a wide range of data that seems appropriate for sophisticated and data-based feedback processes. Nevertheless, implementing LA-based feedback in remote laboratories poses

further challenges from both a technical and a didactical perspective. From a technical perspective, opening up a real laboratory to digital processes, such as remote control and data collection, requires considerable effort to integrate them into a digital infrastructure for learners' access (Adineh et al., 2022). From a didactical point of view, at least two requirements must be met: the activities of learners must be identified in the remote lab exercise for which feedback is to be provided and meaningful indicators must be identified, visualized, and presented (Pardo, Jovanovic, Dawson, Gašević, & Mirriahi, 2019, p. 129).

LA is already widely used for teaching and learning purposes in online labs in Higher Engineering Education. The following section addresses the first research question and provides insight into current scientific studies in which LA is already being used to support feedback processes.

### *2.1 Results RQ 1*

This section focuses on RQ 1: What ways do LA provide to support feedback in remote labs? A look at the research literature shows that the combination of learning LA-based feedback in online labs is rather new and was first mentioned in professional articles in 2014 (see, e.g., Orduña, Almeida, Lopez-de-Ipina, & Garcia-Zubia, 2014; Tibola, Pereira, & Rockenbach Tarouco, 2014). At this point, the most striking results are presented in the following.

In general, it can be stated that some online labs already use LA to provide automated feedback. A typical use of feedback processes facilitated by LA in online laboratories can be seen in the study by Considine et al., in which the authors analyzed the nature and scope of students' mistakes in a remote lab, where they work with an oscilloscope (Considine et al., 2018). Data analysis of their remote lab usage identified a number of common errors, and building on these findings, Considine et al. developed an Intelligent Tutoring System (ITS). The system provides the students with real-time feedback on their mistakes and delivers support when a certain error is detected, i.e. the error is marked with a red flag and if the student is not able to resolve the error using the hints given by the tutoring system, they can contact a human tutor, who offers targeted assistance. This tutor also has insights into the individual results, and they are able to offer help if required (Considine, Nafalski, & Nedic, 2018, p. 2). In their laboratory, Goncalves et al. use a recommender system that provides similar functions for the provision of real-time feedback as the ITS (Gonçalves, Carlos, Alves, & da Silva, 2018b). Students receive automated feedback on errors that happen in the remote lab. Each error is mapped with a corresponding explanation,

which is displayed to the students. With the help of LA-based feedback in the form of suggestions and recommendations, the aim is to generate valid recommendations to increase students' performance in their laboratory learning activities. In the remote lab of Wuttke et al., automatic feedback is also generated for students as soon as an error is detected by the system. Based on an error database, the most frequent errors were recorded in advance, analyzed, and matched with corresponding automated feedback (Wuttke et al., 2015). This includes feedback for exercises that were completed by the students in the learning management system (quizzes) as well as tasks that involved the remote lab environment (practical handling of the remote lab). In these studies, data analysis is focused on monitoring the logs, acquiring all requests, remote operations, and responses from the experiments. This data is used to build LA-based feedback such as summarizing and analyzing data and providing the results presented as information that may help both students to improve their performance as well as teachers to better understand their students' performance during remote experimentation activities.

In the virtual lab of Castillo, students work together in groups to program a virtual agent. Every two weeks, they receive LA data-based feedback, which includes key performance indicators such as number of attempts, time elapsed, absolute time elapsed, and number of different solutions generated. The feedback is openly accessible, and the students can compare their results with the anonymized feedback of their fellow students. According to Castillo, this information is primarily valuable for the teacher to guide the learning process. For the students, it can be observed that the feedback presented results in changes in team behavior and improvements in their performance (Castillo, 2016). To what extent and how this is expressed in concrete terms is not further explained in the study. Akhtar et al. primarily use feedback based on LA data to inform teachers about the lab performance of their students. They were able to identify two indicators that correlate with performance in the VR lab they researched: attendance and working in groups. Feedback on this can be retrieved from the instructors (Akhtar, Warburton, & Xu, 2017).

Venant et al. developed a dashboard for different complex feedback processes to enable students to reflect on their lab exercises in a mixed reality (MR) lab. Therefore, a dashboard integrated into the MR lab, first of all, provides a *social awareness tool* that reveals current and general levels of lab performance via progress bars and allows students to compare their own achievements to their peers. Secondly, the authors provide a *reflection-on-action tool* that delivers detailed insights into the lab tasks to make the students deeply analyze both their own completed work and the tasks achieved by their peers in greater detail. The third and last tool they implemented is a

*reflection-in-action tool*, a live video player which makes it easy for students to observe what their peers are doing and how they are operating the lab (Vidal, Venant, & Broisin, 2017).

In addition to Venant's already very elaborate results of LA-based feedback, several online labs exist in which LA are used primarily to provide teachers with feedback on their students' online-lab usage, such as date, start, end of the experiment, number of uploads, measurement results, number of operations, and for lab initiatives especially IP addresses, country, or timestamp. The first step here is to collect the data and assess its suitability for further feedback processes. For teachers, this data can already provide interesting feedback about the use of the lab, common errors, and the studying behavior (e.g., cooperation, study regularity, etc.) of their students (see, e.g., García-Zubía et al., 2019 ; Schwandt et al., 2021).

What is missing are findings about whether and how students use the feedback provided for their learning process. Equally lacking is more complex feedback that corresponds to the needs of Higher Education processes, such as fostering processes that stimulate the learners' disposition to seek feedback and take responsibility for their own laboratory-based learning processes. Some approaches seem very promising in this regard; however, no research is yet available on students' reception and concrete usage concerning reflection tools (see, e.g., Vidal et al., 2017). What is not currently clear from the studies, with some exceptions, is the extent to which LA-based feedback is used as the basis for individual, pedagogical interventions or F2F conversations between teachers and students. Are these taken as an opportunity to contact the students involved or is this not feasible due to large study cohorts? Table 1 shows an overview of feedback processes in labs. The structure is oriented on Hattie's recommendation for feedback (Hattie, 2007) The diverse data collection in laboratories offers many opportunities for feedback processes. At this point, the question arises as to what extent more complex dialogical feedback processes can be stimulated with the help of LA in the future. This includes feedback for *self-regulation* and *personal feedback* processes, which are currently underrepresented in laboratory-based learning processes.

Table 1 Feedback in laboratory-based learning processes

Study	Feedback on tasks	Feedback on processes	Feedback for self-regulation	Personal feedback
Wuttke et al., 2015	x	x		
Castillo, 2016	x	x	x	
Akhtar, Warburton, & Xu, 2017	x			x
Vidal, Venant, Broisin, 2017	x	x	x	
Considine et al., 2018	x	x		x
Gonçalves, Carlos, Alves, & da Silva, 2018	x	x		

While learning scenarios mediated via technical systems are often easily outfitted with LA data collection capabilities, real-world F2F learning is more elusive. One way to bridge this gap is by recording learning activities on video and manually annotating them later, using tools such as the one presented by Heinemann et al. (2022). Another way to access hybrid lab environments lies in the use of multimodal learning analytics (MLA). The sources or modalities in MLA include data resources that are easily available, like log-file and learning data from lab environments and learning management systems, but also learning artifacts and natural human signals such as gestures, gaze, speech, or writing. As learning is always a multimodal activity, MLA aims to analyze, understand, and optimize learning by capturing traces of the interactions occurring in each of the relevant modes (Ochoa, 2017). In the future, this opens up the possibility of developing LA-based feedback processes likewise for traditionally non-digital learning scenarios.

### 3 Example of Implementing LA in an RFID Laboratory

In this chapter, we present the integration of LA as part of feedback using a concrete example. First, we will explain this and then show the first results of the work done so far.

### 3.1 The lab RFID measuring chamber setting

The RFID measuring chamber at HFT Stuttgart is a test environment for RFID UHF tags. RFID technology is a key technology in logistics, as it makes warehousing and the movement and trafficking of goods transparent. To learn the correct use of the RFID measuring chamber, students are given an industry-specific use case to learn the background knowledge, the practical use of the chamber, and the interpretation of the results. The students work together in small teams and should gain multifaceted experiences which help them to know, remember, and explain the technical use and handling of the measuring instruments and to apply, analyze, and evaluate selected RFID measurement values to optimize the use of RFID for a certain use case.

The laboratory exercise proceeds in different phases, and LA data collected in different phases and partly prototypical scenarios can be checked in terms of its relevance for feedback processes. This is illustrated by the developments for the example of the RFID measurement chamber laboratory exercise and the following table. In addition, the phases of the laboratory exercise in the summer semester of 2021 were examined with the aid of qualitative content analysis to determine which problems and difficulties were encountered particularly frequently.

Table 2 Analysis grid of the laboratory exercise

Lab phases	Lab exercises and activities	Social format	Most common problems	Data acquisition
Introduction	Pre-test	Single	lack of basic knowledge in physics	Test results
	Access to all learning resources via LMS	Single	Learning resources provided are not used,	Login data, access numbers, downloads, forum usage, time
	Preparation task: generating a hypothesis for their practical remote lab exercise	Group	Terminology is used incorrectly, Basic knowledge of laboratory measurements is not known	# of uploads, time with LMS tap inactive (# of unfocused) data about video usage, e.g. # of video starts

Lab phases	Lab exercises and activities	Social format	Most common problems	Data acquisition
Lab experiment	Preparing their remote lab exercise with a VR application of the RFID measuring chamber	Single	-	VR motion profiles; duration; # of performed measurements, non-verbal gestures, gaze, log data, like controller interactions
	Conducting a laboratory exercise with the remote laboratory	Group	Interpretation of measurement results is often incorrect: Graphs are interpreted incorrectly (terms, correlations), the correlation between RFID tag and substrate is not explained correctly, Difference between measurements cannot be explained;	EOD of the remote RFID measuring chamber, # of performed measurements, and video recordings, which will be annotated
Documentation and presentation	Creating a test report	Group	Errors that were already evident during the practical laboratory exercise are reproduced.	Uploads: time, # of uploads, scope
	Post-test	Single	Measurement results are not interpreted correctly (missing terminology, wrong correlations, lack of physical knowledge); partly incorrect terminology;	Test results

### 3.2 Results RQ 2

RQ 2 is dedicated to the question of how and at which point in the teaching/learning process LA should be anchored in hybrid learning environments to support feedback processes—using the example of the RFID measuring chamber.

The preliminary tests conducted to check the LA visualizations for the Introduction phase were mainly done so with educators. In order to generate testable LA results for this step, we added possible and artificial data in addition to the data accrued. The overall results of the discussions with the educators are in line with Herding (2013) and Martinez-Maldonado et al. (2020), for example, the indicators relating to requests, logins, and learning material access are relevant for educators in digital labs, which was also shown by Dyckhoff et al. (2012) for fully virtual learning environments. Fig.1 shows a visualization related to that content. Our test showed that educators ask for the ability to filter according to the previously achieved e-test

score, which could help to get an overview of the current learning situation and the preparation of the students. The result, namely enabling teachers to give students feedback on their own learning situation, is considered to be valuable for the students by the educators questioned.



Source: LMS

Figure 2 Most used resources and visited pages

The Lab experiment phases provide interesting data for a multimodal view of the learning process. The correct physical explanation of the measurement processes and the interpretation of the data (see Table 2) especially are central problems in the laboratory exercise, which can be reflected with the help of LA feedback. The remote measuring chamber and the VR version provide a wide range of possible indicators. The VR version is guided by a digital avatar that communicates verbally with the learners. To provide feedback about the quality of instructions to the educators, we implemented a data collector that can recognize gestures such as a nod of the head, as this can express understanding. If this data is linked to the learners' interactions, it is not only possible to analyze the learning process. We can also use this data in future versions to give immediate feedback to the learners and be more flexible in responding to prior knowledge. Let's stay with the example of the RFID measuring chamber. If a learner does not respond to an instruction from the robotic assistant, the system could recognize this and offer further assistance, e.g. highlighting the possible interaction spots. The opportunities of multimodal LA in the context of hybrid labs and the

technical implementation of the architecture have already been described in Pfeiffer et al. (2020).

LA could be used in the documentation phase in different ways. Following the conceptual model of the tutor-in-the-loop approach, which is described in detail in the dissertation by Herding (2013), it is possible to use logs when students request feedback and to get insights into their course-wide performance. To obtain good support for feedback through LA in the final phase of multifaceted courses such as the HFT measurement chamber, other factors must be considered in addition to a user-centered approach. What prior knowledge do teachers and students have and what ways are there to use the various data streams for a helpful visualization of the course-wide learning process? To work on these questions in more depth, we will continue with a HCLA development process (see Shum et al., 2019).

To answer RQ 2, the evaluation results of the summer term 2021 can also provide first indications of where to anchor the LA-based feedback. For the preparation phase, the *quiz results*, the *time spent on task*, and the *downloads* are, for example, helpful for a first estimation and assessment of who has adequately prepared for the laboratory exercise and who might have knowledge gaps for the subsequent laboratory exercise. These results should be understood as preliminary, as the numbers of participants were too low ( $N = 37$ ) to obtain meaningful results. Nevertheless, as far as the integration of LA-based feedback is concerned, the evaluation results can provide first indications of where the feedback should be anchored.

To conclude, there are different ways to integrate LA into the learning process and to support it with multimodal feedback. First, answers to the question of how to integrate LA into the feedback process are given, as is an analysis of the different times at which LA can be used.

## 4 Conclusion

The employment of LA-based feedback, as in many other LA fields, makes it clear that one size does not fit all. To provide LA-based feedback, it is necessary to adapt LA to laboratories and the objectives they pursue as precisely as possible. What is the intended learning outcome of the lab exercise? Where do students exhibit problems? What is the nature of these problems etc.? A detailed look into the implementation and use of LA in an increasing number of online labs makes this observable.

The process described in this paper shows the ways of generating LA-based feedback in a laboratory-based learning environment. The next step will be to exploit the potential of combining digital traces captured by

technology mediation via LA in online labs with teacher knowledge and expertise to provide frequent and personalized feedback messages for the students using the remote lab. This will happen in the summer term 2022 when a further evaluation of using LA-based feedback in the remote lab will be conducted.

This research has some limitations: one is that the student cohorts undergoing the RFID laboratory exercise are relatively small for LA investigations and can only reveal developmental trends at this time, if at all. Nevertheless, providing access to the remote lab via a lab network is planned, so that higher numbers of participants can be expected in the future.

## Acknowledgements

This work has been funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding codes 16DHB2112 & 16DHB2114.

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## 2 Educational Chapters (Didactical Considerations)



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## **Universal Design & Personalization for Smart Homes – Concepts**

### Abstract

This learning unit teaches the concepts of Universal Design and Personalization in the context of smart homes. Practical assignments include the study of personas with disabilities, and the specification of preference profiles for users with disabilities, using the OpenAPE framework notation (based on ISO/IEC 24752-8).

### Keywords

Accessible design, Personalization, OpenAPE

## **1 Preface**

The first Learning unit provides the fundamental knowledge of universal design & personalization in smart homes.

The module first starts with an explanation and proof of why there is a special need for smart home devices for the elder generation.

After that the students will be introduced to Universal Design: As every human is unique, there is a large variety of user needs when it comes to interaction with electronic devices, which need to be identified and addressed.

After getting to know how to do proper User research, we will discuss how a website can automatically adapt itself as well as be manually adapted to the user's preference. This adaptability is called "Inclusive Responsiveness".

Finally, we will get a brief introduction to the OpenAPE framework, so that we can experience how a user preference can be described technically.

To strengthen the acquired knowledge, the students will have to complete 2 assignments: In the first assignment, the students are asked to create a persona profile by using the online tool "PersonaGenerator" (<https://personagenerator.com>) and identify the needs of their persona. The solutions should be uploaded onto the platform, where the course is held. In

the second assignment the identified needs should be met by creating an OpenAPE profile with the desired preferences of the persona. As part of the second assignment, the created preferences should also be embedded into the “Barrierfree Smarthome” App.

### 1.1 Didactic fundamentals

- Target group: Computer science students with prior knowledge of programming.
- Effort in lecture hours: 60 minutes theory, 180 minutes practice
- Effort for self-study material: approx.. 20 minutes
- Prerequisites: Computer, Android smartphone, tablet or emulator with the already downloaded app “Barrierfree Smarthome”
- Needed background: Basic knowledge in HTML/JavaScript
- Additional information: The students need an account on the OpenAPE Webservice (<https://openape.gpii.eu/>) and on the Term-Registry Service (<https://terms.gpii.eu/>).

### 1.2 Learning Objectives and Competences

There are 3 main learning goals of this learning unit:

- To understand the basic needs of persons with disabilities in interacting with a smart home.
- To know the basic principles of accessible design and adaptive user interfaces.
- To understand the purpose of the OpenAPE framework and how to describe user preferences with it.

## 2 The need for smart homes

### 2.1 Why are smart homes so important for elderly people and people with disabilities?

Initially, smart homes were primarily designed to increase security at home and to reduce energy costs e.g., by installing smart meters. Through constantly improving technologies, the concept of smart homes is now expanding its focus on enhancing the overall quality of life. This has especially made a big impact on the everyday life of elderly people and people with disabilities, as their functional capabilities are quite limited. Loss of vision,

hearing or mobility affects the way people function in their daily lives, and naturally, no one wants to have to rely on the constant assistance of others. Smart home tools are designed to adjust the environment to the special needs of the homeowner and grant him the chance of freedom and to preserve his dignity.

## 2.2 *Smart home market in Germany*

A decade ago, a smart home seemed like a luxury item and out of reach for many. Nowadays, thanks to advancements in modern technology, assistive systems are more easily accessible to the middle class. In 2019 the revenue in the smart home market was approximately € 3,580 M. According to the forecast, a market volume of € 6,963 M will be reached in 2023; this corresponds to an annual revenue growth of 18.1%. The penetration rate was 19.9% in 2019 and is expected to reach 34.5% in 2023. The average revenue per existing smart home is currently € 163.72. A global comparison shows that the most revenue is generated in the USA.

## 2.3 *Market driver*

What are the reasons that the smart home market is trending more and more in our everyday life? There are 5 main factors, that lead to the success of smart home systems:

**Digital networking:** More and more households have some sort of access to the internet (e.g., through Wi-Fi) and at the same time new, mobile device categories are created and distributed. Therefore, tablets and smartphones are now used as a new operating solution for smart home applications.

**Demographic trends:** Life expectancy is growing year by year, making society increasingly aging. Simultaneously, the numbers of single households and single parents are also growing. These two phenomena create a potential for digital health- and surveillance solutions.

**Home lifestyle:** Especially because of the corona pandemic, the importance of one's own home has increased, as more and more people were made to stay at and work from home. This "Cocooning"- Trend has led to a growing willingness to pay for smart home devices and services.

**Environmental awareness:** The importance of sustainability has steadily increased in the last few years. People are trying to reduce their energy costs by increasing the energy efficiency of their homes, for example by renovating their homes. The Home Automation market benefits from the sustainability trend.

**Ambient assisted living (AAL):** With aging, there come various issues about health and social isolation. Elderly people want to maintain their dignity and live as independent as possible, this lead to an increase in interest in AAL-Systems.

### 3 Universal design and variety of user needs

#### 3.1 Definition of the terms “smart home” and “AAL”

Smart home is defined as the intelligent networking of individual components within the house (hardware and services)) and their central control and monitoring via end devices. A smooth interaction of the various components is key to a pleasant user experience. Typical components of a smart home are for example smart heaters, lights, switches, and doors.

AAL (Ambient Assisted Living) is an intelligent system, that assists elderly people in a better, healthier, and safer life. It covers concepts, products, and services, that interlink and improve new technologies. AAL systems can support the older generation in different parts of their lives:

- **At work:** With an improved quality of work, the senior worker will remain active and productive for a longer time.
- **In the community:** Through ICT (Internet Communication Technologies) solutions, elderly people can stay socially active and creative.
- **At home:** Assisted by technology, older people can maintain a high degree of independence, autonomy, and dignity and therefore enjoy a healthier and higher quality of daily life.

#### 3.2 User profiles & features

User profiles provide the basis for the design of the user interface of a product. With the help of user profiles, personas and use cases can be created, which lead to a more focused product development: Which tasks are important for a particular user? What are his assumptions and expectations of the product?

To answer these questions and to create an accurate user profile, comprehensive user research is needed. Some possible ways to access valuable information could be:

- Choosing target groups
- Interviews, questionnaires
- Participatory observation

- Demographic surveys:
  - Public data
  - Market research
  - Field studies
- Workshops with user experts and developers, e.g.:
  - Market researchers, sales, marketing, usability specialists, technical support
  - Designers, programmers, system architects
  - Project manager

Finally, after finishing user research, various information about the features of possible future users should have been collected. They can be classified into different categories, like:

- **Demographic data:** age, income, cultural background
- **Profession:** working experience, working conditions, job position, size of the company
- **Technical Affinity:** computer usage, internet connection, and usage, experience with technical devices, decisionmaker for technical acquisitions
- **Environment:** a place of usage (at home, at work, ...), time of use, usage with additional tools/products
- **Lifestyle:** morals and beliefs, usage of media, leisure activities, hobbies
- **Roles:** professional titles, training, relationship to other users
- **Goals:** motivation to use the product (or not), long-term impacts
- **Wishes and needs:** reasons for use, emotional needs, preferences, habits
- **Knowledge:** expert knowledge, product knowledge, knowledge of competitive products
- **Trends in use:** frequency of use, reasons for purchase, brand awareness, loyalty
- **Tasks (user's perspective):** frequently used tasks, critical tasks, special sequence-order of tasks, traditional processing of tasks (without product)
- **Restrictions/impairments:** Access to data while driving, people with vision-impairments prefer speech output for long documents

### 3.3 User needs

As every human being is unique, there is a big variety of impairments that bring along different kinds of user needs. These impairments can be categorized into 4 groups:

### 3.3.1 Visual impairment

There are various forms of visual impairments, which range from complete loss of vision in both eyes (blindness) to minor or moderate loss in one or both eyes (low vision). Other visual impairments include heightened sensitivity to brightness (light sensitivity) and the opposite: lowered sensitivity to colors (color blindness).

People with visual impairments require different types of aids to succeed in various tasks: Minor visual impairments like near-sightedness and far-sightedness can be corrected with glasses and contact lenses, while interacting with mobile devices with customizable interfaces like high contrast mode or alternative color palettes support a larger variety of people. Some key needs related to vision when designing for the web are brightness, color, perception, spacing, highlighting, and user customization. In addition, to the customization of the User Interface there are also assisting tools a visual impaired person could use:

- Screen readers that transform the text into speech.
- Refreshable braille displays which put text into tactile feedback.

### 3.3.2 Hearing impairment

Hearing impairments are sensory disabilities that range from partial to complete hearing loss. Hearing loss is unique to each person and varies in frequency and loudness, which is why there are 5 degrees of hearing loss established:

- People with normal hearing can hear soft sounds below 25 dB, like whispering.
- People with mild hearing loss are unable to hear sounds that are quieter than about 25-40 decibels, which is why noisy environments can be challenging to them.
- People with moderate hearing loss hear sounds lower than about 40-70 dB. They often need to ask people to repeat themselves during conversations one-on-one.
- People with severe hearing loss cannot hear sounds lower than 70-95 dB for example speech and music.
- People with profound hearing loss cannot hear anything below 95 decibels and can only hear loud sounds like drums or an airplane taking off.

To reduce the barriers encountered by people with an auditory disability you basically need to provide important audio information in another form, such as visual or tactile interfaces. Possible solutions and tools are

for example hearing aids, captions and subtitles (spoken dialogue), speech recognition (speech-to-text), visual signs (warning lights), and sign language.

### 3.3.3 Motor impairment

Motor disabilities affect a person's ability to move around, manipulate interfaces or lift heavy objects. Disabilities in this category include the absence of limbs, full or partial paralysis, or reduced muscle capacity. Common challenges for persons with motor disabilities include for example:

- Inability to use a mouse.
- Inability to use both mouse and keyboard.
- Risk of fatigue when using assistive technologies.
- Inability to physically interact with hardware devices.
- Voice activated software could be challenging for some.

There are many solutions that allow persons with different types of motor disabilities to use the web; most of them work through a mouse, keyboard, or touchpad interaction. Examples include a mouth stick, a head wand, an adaptive switch or keyboard, an oversized trackball mouse, eye-tracking, and voice recognition software.

### 3.3.4 Cognitive impairment

While there is a range of different cognitive impairments with specific characteristics and needs, all issues with cognition concern the ability to take in and understand information. Therefore, there are quite a lot of common needs when it comes to web accessibility, for example:

- **Recognition:** As for some people it can be challenging to concentrate both on the content and the design of a website, it is important that the website is structured in a recognizable way so that the user can focus on the content.
- **Coherence and clarity in both structure and content:** Structuring a website's design and content in a logical way helps the user to concentrate and focus on the most important information.
- **Multimodality:** A combination of different modalities, for example adding images to a text, makes it easier for a user to understand the information that is presented.
- **No distraction:** The more elements a website is filled with, the more the cognitive load increases. Users who find it difficult to sort out information will find it challenging or even impossible to concentrate on the

content if there are too many elements on a website, such as banners, pop-up windows, etc.

To increase cognitive accessibility there are a few examples of support tools such as text-to-speech solutions that read out the text on the screen, a screen mask that helps to put focus on the text, and a tool for symbol support that provides images that explain words and concepts further.

### 3.4 Scenarios

A scenario is a concrete description of a hypothetical chain of actions from the user's perspective. Ideally, a scenario should describe what a user is doing, what his motivation is, and what he expects. The scenario is based on a specific Persona and presents its daily life routine.

A scenario can be presented in various formats such as:

- Textual description (analysis phase):
  - Step-to-step demonstration and description of main functions and tasks.
- Enriched with sketches (design phase):
  - Interaction design based on use cases, detailed for every step.
  - Illustrated by sketched user interfaces, images and screenshots.
- Storyboard or comic form
- Video (optionally with actors)
- (Mock-up-) Prototypes

Scenarios should be written in a way of storytelling, so the readers can relate to the persona and understand its actions.

## 4 Guidelines on accessible design

### 4.1 The three accessibility guidelines

When designing for digital devices or applications it is important to think of ways to enable access for everyone. The World Wide Web Consortium (W3C) is an international community that develops standards for the web. In 1997, W3C launched the Web Accessibility Initiatives (WAI), which provides guidelines, standards and techniques for accessibility.

The WAI has created three core guidelines for web:

- **Web Content Accessibility Guidelines (WCAG):** This is the most known guideline, as it is an important source of reference for international policies, standards, and legislations. It addresses the information on a website, including text, images, forms, sounds, and such.
- **Authoring Tool Accessibility Guidelines (ATAG):** Addresses software that creates websites.
- **User Agent Accessibility Guidelines (UAAG):** Addresses web browsers and media players and relates to assistive technologies.

Every guideline provides four layers of guidance for UX designers. At first, principles provide the foundation for web accessibility and build the top layer of guidance. Each principle has specific guidelines which provide the basic goals that designers should work towards. With every guideline there comes a set of testable success criteria to verify accessibility for a web application or website. These criteria have 3 different success levels: A, AA, and AAA, whereas A is the minimal level. For each of the guidelines and success criteria, there are a wide variety of sufficient and advisory techniques for meeting the success criteria.

Web Content Accessibility Guidelines 2.0 follows 4 main principles, which provide 12 guidelines altogether:

- **Perceivable:** Information and user interface components must be presentable to users in ways they can perceive. This principle includes four guidelines: Provide text alternatives, alternatives for time-based media, create adaptable content, and develop distinguishable content.
- **Operable:** User interface components and navigation must be operable. It also has 4 guidelines: Make all functionality keyboard accessible, provide enough time to read and use content, prevent designs that can cause seizures, and at last make your website navigable.
- **Understandable:** Information as well as the operation of the user interface must be understandable. This principle has only 3 guidelines, which state that you should make text content readable and understandable, make web pages appear and operate in predictable ways and you should help users avoid and correct mistakes.
- **Robust:** Having only 1 guideline, this principle determines that content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

The Authoring Tool Accessibility Guidelines 2.0 has two main parts:

- Part A is about making the authoring tool itself accessible.
- Part B is about the authoring tool helping authors produce accessible content.

Software and services, that authors of webpages use to produce web content are called authoring tools. These include for example:

- Web page authoring tools like HTML editors
- Software for generating websites. For example, content management systems (CMS)
- Software that converts to web content technologies like word processors.
- Multimedia authoring tools
- Websites that let users add content as for example, social networking sites do.

UAAG documents explain how to make user agents accessible to people with disabilities. User agents include browsers, browser extensions, media players, readers, and other applications that render web content. Following UAAG 2.0 improves accessibility through the user agents' own user interface and its ability to communicate with other technologies, including assistive technologies.

UAAG 2.0 follows 5 main principles:

- **Perceivable:** Ensure that the user interface and rendered content are perceivable.
- **Operable:** Ensure that the user interface is operable.
- **Understandable:** Ensure that the user interface is understandable.
- **Programmatic access:** Facilitate programmatic access to assistive technology.
- **Specifications and conventions:** Comply with applicable specifications and conventions.

## 5 Assignment 1: Persona Presentation

### 5.1 Intro

You are a member of the founder team of a start-up that wants to build new smart home gadgets for elderly people. Before you start with the production of the gadgets, you need to do fundamental research on user needs and pre-

ferences. For that, you will start by creating representative Persona profiles and possible use cases.

## 5.2 Tasks

1. Choose one elderly person from the CURE personas. There is a document with linked CURE personas in the course.
2. Use the online tool PersonaGenerator (<https://www.personagenerator.com>) and create a persona profile for your chosen person
3. Make a presentation on the selected persona with the following content:
  - Introduction to the persona
  - Bad examples: Current smart home features that result in bad usability for the persona.
  - Use case/scenarios: In what ways could the persona benefit from a smart home?
  - Good examples: How does a smart home need to be designed to be most usable by the persona?
4. Upload your PowerPoint presentation on Moodle.

## 6 Inclusive Responsiveness

### 6.1 Definition of “responsive”

Adaptability is key for good interaction between the user and website. A website must be both: adaptable and adaptive. While being adaptive ensures that the system automatically adapts its content to some specific features of the user’s medium (e.g., to the screen size), being adaptable gives the user the opportunity to adapt the website to his own needs and preferences (e.g., bigger font size).

Adaptability ensures that a website is responsive to the user's input.

### 6.2 Definition “context of use”

Context of use describes the circumstances under which the user is interacting with a website. There are four main components of context of use: The user himself, the tasks, the equipment, and the environment.

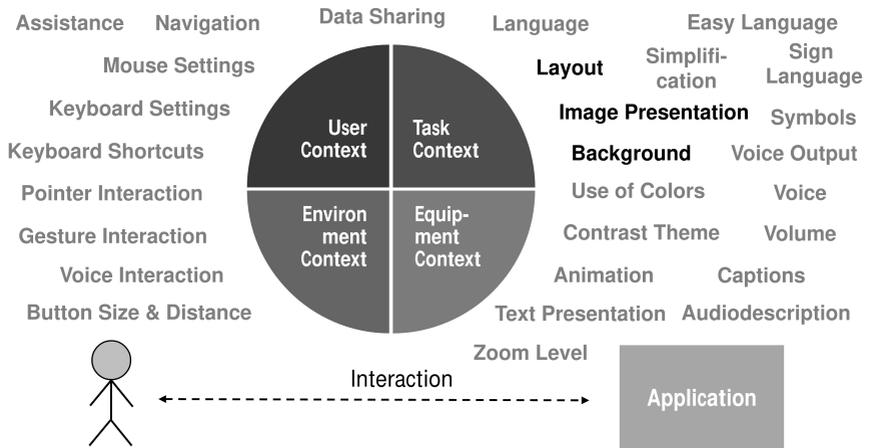


Figure 1: The four main components of context of use.

**User Context:** What are the user's preferences and needs?

**Task Context:** What is the user trying to accomplish?

**Equipment Context:** What input and output devices the user is using?

**Environment Context:** What situations is the user in?

### 6.3 Responsive web design (Equipment Context)

Websites can be reached from different kinds of electronic devices, e.g., smartphones, tablets, and computers. One of the main differences between them lies in the variety of their screen sizes. To ensure a pleasant User experience, it is important to adapt the content of the website to the screen

size of the user's device. This can be done through responsive web design, which is based on a dynamic grid, flexible images, and CSS media queries.

In order to display the website optimally on every device, the conditions of the respective output medium are requested in detail through media queries. Whenever a "breakpoint" is reached (e.g., by enlarging the font size), the web browser should instantly switch to a different layout at runtime. Images are dynamically sized by relative units, e.g., percent.

The following adaptations can be implemented with the most recent CSS media queries level 4:

- **Layout & Background:** Most prominent aspect of responsive web design.
- **Imagine presentation:** Choice of image type being rendered, depending on resolution and color mode of the screen.
- **Navigation:** Switch between different navigation mechanisms, e.g., full-blown menu navigation vs. Iconized menu button (sometimes called "hamburger menu").
- **Button size, spacing, and alternate pointing interactions:** Enlarge buttons and other input elements, increase the spacing between them when the pointing device is inaccurate; provide alternatives for pointing when there is no pointing device available; provide alternatives for activation of hovering effects when hovering is not possible.
- **Substitute animations:** For screens, that cannot refresh quickly, animations can be replaced by other means.

#### 6.4 Personalization (User Context)

To meet the needs and preferences of the user interacting with the website, the application is required to allow custom changes by the user. Personalization can go as far as providing full accessibility by accommodating the specific interaction needs of a user with disabilities.

Simple presentation parameters which can be personalized on most websites are for example font size, color, and type. However, when looking at the full range of users with and without disabilities, there are more interaction aspects that should be subject to change for particular users:

- **Line height:** Some users may need to have an extra space between text lines.
- **Speech output:** Some users (e.g., users who are blind, who are dyslexic, who are analphabets, who are reading a foreign language) may want to have the text be spoken to them rather than having to read it. For speech output, they will want to control parameters such as volume, speed, and

pitch. Also, some users may want to have the text highlighted as it is read aloud. Highlighting granularity can be set to word, sentence, or paragraph level.

- **Size and distance of input elements:** Some users (in particular those with manual motor impairments) may prefer to have input elements and buttons increased in size and be farther apart from each other. This will make it easier for them to hit them with a pointing device.
- **Navigation:** Some users with cognitive disabilities may need a simplified navigation tree, with fewer items. Users with motor disabilities may prefer a “button matrix” rather than a navigation menu. The matrix of buttons can be quicker operated switch access interface.
- **Layout:** Some users may not want to switch the orientation from portrait to landscape (or vice versa) even when the mobile device is tilted.
- **Simplification:** Some users may need a simplified version of the content, or specific words and symbols to be explained in simple language.
- **Sign language:** Users who are deaf may prefer to receive information in sign language, and to provide input by signing in a specific sign language.
- **Symbols:** Some users may need text to be translated to symbols, or specific words to be translated to symbols for a better understanding.

There are many more settings a user could set, making the personalization experience overwhelming or intimidating to some users. Also, some settings may not be available across all applications and platforms, which means that they need to be set manually on every single application and device. This process can be very time-consuming, and users would start rethinking whether before using a website whether the effort is really worth it or not.

Therefore, an adaptable application should provide an easy and understandable way for new users to set up an initial user profile. Some possible ways to set up a user profile could be:

- **Step-by-Step dialog:** A dialog guides the user through all settings, that are relevant for them, e.g., choosing a type of disability ("I am vision-impaired") or a type of requirement ("I need to get the screen read out loud").
- **Serious games:** Rather than filling out difficult forms, a user could "joyfully" set up an appropriate interaction profile by playing a game.
- **Pre-defined user profiles:** For the beginning, the user could choose a pre-set personal profile that fits approximately their abilities and preferences. Then, as they get along with the application, they can fine-tune their profile as needed later. Such pre-set profiles can be derived from user research and personas.

### 6.5 Context queries (Environment Context)

In order to respond to the environmental context, the system is required to sense the situation in which the user interaction is taking place. Typical parameters that drive such an adaption are date/time, location, ambient light and noise, movement, screen positioning, bandwidth, and connection (e.g., cellular vs. Wi-Fi). Since the environmental context is more likely to change during a user interaction session (e.g., ambient light changes), web authors need to embed dynamic adaption mechanisms, which can be a challenge.

Built-in sensors provide a constant stream of situational data, which triggers adaptations on the operating system level. On the web application level, most of these sensor data are not easily available. Therefore, new web APIs allow web authors to query the state of device sensors that provide information on the specific environment.

These are some rendering solutions for different kinds of environmental situations:

- **Night mode for image rendition:** At nighttime, an image may be rendered in a “warm temperature mode” by reducing the amount of blue color that can be unhealthy and delay falling asleep at night. Although a night mode is available on some devices on the operating system level, employing it on a web application level gives the web author more fine-grained control over the scope and effects of color filtering.
- **Seasonal layouts:** Web applications may appear in different layouts, depending on the season of the year. This requires web authors to react to changes in date/time and location.
- **Ambient light-sensitive themes:** In environments with very high ambient light (e.g., in the sunlight), it can increase the ease of reading when choosing a theme that inverses colors (e.g., black on white rather than white on black). Also, in very low ambient light conditions, the user’s eyes may be strained when using a theme with a lot of white background.
- **Enlarge input elements when moving:** The web author may increase the size of input elements when they sense that the user is moving, to make up for a potentially shaky environment.
- **Location-based content:** Web content that is specific to a physical location (e.g., a public library) can be presented more prominently when the user is in close proximity.

- **Bandwidth-driven image resolution:** When the connection speed is constrained by low bandwidth, low-resolution images may be loaded to reduce the waiting time for the user.
- **Saving energy on low battery status:** When the battery reaches a low level, the web application could be more energy-conservative by switching to a low-light theme. Note that many devices today have an OLED screen on which black pixels do not consume any energy.

## 6.6 Task Context

Adapting to the task context is the easiest exercise of the four types of adaptation. Most web applications are made to facilitate a set of tasks from which the user can select. For example, an online shop allows the user to browse the shop items, read their descriptions, put them into a shopping card, and finally check out. There may be supplemental tasks offered such as contacting customer support. Whenever the user – by navigation – selects a specific task or subtask, the web application adapts by changing the content of the web page. This is one of the most basic functionalities of a web application, and it follows right from the first dialogue principle, the suitability for the task. A web application may also react to task changes in a subtler way. For example, on the check-out page, when the customer selects the payment type “credit card”, input fields for the credit card number and expiration date (which were previously hidden) become visible on the page.

Applications reach their limits when the user tries to achieve a task for which they are not made. For example, if the user tries to solve complex mathematical operations in a text processing application, it could inform the user that it is not suited for this kind of task, and (for good usability reasons) ask them if it should start a spreadsheet application and embed the spreadsheet in the text document. So, although most web applications handle the basics of adapting to the task context, there is still some leeway in making this adaptation even better for the benefit of the user.

## 7 OpenAPE framework

### 7.1 What is OpenAPE?

OpenAPE is an open Accessibility and Personalization Extension framework that transfers platform-independent context information from one device to another and infers personalized settings for user interface and device

adaptation according to the user's needs. This shall contribute to improved usability and accessibility in smart environments.

Development goals of OpenAPE:

- Enable a platform-independent mechanism to transfer the context of the use of data from one device to another.
- Provide adaption and UI settings information independent of place (e.g., in every room of a smart home)
- Enable third parties to contribute specialized content.
- Provide specialized content independent of place.

## 7.2 Use cases

Let us think about a visually impaired businessperson from Germany. In Germany, he is living in his own apartment equipped with different devices like a smart TV, a lighting system, and a smart heating system. He has configured his home in a way, that when he switches to TV mode the TV is switched on and the light is dimmed down. He has also set a preferred room temperature. He can control the status of his home via his smartphone. The smartphone is configured with a large font size and strong contrast.

Now, the businessperson must travel to China. When he arrives in his hotel room, he immediately notices that the air-conditioning system has cooled the room too much. He approaches the control panel at the wall that is connected to the OpenAPE infrastructure. The businessperson authenticates himself via an RFID tag and the panel connects to the OpenAPE infrastructure to look up the user's preferred settings. Among other information, there is stored that the user has configured their smartphone with a larger font size and stronger contrast and that his preferred language is German. Therefore, the control panel reads aloud a short welcome message with some basic explanations. It also increases the font size and contrast and downloads all text labels for the UI in the German language.

Furthermore, it proposes the user's preferred room temperature.

Some weeks later, a deaf person stays in the same hotel. For him, there are no adjustments made regarding font size and contrast. However, since the person has problems with written language, for him the welcome message and all help texts are displayed as sign language videos.

## 7.3 OpenAPE Context service

A context as a JSON-Format is a list of references to Terms you would like to give values to. The OpenAPE Context service is an online catalog

of contexts. The prefix you should always use to refer to a term on the Term-Registry service is: <http://terms.gpii.eu/> and add it with the name of your desired term. The Context service is available at: <https://openape.gpii.eu/>

```
{
  "default": {
    "name": "Default context",
    "preferences": {
      "http://terms.gpii.eu/screenLockTimeout": 600
    }
  }
}
```

Figure 2: Example OpenAPE context.

#### 7.4 Term-Registry-Service

A term is a keyword to describe an "atomic" aspect of the adaption or of a specific context. The Term-Registry-Service is an online catalog of context-specific preference terms. You can select already registered terms or register new ones. The Registry Service is available at: <https://terms.gpii.eu/>

There are two terms to be classified:

- Common terms:
  - Generally reusable beyond application and platform boundaries.
  - Example: `common_fontSize`
- Application-specific terms:
  - Specially intended for one application, not generally usable.
  - Example: `myApplication_alarmMode`

```
{  
  "$schema": "http://json-schema.org/draft-06/schema#",  
  "title": "Screen lock timeout",  
  "description": "No definition available.",  
  "type": "number",  
  "minimum": 1  
}
```

Figure 3: Example term of the Term-Registry-Service.

## 8 Assignment 2: Create an OpenAPE profile

### 8.1 Tasks

1. In assignment 1 “Persona Presentation” you have successfully created a persona for one of the 30 elderly CURE-Profiles.  
Now, you are asked to create an exemplary OpenAPE profile for your previously selected persona. Think about the possible preferences and needs of your persona and provide a solution by setting a specific user context.  
Link to the OpenAPE-Service: <https://openape.gpii.eu/>  
Link to the Term-Registry-Service: <https://terms.gpii.eu/>  
Please upload your solution as a JSON-File onto Moodle. Additionally, provide a brief explanation of your choice of preferences and their values.
2. Start the App “Barrierfree Smarthome App” on your Android smartphone. Login into your OpenAPE account and download the context you just created.  
Check, if the settings were set correctly.

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## **1 Didactical Concept – Handout for Teachers**

### **Universal Design & Personalization for Smart Homes - Concepts VPUX-Lab**

## **2 Didactical Analysis**

This learning unit teaches the concepts of universal design and personalization in the context of smart homes. Practical assignments include the study of personas with disabilities, and the specification of preference profiles for

users with disabilities, using the OpenAPE framework notation (based on ISO/IEC 24752-8).

### Target Group

The target group for the first learning unit is bachelor students of computer science or similar course programs (e.g., media informatics), in the 3<sup>rd</sup>-6<sup>th</sup> semester. Some of the learning content may also be useful for students of less technical subjects such as social sciences.

### Institutional Requirements

The required resources are all described in the learning unit itself, as the first unit is aimed to teach the students the theoretical part of universal design and personalization. The teachers should ideally be familiar with the basic interaction of the web interface of OpenAPE.

### Learning Objectives

Students should deepen their understanding of the basic needs a person with disabilities faces when interacting with a smart home. To meet those needs, basic principles of accessible design and adaptive user interfaces will be taught as “inclusive responsiveness”. A first introduction to the personalization framework “OpenAPE” will let the students understand the purpose of the framework and how to describe user preferences with it.

### Learning Content

This learning unit provides the theoretical foundation for the practical 2<sup>nd</sup> learning unit. The following topics will be covered in this unit: Introduction to the module, universal design, guidelines on accessible design, inclusive responsiveness, and introduction to the OpenAPE framework. The content will be provided through documentations but also through video tutorials. To strengthen the acquired knowledge, students will also have to complete 2 assignments in group work: In the first assignment the students are asked to hold a short persona presentation and identify the needs of their persona and in the second assignment those needs should be met by creating an OpenAPE profile with the desired preferences of the persona.

### 3 Didactical Concept

#### Methodical implementation

Are special methods used, such as serious gaming, self-directed learning, collaborative learning, etc.? What is the concrete procedure of this exercise (please note in the bullet point)?

#### Media

The content will be shared as PDFfiles. Additionally, students will access the servers of OpenAPE and the Term-Registry-Service through the web interface. The “Barrierfree-Smarthome“ app is provided as download.

#### Learning Organization

The first learning unit is taught by teachers to their students. Teachers will provide the fundamental knowledge for the 2<sup>nd</sup> unit. Additionally, the students will have to complete assignments, which can be presented to the class. The class can be held both in the presence and online. For presence classes, a lab with computers and Android devices or emulators is required as students will have to interact with the OpenAPE web interface and the “Barrierfree-Smarthome” app.

#### Feedback and Evaluation

The solutions to the assignments should be presented in front of the class, whether online or in presence. An open discussion afterward gives feedback on the work and can lead to new ways to approach the task.

Teachers can conduct a survey at the end of the learning unit to give the students the chance to give feedback on the course. Changes for improvement can be made for the next students.

### Expert Tips

Teachers should already have an interest and maybe already first interaction with the subject so that they can give real examples of the use of knowledge. Furthermore, a little experience in the use of the respective interface is useful.

The pdf and word files of the learning unit are mostly accessible. So, if new content is added, care should be taken to ensure accessibility. The videos created also have English subtitles for this purpose.



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# **Universal Design & Personalization for Smart Homes – Implementation**

## Abstract

This unit aims to provide a technical understanding of how accessibility can be implemented during application development. The personalization framework OpenAPE is used for this purpose. In addition, basic knowledge in the area of smart homes will be taught, for this purpose, the smart home framework OpenHAB will be used.

## Keywords

Personalization, OpenAPE, OpenHAB

## **1 Preface**

### *1.1 Overview*

In this chapter, a practical study unit is provided. The unit is about personalization and accessibility, on the one hand, and a possible interface to smart homes, on the other.

First, an attempt is made to get a sense of why personalization might be helpful. Then we describe how OpenAPE, the personalization framework we use in the chapter, works and which functionalities are needed for this study unit. These functionalities are described in technical detail and are also supported with short videos.

In the following part, OpenHAB is explained, a framework that is used in smart homes. Basic knowledge of this framework is presented and the functionalities that are needed in this unit are explained in more detail. This is again supported with short videos.

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Then the OpenAPETutorial app is presented, an example application where missing source code must be filled in. When filling in this source code, students must apply knowledge from the previous parts of the tutorial.

## 1.2 Didactic fundamentals

Didactical aspect	Description
Target group	Computer science students with prior knowledge of programming.
Effort in lecture hours	60 minutes theory, 180 minutes practice
Effort for self-study materials	~ 20 minutes
Prerequisites	<ul style="list-style-type: none"> <li>– Computer with an IDE for Java development; eclipse should work best</li> </ul>
Needed background	<ul style="list-style-type: none"> <li>– Basic knowledge of programming, at best of Java</li> <li>– Study Unit "Universal Design &amp; Personalization for Smart Homes—Concepts"</li> </ul>
Additional information	<ul style="list-style-type: none"> <li>– The students need an account with OpenAPE</li> <li>– An OpenHAB server must be available; this can also be provided by the VPuxLab.</li> </ul>

## 1.3 Learning Objectives and Competence

The goals of this chapter are that the students:

1. pay more attention to accessibility problems
2. learn how to improve accessibility through personalization
3. know what OpenAPE is
4. know how to use OpenAPE
5. know what OpenHAB is
6. know how to use OpenHAB

## 2 Why Personalization

An example now demonstrates why personalization can be useful. In the example, visual impairment is demonstrated because a visual impairment is more tangible and comparable to other barriers.

Imagine not being able to see a specific color. You want to book a seat in the cinema, and you get one of the following views on your screen. Above it, it says: "Select a free seat; the free seats are marked in green."

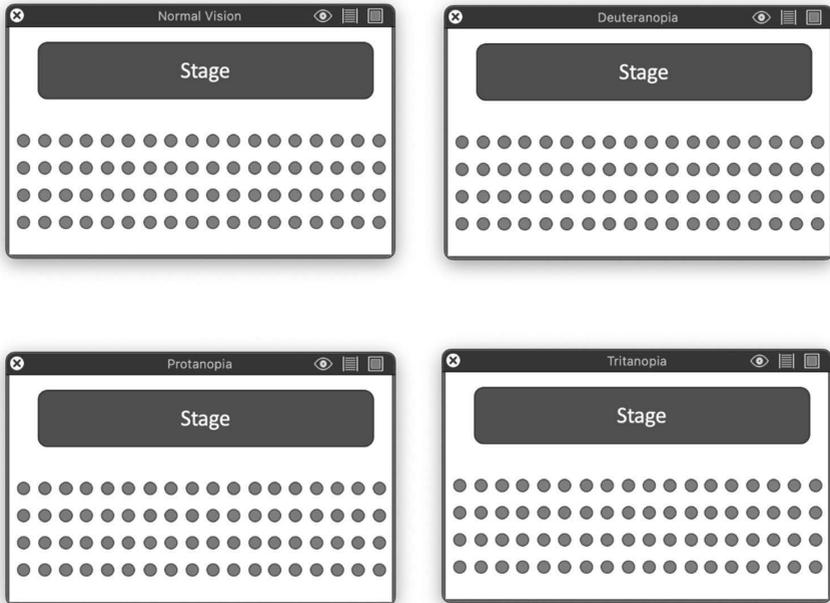


Figure 1: Seat selections with different visual impairments

The images above were created using the application Sim Daltonism: (<https://apps.apple.com/de/app/sim-daltonism/id693112260?mt=12>)

The picture on the top left shows how a person without a visual impairment sees the selection. All others are from the point of view of a person with a visual impairment. The picture on the top right shows deuteranopia, i.e., a red–green weakness. The image bottom left demonstrates protanopia, a red weakness. The last picture shows tritanopia, a blue–yellow weakness.

As you can see, the selection of colors can be a big problem, especially if the color is the only characteristic used for the selection. But this is not recommended either way. The example should nevertheless clearly illustrate how such problems can arise.

With personalization, you could customize these colors. Users could choose the colors that suit them best. This can be applied to many settings like font, font size, contrasts, or even language. Additionally, these settings could then be saved and transferred to other devices and applications.

### 3 OpenAPE

The basic knowledge of OpenAPE should already have been covered in study unit 1 “Universal Design & Personalization for Smart Homes—Concepts”. Therefore, this unit will focus more on technical details.

OpenAPE differs in four context types: User Contexts, Task Contexts, Equipment Contexts und Environment Contexts. Each context type is used specifically for certain use cases. In this unit, only the User Context matters, so in examples, this context type is always used.

OpenAPE: <https://openape.gpii.eu/>

#### 1.1 OpenAPE Rest-API

Besides the call for authentication, there are five rest calls for each context type:

Description	Rest-Method	Path
Authentication	POST	/api/token
Get list of all contexts	GET	/api/<type>-contexts
Get single context	GET	/api/<type>-contexts/<context-id>
Create context	POST	/api/<type>-contexts
Update context	PUT	/api/<type>-contexts/<context-id>
Delete context	DELETE	/api/<type>-contexts/<context-id>

Rest-Documentation from OpenAPE via Swagger: <https://docs.openape.gpii.eu/>

Examples of all rest calls can be found in the following playlist. The link to each individual example is additionally directly next to the example. The videos with the numbers 1–6 belong thematically to this section:

[https://www.youtube.com/watch?v=gDIyaC3eC\\_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbejXDV](https://www.youtube.com/watch?v=gDIyaC3eC_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbejXDV)

All the examples were made with the help of the tool Insomnia (<https://insomnia.rest/>). In the appendix of this unit, there is an exported file containing the examples. This file can be imported into Insomnia to try out the interfaces independently using the examples. A tutorial on how to use Insomnia can be found here: <https://docs.insomnia.rest/>

#### 3.1.1 Authentication

Aspect of authentication	Description
Method	POST
Path	/api/token
Header	content-type: multipart/form-data

Aspect of authentication	Description
Multipart/form-data	<ul style="list-style-type: none"> <li>– grant_type: password</li> <li>– username: &lt;username&gt;</li> <li>– password: &lt;password&gt;</li> </ul>
Example response body	<pre>{   "access_token": "eyJhb... ",   "expires_in": "1440" }</pre>
Example error body	<pre>{   "error": "&lt;error&gt;",   "error_description": "&lt;errorText&gt;" }</pre>
Example execution	<a href="https://youtu.be/gDlYaC3eC_Q">https://youtu.be/gDlYaC3eC_Q</a>

### 3.1.2 Get list of contexts

Aspect of get contexts	Description
Method	GET
Path	/api/user-contexts
Header	authorization: <token>
Example response body	<pre>{   "totalContexts": 1,   "user-context-uris": ["6130c06503604740e28eb27a"] }</pre>
Example errors	<ul style="list-style-type: none"> <li>–Status 401 – Unauthorized</li> <li>oNo or wrong Token?</li> </ul>
Example execution	<a href="https://youtu.be/zwWqU7LsqSU">https://youtu.be/zwWqU7LsqSU</a>

### 3.1.3 Get single context

Aspect of get context	Description
Method	GET
Path	/api/user-contexts/<context-id>
Header	<ul style="list-style-type: none"> <li>– authorization: &lt;token&gt;</li> <li>– content-type: application/json</li> </ul>
Response	Context in json format
Example errors	<ul style="list-style-type: none"> <li>– Status 401 – Unauthorized</li> <li>– No or wrong Token?</li> <li>– Status 404 – Not found</li> <li>– No Content-Type?</li> <li>– “no object with that id”</li> <li>– “invalid hexadecimal representation of an ObjectID”</li> </ul>

Aspect of get context	Description
Example execution	<a href="https://youtu.be/HkuBlghoxgs">https://youtu.be/HkuBlghoxgs</a>

### 3.1.4 Create context

Aspect of create context	Description
Method	POST
Path	/api/user-contexts
Header	<ul style="list-style-type: none"> <li>– authorization: &lt;token&gt;</li> <li>– content-type: application/json</li> </ul>
Body	Valid json of context
Response	No response body
Example errors	<ul style="list-style-type: none"> <li>– Status 400 – Bad Request</li> <li>•Not a valid User Context?</li> <li>– Status 401 – Unauthorized</li> <li>•No or wrong Token?</li> <li>– Status 404 – Not found</li> <li>•No Content-Type?</li> </ul>
Example execution	<a href="https://youtu.be/Fkn7KVboqHg">https://youtu.be/Fkn7KVboqHg</a>

### 3.1.5 Update context

Aspect of update context	Description
Method	PUT
Path	/api/user-contexts/<context-id>
Header	<ul style="list-style-type: none"> <li>– authorization: &lt;token&gt;</li> <li>– content-type: application/json</li> </ul>
Body	Valid json of context
Response	No response body
Example errors	<ul style="list-style-type: none"> <li>–Status 400 – Bad Request</li> <li>• Not a valid User Context?</li> <li>–Status 401 – Unauthorized</li> <li>• No or wrong Token?</li> <li>–Status 404 – Not found</li> <li>• No Content-Type?</li> </ul>
Example execution	<a href="https://youtu.be/HRy8_RsBuVU">https://youtu.be/HRy8_RsBuVU</a>

Be careful with this call. When you update a context, it will be completely overwritten on the OpenAPE server. So, the full context must be sent along with it.

### 3.1.6 Delete context

Aspect of delete context	Description
Method	DELETE
Path	/api/user-contexts/<context-id>
Header	authorization: <token>
Response	No response body
Example errors	<ul style="list-style-type: none"> <li>- Status 401 – Unauthorized</li> <li>• No or wrong Token?</li> <li>- Status 404 – Not found</li> <li>• No Content-Type?</li> <li>• “no object with that id”</li> <li>• “invalid hexadecimal representation of an ObjectID”</li> </ul>
Example execution	<a href="https://youtu.be/3uld25UeXQc">https://youtu.be/3uld25UeXQc</a>

## 3.4 OpenAPE Java Client

In the OpenAPE Java client, the following methods are available:

Method Call	Link to Example Execution
login(..)	<a href="https://youtu.be/HQjCGhvk4Ms">https://youtu.be/HQjCGhvk4Ms</a>
isLoggedIn()	Same video as for the login method
getUserContexts()	<a href="https://youtu.be/WbJO1vZw500">https://youtu.be/WbJO1vZw500</a>
getUserContext(..)	<a href="https://youtu.be/4trZ1HsWSgo">https://youtu.be/4trZ1HsWSgo</a>
createUserContext(..)	<a href="https://youtu.be/sgflu_hikxM">https://youtu.be/sgflu_hikxM</a>
updateUserContext(..)	<a href="https://youtu.be/h9emwffYH1A">https://youtu.be/h9emwffYH1A</a>
deleteUserContext(..)	<a href="https://youtu.be/9AV3O1VNYsc">https://youtu.be/9AV3O1VNYsc</a>

Besides these methods the constructor is needed, i.e. OpenAPEClient(). Besides calling it up without parameters, it can also be called up with a URL as a string parameter. If this is done, the application will try to initialize the client with the corresponding URL as the OpenAPE Server. If this is not done, the default URL <https://openape.gpii.eu/> will be used.

You can watch example videos of the methods in the following playlist. Videos 9–15 are about the OpenAPEClient: [https://www.youtube.com/watch?v=gDIyaC3eC\\_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbeEjXDV](https://www.youtube.com/watch?v=gDIyaC3eC_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbeEjXDV)

The documentation and further information about the client can also be found in the README.md file in the client's repository. You can find it here: <https://gitlab.bf-hdm.de/benedikt.reuter/openapeclient>. Among other things, it describes how to build the jar file of the OpenAPE-Client or how to include it in existing projects.

Since the client uses the Rest API of OpenAPE, the methods mentioned are of course based on it.

The following image describes an example workflow using the OpenAPEClient. In the example, a user logs in via the interface and saves their settings for the first time. The example is simplified.

First, the OpenAPEClient logs the user into the OpenAPE interface. The token it receives is then stored. Then the OpenAPEClient creates a new context with the user's saved settings. The ID of the new context is sent in response. What is done with it varies depending on the use case.

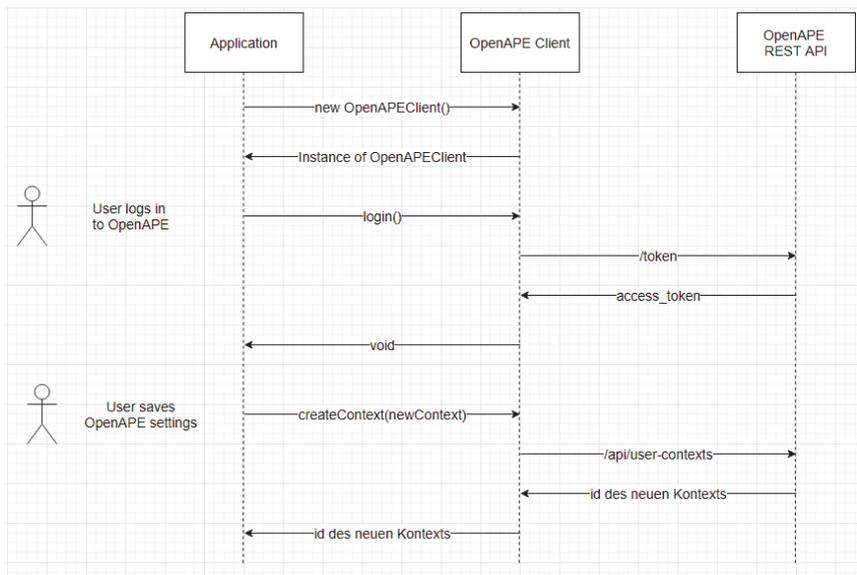


Figure 2: Sequence diagram for an example workflow

Careful! In real applications, it should first be checked whether a context already exists which can be updated.

Instructions on how to import the .jar file into a project can be found here: <https://youtu.be/oD0loJaHtoE>

### 1.1.1 Data structure

The data types used in the client all end with the abbreviation DTO, which stands for Data Transfer Object. Using these data types, the data is de-serialized from the rest interface, i.e., from a JSON format into a suitable format and the other way round.

The most important and complex are `UserContextMapDTO` and `UserContextDTO`. The `UserContextMapDTO` contains a map which is returned when all contexts are retrieved. The key in the map is the ID of a context and the value is then the context itself. The context is a `UserContextDTO`. To understand the basics of these classes, corresponding UML diagrams are shown. These UML diagrams do not represent the entire data structure of the `OpenAPECClient`, but the most important parts.

In the following UML diagram, you can see all the publicly visible methods of the `UserContextMapDTO`. With it you can add, update, and remove contexts.

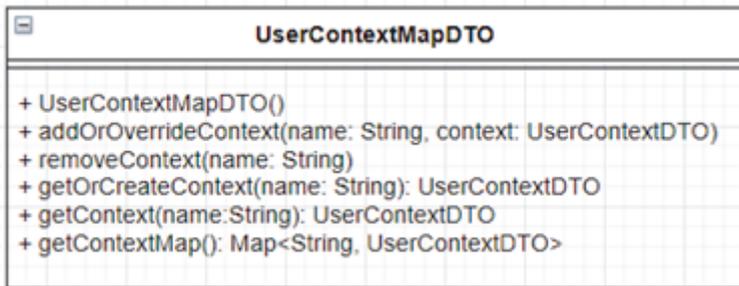


Figure 3: UML Diagram `UserContextMapDTO`

The next UML diagram shows the class `UserContextDTO`. Here, again, all the important publicly visible methods are described. With this class, you have the chance to change the name, the preferences, and the conditions of a single context.

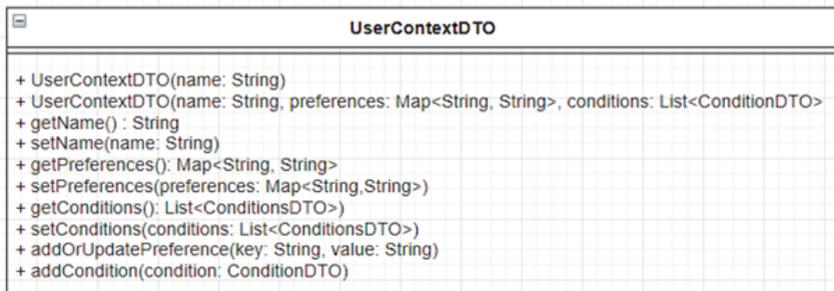


Figure 4: UML Diagram *UserContextDTO*

The *ConditionDTO* mentioned in the diagram will not be discussed further in this unit, as it is not required for the time being.

### 3.4.7 Error Handling

There are six exceptions, which arise depending on the use case. The name of the exception should already indicate when it is thrown up.

Name of Exception	Short description
<code>OpenAPEAuthenticationException</code>	thrown up when an authentication error happens
<code>OpenAPECreateContextException</code>	thrown up when an error happens during context creation
<code>OpenAPEDeleteContextException</code>	thrown up when an error happens during context deletion
<code>OpenAPEUpdateContextException</code>	thrown when an error happens during context update
<code>OpenAPEResourceNotFoundException</code>	thrown up when a requested context is not available
<code>OpenAPEServerConnexionException</code>	thrown up when the server is not available

All exceptions derive from the `OpenAPEException`. This exception can be caught to handle all error messages from this client.

## 4 OpenHAB

### 4.1 Background

The open-source project *OpenHAB* stands for open Home Automation Bus. It is used in smart homes, where it can do different jobs. Many devices, systems, or technologies can be connected to the *OpenHAB* system and *OpenHAB* can become the center of a smart home. Moreover, automation

can be achieved in the area of smart home with OpenHAB. A cloud connection is not necessary with OpenHAB, but if desired, it can be connected to common cloud-based systems. You can host OpenHAB on your own local system or via a cloud connector directly in the cloud.

To connect OpenHAB with other devices, you can install bindings in your OpenHAB system. These bindings create a connection to the devices and then create so-called things. These things are the corresponding representations of the devices.

Things can then be used to generate items. Items represent functionalities of the things. They have a status which can be changed if necessary. For example, there is the item type "Switch", which can represent the on/off switch of a lamp.

For automation, rules can be created that can execute different commands in different situations.

Read more:

- Website: <https://www.openhab.org/>
- Documentation: <https://www.openhab.org/docs/>
- Documentation Rest-API: <https://www.openhab.org/docs/configuration/restdocs.html>
- Install Instructions: <https://www.openhab.org/docs/installation/>
- Tutorial: <https://www.openhab.org/docs/tutorial/>

## 4.2 OpenHAB Rest-API

For the task in this study unit, two rest calls are needed: a call to get all the items of the interface and a call to change the state of an item.

Examples of all rest calls can be found in the following playlist. Videos 7 and 8 show the examples from this chapter: [https://www.youtube.com/watch?v=gDIyaC3eC\\_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbejXDV](https://www.youtube.com/watch?v=gDIyaC3eC_Q&list=PLNVCxdMrGvQkmUjCS8gHd31qXWUbejXDV)

### 4.2.1 Get all Items

Aspect of get all items	Description
Method	GET
Path	/rest/items
Basic Authorization	<ul style="list-style-type: none"> <li>- username = &lt;api-key&gt;</li> <li>- password = empty</li> </ul>
Response	List of all items with some information
Example execution	<a href="https://youtu.be/8rwBLBFSU1k">https://youtu.be/8rwBLBFSU1k</a>

### 4.2.2 send Command

Aspect of send command	Description
Method	POST
Path	/rest/items/<item_name>
Basic Authorization	– username = <api-key> – password = empty
Header	content-type: text/plain
Body	Command as string, e.g., "ON"
Response	No response body
Example execution	<a href="https://youtu.be/CmhP-veYAZ4">https://youtu.be/CmhP-veYAZ4</a>

To use the Basic Authorization, the Authorization field must be set in the header. This must be set with the value "Basic <credentials>", where the credentials must contain the following string encoded as base64: "username:password" (<https://www.openhab.org/docs/configuration/restdocs.html#authentication>)

### 4.3 OpenHAB Server

To implement the task from the tutorial, you need an OpenHAB server. You have two possibilities:

1. Set up a local OpenHAB server and connect your own devices

You need at least one item in your OpenHAB configuration.

Tutorial: <https://www.openhab.org/docs/installation/>

2. Use the virtual OpenHAB interface of the VPuxLab

A tutorial on how to use the VPuxLab will be provided by the instructor.

## 5 OpenAPETutorial Application

The application is a simple control application for lamps in a smart home. The lamps are connected via the OpenHAB interface; their personalization should be able to be synchronized via OpenAPE.

The application could be used, for example, on a tablet in a building where different people come and go. OpenAPE can be used effectively so that all people can use the lamp controls. To do so, the people can log in and their own settings will be adopted.

App functionalities:

- OpenHAB
  - Fetch & display items
  - Send commands (change device state)
- OpenAPE
  - Log in
  - Save Settings in Context
  - Load Settings from Context

The application is implemented using maven. Therefore, you start the project using maven. How this works can be found in the README.md file of the project. When maven is used, the project's configuration is done through the pom.xml file. When you download the project, you will have to enter the path to the .jar file of the OpenAPEClient there.

Only certain classes have to be filled in for the task. In these classes, empty methods, which are called up from other parts of the source code, already exist. So, if the functionality is implemented in these methods, the application should work properly.

In order to be able to save or retrieve settings, there is another method in the class for the OpenAPE functionalities. This method returns the object AppSettings. This object can be used to retrieve or save the settings of the application.

For more Information about the app, see:

<https://gitlab.bf-hdm.de/benedikt.reuter/openapetutorialassignment>

### 5.1 HTTP Client retrofit

To implement the functionalities for the rest interface of OpenHAB, an http client is needed. In this application, retrofit is used for this purpose. With retrofit an interface is created which implements appropriate wrappers for rest calls. These wrappers can then be used to execute the corresponding calls.

To implement the functionalities, you will need to know more about the retrofit client. You can find instructions on how to implement retrofit here: <https://square.github.io/retrofit/>

Note: The de-serialization of the items from the OpenHAB interface is already given. For this, you can use the ScalarsConverter and the JacksonConverter in retrofit. The ScalarsConverter is used to convert strings into JSON data. With the JacksonConverter retrofit can automatically convert the JSON data into the OpenHABItemDTO class. To use the ScalarsConver-

ter and the JacksonConverter you need the ScalarsConverterFactory and the JacksonConverterFactory. When the retrofit client is built with these converters, the required resources will be automatically converted.

You can find more detailed instructions on how this works in the documentation already linked. Example:

```
... .addConverterFactory(ScalarsConverterFactory.create()) ...
```

## 6 Assignment

Now you should know how OpenAPE and OpenHAB can be used. In the exercise, you must now complete the smart home application mentioned in Chapter 4. If you get stuck, you can always refer to the information in this document.

How you proceed with the exercise is described below:

### a) Download source code

- Download OpenAPETutorial
- Download the .jar file of the OpenAPEClient and add the path to the pom.xml file
- Check if you can run the application; you can find a launch guide in README.md
- The basic functionalities should work, but due to the missing source code no items will be displayed and the OpenAPE synchronization will not work

### b) Fill in the missing code

- package: org.openAPETutorial.openAPETutorial.exercise
- classes: OpenAPEService, OpenHABService, OpenHABRest
- There are already empty methods in the classes; these methods are called from the rest of the source code

### c) Check functionality

- Lamps (OpenHAB Items) are shown
- Commands on OpenHAB lamps work—a command will change the status of a lamp
- A login to OpenAPE will download the saved config from OpenAPE
- After a login, a change in the settings will sync to the OpenAPE Account—check this on the website

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## **1 Didactical Concept—Handout for Teachers Universal Design & Personalization for Smart Homes— Implementation**

OpenAPETutorial App

## **2 Didactical Analysis**

### Short Description

This study unit aims to provide a technical understanding of how accessibility can be implemented during application development. The personalization framework OpenAPE is used for this purpose. In addition, basic knowledge in the area of smart homes will be taught, for this purpose the smart home framework OpenHAB will be used.

### Target Group

The unit is intended for students of computer science. Students should already have prior knowledge of programming and have already completed the study unit "Universal Design & Personalization for Smart Homes—Concepts".

### Institutional Requirements

The required resources are all described in the unit itself. For questions regarding content, the teachers should be available and already have some understanding of OpenAPE, OpenHAB, and the development of Java applications. The students need an OpenHAB interface. This can be provided centrally or made available via a VPuxLab.

### Learning Objectives

Students should learn how to pay attention to the needs of all people while developing an application. Personalization with OpenAPE as a personalization framework will be used to teach these skills. Furthermore, the students will learn how to use OpenHAB and thus get to know basic knowledge in the field of smart homes. After the unit, students should be able to use the OpenAPE and OpenHAB interfaces and implement them in applications.

## Subject matter

This study unit consists of theory and practical exercises at the same time. Some short videos with practical examples are shown in the unit, while further information on documents and videos is provided as further resources. The theory unit is followed by the practical exercise, in which the students must apply the knowledge they have gained. To do this, they can always check the resources provided.

## 3 Didactical Concept

### Methodical implementation

Aspects of problem-based learning are used in this unit. In this regard, the students will learn mostly in a self-directed way. However, they should always have the opportunity to ask the lecturer questions if there is a problem. The procedure:

- Theoretical unit with the help of
  - basic knowledge
  - sample videos
  - further third-party documentation
- Exercise
  - Download the source code
  - Fill in the missing source code
  - Check the functionalities

### Media

The unit requires an OpenHAB server in addition to the students' development environment. This can either be provided via a real OpenHAB server, or the OpenHAB interface of the VPuxLab can be used. Besides that, the resources provided in the course and the third-party documentation are sufficient.

### Learning Organization

The course unit is treated individually by each student. The lecturer should only be ready for possible questions at any time. A forum where students can discuss problems or solutions could also be useful. The unit can therefore

re be conducted in an online course, especially if the VPuxLab is used as an OpenHAB server.

### Feedback and Evaluation

Students can check their work themselves by checking the functionality of the application for correctness. If further questions arise, a sample solution can also be provided to students.

Learning analytics could be used in the development phase to find out where students have problems and where the tasks are too easy.

### Expert Tips

Probably the best preparation for the unit is to perform the exercise once yourself. Furthermore, a little experience in the use of the respective interfaces is useful.

The pdf and word files for the study unit are mostly accessible. So, if new content is added, care should be taken to ensure accessibility. The videos created also have English subtitles for this purpose.

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## **Heuristics to Solve a Team Orienteering Problem**

### Abstract

Combinatorial optimization problems are challenging, especially in the real world. Several heuristics could be utilized to solve them. These heuristics differ in their characteristics and solutions found to the problems. One example of the real-world problem was the picking and distribution of face shields at the beginning of the Covid-19 pandemic. Solutions to this problem were needed every day to arrange their picking and distribution. This problem was modelled as a team orienteering problem. Accordingly, heuristics might be used to solve it. These heuristics might be modified to handle instances of large problems and the stochasticity of different data input. This chapter presents the basics of the team orienteering problem and two heuristics used to solve it. Python might be used to realize the heuristics and run experiments to compare the heuristics.

### Keywords

Team orienteering problem, heuristics, GRASP, savings-based heuristic, logistics, healthcare logistics

## **1 Overview**

The Internet of Things (IoT) has been a rapidly expanding technology at the industrial level. Nowadays, a network of objects is surrounded by electronic systems, software, sensors, and network connectivity, which enable the collection, storage, and exchange of large data. This network requires optimal data management systems that enable the efficient operation of physical processes. In transportation logistics, more and more systems are being used that automatically monitor vehicle movement, location, status, among other parameters, and generate alerts or make intelligent decisions about them. Solving problems in transportation and logistics is a challenging task today. These problems might be formulated as combinatorial optimization problems. In a combinatorial optimization problem, the search space consists

of a finite space of elements. These elements are selected and arranged in a solution. The number of potential solutions increases exponentially with the number of elements in the search space.

In order to solve combinatorial optimization problems, several heuristics could be utilized. As a result, an optimum or promising solution might be identified depending on the problem and the heuristic. For example, an optimum solution could be guaranteed for small problems. However, for large problems, a promising solution might be identified.

Solving a combinatorial optimization problem becomes challenging if real-time problems are being solved. For example, the integration of the Internet of Things (IoT). In this case, a solution should be recommended within a small time window, immediately. Agile optimization concepts are utilized to handle these problems.

In this chapter, a real case study is presented. This case study appeared at the beginning of the Covid-19 pandemic because of the shortage of face shields. Volunteers printed these shields using their 3D printers, and other volunteers registered to pick up these printed items. This problem is an example of IoT integration and was a challenging task because the decisions were to be made by the following day to assign routes for each volunteer driver. The number of drivers varied from one day to another. To solve this problem, several heuristics might be used. Their performance was evaluated and compared. As a result, students can compare the performance of different heuristics using a real-world case study.

## *1.1 Didactic Fundamentals*

### *1.1.1 Target Group*

The course has been designed for a lecture on analytics for bachelor's or master's students in industrial engineering, statistics, and logistics.

### *1.1.2 Prerequisites*

Basic knowledge of programming, analytical capabilities, applied optimization, data plotting, scientific paper reading, and report writing is required.

### *1.1.3 Learning Resources*

Learning materials involve presentations and videos, reading, and exercises. These materials are uploaded onto a Moodle learning platform. In the following sections, the basics related to this use case are presented.

## 1.2 Learning Objectives and Competence

Learning outcomes in this chapter based on Bloom's taxonomy and lab-specific psychomotor skill extensions are:

- Remember
  - Students should remember and define the team orienteering problem (TOP).
  - Students should be able to reproduce program codes to solve the TOP.
- Understand
  - Students should distinguish between different methods used to solve the TOP.
  - Students should report their findings in a short report.
- Apply
  - Students should apply the GRASP heuristic learned to solve the TOP's instances.
- Analyze
  - Students should analyze the results obtained and compare the performance of heuristics in different experiments.
- Evaluate
  - Students should evaluate their code and modify it.
- Create
  - Students should be able to describe their results in a report.
- Specific psychomotor skills provided through lab-elements
  - Students will learn how to establish their Python program to solve the TOP.
  - Students will learn how to evaluate a heuristic used to solve the TOP.

## 2 Use Case

### 2.1 User Story

Martha is an expert in Operations Research who lives in Barcelona and is worried about the growing number of Covid-19 cases in this region and the increasing burden they are placing on healthcare centers. Her brother, Michael, who is a doctor and works long shifts in a hospital, has told her about shortages of protective elements such as face shields, ear

savers, door openers, and similar sanitary items. Although these elements were not frequently used before the pandemic, the crisis caused healthcare staff to require extra protection, increasing the demand for such elements unexpectedly. Michael and his colleagues in the hospital knew about an initiative called “Coronamakers”, or simply “Makers”. This initiative is a new community of people who have 3D printers at their respective houses and volunteered to provide these items to hospitals and healthcare centers.

Nevertheless, once the hundreds of volunteers in the surrounding area of Barcelona guaranteed the protective items’ production, a logistics problem arose: volunteers were unable to deliver the printed elements by themselves, given both the lockdown restrictions and a large number of items. Hence, only a few external vehicles were able to visit Makers’ houses to collect the 3D-printed items and deliver them to healthcare centers. During a conversation about this problem between Martha and Michael, she told him about some math and computational tools she had employed to solve similar problems in the past. She explained to him that, in general, these tools are called heuristics, and they provide fast and good solutions to transportation, manufacturing, and other complex problems. Therefore, heuristics are quite suitable to solve the logistics problem since, although they are not capable of providing optimal solutions, the speedy growth in Covid-19 cases required good-quality solutions that could be obtained in a short time (minutes or seconds).

Immediately after this conversation, Martha and Michael contacted the Makers. Martha offered to solve this logistics problem, together with her research group at Super open University. Moreover, Michael recruited a group of six friends who worked as volunteer drivers. All the friends expressed their willingness to join this project and claimed to be ready once Michael and Martha indicated both the Makers’ houses that each driver should visit and the sequence in which these visits had to be carried out. Hence, this was a real and complex problem that Martha’s research group had to solve by defining collection routes to maximize the number of items collected.

Martha’s group needed to consider a series of conditions or constraints that had to be met to keep the computational model as realistic as possible. Firstly, all the Makers’ houses and the healthcare centre locations were identified using Cartesian coordinates. Secondly, the drivers’ time was limited, i.e., each route could not exceed a maximum number of hours per day due to curfew hours during the pandemic period. Given both these constraints and the limited number of volunteer drivers, the drivers might not visit all the Makers on the same day. Therefore, an additional decision had to be made regarding which Makers should be visited. Fortunately, since this case represents a daily challenge, Martha knew that Makers who were not

visited on a particular day could be visited on the following days. Thirdly, vehicles were considered virtually unlimited in capacity since the size of the items to be transported was small. Finally, both the travel times between the locations and the visiting time in each house were known. The former is the time taken to travel between any pair of houses or healthcare centres. The latter is the time spent by the driver in carrying out a collection at each house.

After a short discussion with her colleagues at the research group, Martha concluded that this real-world problem should be modelled as the Team Orienteering Problem (TOP). Two reasons led to this decision: the TOP allowed some houses to be skipped, given the strict time limit; and the TOP's typical objective maximized the total reward collected after visiting the houses. In this case, it was so obvious to Martha's group that the reward each Maker offered was the number of 3D-printed items to be collected.

## 2.2 Tasks

Tasks for students:

- Formulate the TOP to be solved by Martha and her colleagues:
  - Define decision variables
  - Define the objective's function
  - Define the constraints
- Propose more than one heuristic to solve the problem
- Implement the heuristics using Python
- Run experiments and compare the heuristics based on the results obtained

## 3 Team Orienteering Problem

The TOP is derived from the orienteering problem (OP), an outdoor sport practiced in a mountainous area, where a player has a compass and a map. The player starts at a specific checkpoint from which he/she has to visit as many checkpoints as possible within a set time limit and finally return to the starting point. Each checkpoint has a score associated with it, so the game's objective is to maximize the total score. As the time to return to the starting point is limited, not all checkpoints can be visited. Therefore, the player must select the checkpoints with the highest contribution to his/her total score (Chao et al., 1996). The OP is an NP-hard problem that can be considered a combination of the knapsack problem and the travelling sales-

man problem (TSP) (Vansteenwegen et al. 2011). The knapsack problem is an optimization problem in which a number of items are placed inside a fixed-size knapsack. The items have a given weight, and the objective is to fit as many items as possible into the knapsack given the weight constraint on it (Salkin & De Kluyver, 1975). The TSP is an optimization problem with a given list of cities and distances between each pair of cities, and the objective is to find the shortest possible route that allows the players to visit each city exactly once and return to the origin city (Flood, 1956). When the game is extended from a single individual to teams of two or more players, it is called TOP. Each team member must visit as many selected checkpoints as possible within a given time and, then, return to the starting point. Thus, each checkpoint is visited once, and the total score is maximized (Chao et al. 1996).

The TOP was modelled by Chao et al. (1996) as a multi-level optimization problem. In the first level, the nodes to be visited are selected. In the second level, the selected nodes are assigned to the vehicles in the fleet. Finally, the construction of the routes for each vehicle is done on the third level. According to Gunawan et al. (2016), the TOP can be mathematically defined as a set of nodes  $N = [1, \dots, |N|]$ , where each node  $i \in N$  is associated with a non-negative reward,  $r_i$ . The start node and the end node are described by node 1 and  $|N|$ , respectively. The objective function of the TOP maximizes the total reward collected from selected nodes by determining routes that are limited by a given time budget,  $T_{max}$ , and the time between nodes  $i$  and  $j$  is  $t_{ij}$ . It is assumed that rewards can be added and that each node can be visited once at most.

The problem is formulated as an integer programming model with the following decision variables:  $x_{ij} = 1$  if a visit of node  $i$  is followed by the visit of node  $j$ , otherwise it is 0; and  $u_i$  is used in subtour elimination constraints and allows the position of the nodes visited in the route to be determined (cf. Gunawan et al. 2016); subtours represent round tours. The objective's function maximizes the total rewards collected (Equation. 1). The constraints (cf. Gunawan et al. 2016) ensure that: (i) routes start from node 1 and end at node  $|N|$  (Equation 2); (ii) the connectivity of routes guarantees that each node is visited once at most (Equation 3); (iii) the total travel time is limited by  $T_{max}$  (Equation 4); (iv) subtours are prevented (Equations 5 and 6).

$$\text{Maximize } \sum_{i=2}^{|N|-1} \sum_{j=2}^{|N|} r_i x_{ij} \tag{1}$$

subject to:

$$\sum_{j=2}^{|N|} x_{1j} = \sum_{i=2}^{|N|-1} x_{i|N|} = 1 \tag{2}$$

$$\sum_{i=2}^{|N|-1} x_{ik} = \sum_{j=2}^{|N|} x_{kj} \leq 1; \quad \forall k = 2, \dots, (|N| - 1) \tag{3}$$

$$\sum_{i=2}^{|N|-1} \sum_{j=2}^{|N|} t_{ij} x_{ij} \leq T_{max} \tag{4}$$

$$2 \leq u_i \leq |N|; \quad \forall i = 2, \dots, |N| \tag{5}$$

$$u_i - u_j + 1 \leq (|N| - 1)(1 - x_{ij}); \quad \forall i = 2, \dots, |N| \tag{6}$$

### 4 Heuristic 1: Greedy Randomized Adaptive Search

The greedy randomized adaptive search procedure (GRASP) is the first heuristic described to solve the TOP. It belongs to trajectory methods based on using a single solution and seeing how it evolves or when the number of iterations increases. The basic concepts and key information on Python implementation of GRASP are presented below.

#### 4.1 GRASP Basic Concepts

GRASP is a metaheuristic and a global optimization algorithm. The solution strategy consists of an iterative random sampling of greedy stochastic solutions and the use of a local search heuristic to refine them to a locally optimal solution (Feo & Resende, 1995). Conceptually, GRASP is composed of two phases: (i) the intelligent construction of an initial solution through the greedy lexical function, and (ii) a local search near the constructed solution to find an improvement. Throughout the process, the best global solution is maintained. Feo & Resende (1995) present the basic generic pseudocode of a generic GRASP as shown in Figure 1. The first two lines correspond to the inputs of the problem. After that, the iterative process occurs between lines 3 and 9. Lines 4 and 5 are the GRASP construction and local search phases, respectively (detailed in Figures 2 and 3). This process is iterative and checks whether the solution generated is better than the best solution found. Accordingly, the best solution is updated as is shown in lines 6 to 8. Finally, the iterative process ends if a stopping criterion is met, such as the maximum number of iterations is reached, and the best solution is returned.

<b>Procedure GRASP (MAX_ITERATIONS, SEED)</b>
1 Best_solution = 0;
2 Read_Input();
3 for k=1,2,..., MAX_ITERATIONS Do
4 Solution = Greedy_Randomized_Construction (SEED);
5 Solution = Local_Search(Solution);
6 If Solution is better than Best_solution Then
7 UpdateSolution(Solution, Best_solution);
8 end if
9 end for
10 return (Best_solution);
end GRASP

*Figure 1: Pseudocode of a generic GRASP based on Feo & Resende (1995)*

Figure 2 presents the pseudocode of the greedy randomized construction, which utilizes uniform randomization to select the most promising elements of a restricted list of candidates. The restricted list of candidates includes solution elements and restricts the characteristics of elements that can be selected in each iteration. The number of selected elements from the lists might be constrained by a pre-specified number ( $n$ ) or a percentage of the number of elements in the list. A logical type of behaviour is defined to guarantee a random selection of elements from the list to explore a solution space. This list is sorted from the most promising element to the least promising one based on their effect on the objective's function. Each item in the list is assigned a probability ( $p$ ) of being selected. Then, this list is reduced, considering the  $n$  of most promising elements.

<b>Procedure GreedyRandomizedConstruction (SEED)</b>
1 Solution = 0;
2 Sort the candidate elements according to their incremental costs;
3 <b>while</b> solution is not complete <b>Do</b>
4 Build the Restricted Candidate List;
5 Select from the Restricted Candidate List and element $v$ at random;
6 Solution = Solution $\cup$ $\{v\}$ ;
7 Re-sort the candidate elements according to their incremental costs;
8 <b>end while</b>
9 <b>return</b> (Solution);
<b>end GreedyRandomizedConstruction</b>

Figure 2: Pseudocode of a generic GRASP construction phase based on Feo & Resende (1995)

<b>Procedure LocalSearch(Solution)</b>
1 <b>while</b> Solution is not locally optimal <b>Do</b>
2 Find $s' \in N$ such that $f(s') \leq f(\text{Solution})$ ;
3 Solution = $s'$ ;
4 <b>end while</b>
5 <b>return</b> (Solution);
<b>end LocalSearch</b>

Figure 3: Pseudocode of a generic local search phase based on Feo & Resende (1995)

The greedy randomized construction starts by initializing a solution in line 1 of the pseudocode in Figure 2. In the loop between lines 3 and 9, one feasible solution is iteratively constructed by selecting one element from the list at a time. First, the restricted list of candidates is constructed in line 4. Then, a candidate from the list is randomly selected in line 5 and added to the solution in line 6. At each construction iteration, the choice of the next node is determined by sorting nodes in a candidate list with respect to a greedy function. This function measures the reward of selecting each node. The heuristic is adaptive because the rewards associated with each node are updated at each iteration of the construction phase to reflect changes

brought by selecting the previous node. The probabilistic component of selecting the best candidates does not always select the best one because its behavior is entirely random. Finally, the effect of the selected node on the reward is calculated, and the greedy function is adapted in line 7.

Figure 3 presents the pseudocode of the generic local search phase, which is used to improve constructed solutions. The local search algorithm works iteratively by successively replacing the current solution with a better solution in its neighborhood. It terminates when no better solution in the neighborhood is found. Its effectiveness is based on the proper choice of a neighborhood's structure, efficient neighborhood search techniques, and the starting solution. Thus, the neighborhood structure for a given problem relates a solution to the problem to a subset of solutions based on each solution. A solution is then considered locally optimal if there is no better solution in that subset of solutions.

#### 4.2 Key Information for Python Implementation

The implementation of the GRASP heuristic in Python is based on those made by Jason Brownlee<sup>1</sup> and Sain Panyam<sup>2</sup>. Using the well-known instance called berlin52 is recommended<sup>3</sup>. The parameters to be set to find the best solution, for instance, are the maximum number of iterations (outer loop), the maximum number of iterations without improvement, and the greedy factor, the percentage of the elements in the sorted list to be considered by the algorithm.

Implementing the local search in the GRASP might be formulated as a nested loop and generates new solutions based on a stochastic operator. This operator selects non-consecutive edges and swaps them to obtain new connections between the edges, calculating the Euclidean distance between them. Then, it reverses the edges between them to complete the path. The local search keeps track of the best solution and the new solution. Minor modifications are applied to the original solution, and if the new solution with those changes is better than the original or initial solution, the new solution becomes the new best solution (*more details are found on the Moodle platform*).

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1 <http://www.cleveralgorithms.com/>

2 <https://www.saipanyam.net/2011/06/clever-algorithms-python.html>

3 <http://comopt.ifi.uni-heidelberg.de/software/TSPLIB95/XML-TSPLIB/instances/>

## 5 Heuristic 2: Savings-Based Heuristic

The second heuristic is based on the concept of the well-known savings heuristic of Clarke and Wright (1964). This savings-based heuristic handles small and large instances of the TOP (Panadero et al., 2020). The basic concepts and key information on the Python<sup>4</sup> implementation of this heuristic are presented below, and the detailed explanation can be checked on Moodle or in the available references.

### 5.1 Savings-based Heuristic Basic Concepts

The savings-based heuristic starts with a dummy solution from the origin to the destination, where one route per node is considered; each node is connected to the origin and the destination nodes. Since the origin and destination are two different nodes, the connecting arcs are oriented in a specific direction. Basically, a vehicle leaves the origin depot (node 0), visits node  $i$ , and then continues its journey to the destination depot (node  $i + 1$ ). Merging arcs occur when precedence constraints are satisfied. Thus, if a route in this dummy solution does not satisfy the driving range constraint, the associated customer is discarded from the problem; this node cannot be reached with the current fleet of vehicles. Since the objective function of the TOP maximizes the rewards collected in a limited available time, the "saving" is associated with each arc connecting two different customers. This saving is related to the reward obtained by visiting both customers on the same route rather than using two different routes (Panadero et al. 2020). Figure 4 presents the basic generic pseudocode of the savings-based heuristic.

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4 <https://docs.python.org/3/library/index.html>

```

Savings-Based Heuristic (SEED, Nodes)
1 sol ← createDummySolution(Nodes);
2 SavingsList ← computeSortedSavingsList(Nodes);
3 While (SavingsList is not empty) do
4 edge ← selectNextEdge(SavingsLists)
5 iRoute ← getStartingRoute(edge)
6 jRoute ← getClosingRoute(edge)
7 travelTimeNewRoute ← validate MergeDrivingConstraints(NewRoute)
8 isMergeValid ← validateMergeDrivingConstraints
9 if (isMergeValid) then
10 sol ← UpdateSolution(newRoute, iRoute, jRoute, sol)
11 end if
12 deleteEdgeFromList(edge);
13 end While
14 SortRouteByProfit(sol)
15 deleteRoutesByProfit (sol, maxVehicles)
16 return sol

```

*Figure 4: Pseudocode of a generic savings-based heuristic according to Juan et al. (2020)*

The enriched savings heuristic considers a linear combination of classical savings defined by Clarke and Wright (1964) and the reward associated with an arc. Both quantities must be in the same order of magnitude for this linear combination. Mathematically, this represents the efficiency or enriched savings and defines the relevance given to each of the parameters to be optimized, the original savings based on distance or time, and the utility or reward of the visiting node.

There are two associated savings for each arc, depending on the actual direction in which the arc is traversed. After calculating all the savings, the list of arcs can be sorted from the highest to the lowest savings. From this list, the route merging starts. In each iteration, the arc at the top of the sorted list is selected. This arc connects two routes, which are merged into a new route as long as this new route does not violate the driving range restriction. Finally, the list of routes is sorted according to the total rewards provided to select as many routes as possible from this list, considering the restricted number of vehicles in the fleet (Panadero et al. 2020).

## 5.2 Key Information for Python Implementation

The implementation of the savings-based heuristic in Python starts by defining different classes: *Node*, *Edge*, *Route*, and *Solution*. The class *Node* contains the information associated with the nodes. The class *Edge* contains the

information on the edges connecting nodes and the concept of efficiency. The class *Route* is a list of connected edges, the path's cost, and the total rewards (demand) collected. The class *Solution* counts the number of solutions and stores related information on each one of them. Detailed information on each class is available in the learning materials available to the students, as is the complete development of the metaheuristic.

For the construction of edges and nodes, a list of nodes is constructed in which the first node is  $node[0]$  and the destination node is  $node[-1]$ . Then, an edge (arc) is created between each node and other nodes, and the Euclidean distance is calculated accordingly. The efficiency list is a linear combination using  $\alpha$  and  $(1 - \alpha)$ , where  $\alpha$  is a prespecified factor e.g., 0.7, as explained in Section 5.1. The resulting efficiency list is then sorted from the highest to the lowest value.

The construction of a dummy solution, which is the route from the origin to a node and then to the destination, is used to create the initial solution. The total reward for each route created in the dummy solution is also calculated. From there, the algorithm starts performing the iterative process of edge selection and route merging, based on the following conditions: (i) the resulting merged route must not exist in the defined routes; (ii) the first node must be linked to the origin and the last one to the destination; and (iii) the cost after merging the routes should not exceed the maximum time allowed. The merging process must start with a while loop, where the conditions are evaluated, and the merging process occurs. The loop must be executed several times.

In a final step, the solution is sorted by the merged routes generated. Since the final solution needs a certain number of routes given by the number of vehicles in the fleet, unnecessarily stored information must be eliminated. Finally, printing and plotting the solution using the networkx library is recommended.

## 6 Further Input: Comparison between Heuristics

In our studies, we would like to compare heuristics and select a heuristic to be adapted. For the comparison, statistical tests are used to differentiate between different approaches and heuristics (Beiranvand et al. 2017). In order to compare heuristics, benchmark data sets are used. The heuristics are compared with respect to their performance, such as the quality of the recommended solutions and efficiency (Beiranvand et al. 2017). The difference between recommended solutions and the best-known solution

defines the quality of the solutions, and the efficiency of a heuristic might be represented by the time required to get a solution.

In the statistical tests statements, we define hypotheses (Montgomery and Runger 2007, Sheskin 2011). A null hypothesis,  $H_0$ , states that no difference between the heuristics exists, while an alternative hypothesis,  $H_1$ , defines a claim to be tested. For example,  $H_0: S_1 - S_2 = 0$  and  $H_1: S_2 > S_1$ .  $H_0$  states that solutions  $S_1$  and  $S_2$  found by two heuristics do not differ, and  $H_1$  states that the solution found by heuristic 2 is better than the solution found by heuristic 1 with respect to profit,  $S_2 > S_1$ . The statistical tests are performed with strong evidence required to reject  $H_0$ . If  $H_0$  is rejected,  $H_1$  is accepted.

The selection of a statistical test depends on the parameter being tested,  $S$ , and the sample size. In our comparisons, the sample size is defined by the number of heuristic runs on a benchmark data set. Examples of statistical tests are parametric tests and non-parametric tests (Sheskin 2011). Several assumptions are required to utilize parametric tests: (i) tested samples are selected randomly from their populations; (ii) the distribution of the population follows normal distribution; and (iii) the variance of the population is homogenous. If one of the assumptions is violated, non-parametric tests should be used. Non-parametric tests have the advantage of being suitable to test small samples with ( $n < 30$ ).

If a heuristic is run more than 30 times on a benchmark data set, a  $t$ -test could be used (Montgomery and Runger 2007). In the  $t$ -test, the mean of the solutions,  $\mu$ , of the two heuristics considered is calculated and compared. The  $p$ -value of the test defines “the smallest level of significance that would lead to the rejection of the null hypothesis  $H_0$  with the given data” (Montgomery and Runger 2007, p. 300). The  $p$ -value is compared to  $\alpha$ , significance level. If the  $p$ -value is smaller than  $\alpha$ ,  $H_1$  is accepted and it is concluded that both heuristics differ significantly ( $\mu_1 \neq \mu_2$ ). Otherwise,  $H_0$  cannot be rejected. The common values for  $\alpha$  are 10% or 5%.

In addition to statistical tests, we can plot the experiment’s results and tabulate them to highlight the difference between heuristics (Beiranvand et al. 2017). For example, the change of the best solutions found by a heuristic could be plotted versus the number of iterations. The best solutions found by a heuristic in different runs can be tabulated and compared to other heuristics by calculating the difference between them, a gap.

## 7 Assessment

Students work in groups to solve the routing problem, like the one described in Section 2 with their respective tasks (Section 2.2), implementing the heuristics in Python and comparing the heuristics described. First, students should select a problem to solve. Then, they design their experiments and run them. Finally, the results collected should be tabulated and analyzed in a group report. In advanced challenges, students modify the heuristics to become more agile by introducing biased randomization (the material is available on Moodle).

The group report is submitted to a tutor for feedback on the analysis and the experiments performed. Students use this feedback to assess their work and benefit from it in their future analyses. In addition, students can have group discussions to discuss their findings and ideas.

## Abbreviations

GRASP	Greedy Randomized Adaptive Search Procedure
IoT	Internet of Things
OP	Orienteering Problem
TOP	Team Orienteering Problem
TSP	Traveling Salesman Problem

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## 1 Template Didactical Concept — Handout for Teachers

Title Name of the Concept

Heuristics to Solve the Team Orienteering Problem

Lab Environment

X-Heuristics in Intelligent Transportation, Sustainable Logistics, and Smart Cities.

## 2 Didactical Analysis

Students should utilize Python to optimize a given function. Then, they are asked to construct their Python code for the greedy randomized adaptive search procedure (GRASP) and the Clarke & Wright Savings (CWS) heuristic to solve the team orienteering problem (TOP).

Target Group

The course targets bachelor's and master's students in industrial engineering, statistics, and logistics. These students need basic programming knowledge, analytics, applied optimization and simulation, data plotting, scientific paper reading, and report writing. The requirements target beginners, while optional exercises target advanced or expert students.

Institutional Requirements

The primary resource is a computer and access to the material. A Python language environment should be installed, e.g., Pycharm, to run experiments. The tutor needs to be familiar with the problem presented and the Python code used to solve it. These problems are fundamental in transportation and logistics, and the Python programming language is one of the easiest programming languages. Students may raise questions regarding running experiments and debugging the code.

Learning Objectives

- Students should remember and define the TOP.
- Students should be able to reproduce program codes to solve the TOP.
- Students should understand the basic heuristic used to solve the TOP.
- Students should apply the heuristic learned to solve the TOP's instances.

- Students should analyze the results obtained.
- Students should evaluate their code and modify it.
- Students should be able to describe their results in a report.

### Subject Matter

This handout is related to the “Heuristics to Solve the Team Orienteering Problem” educational chapter. In this chapter, the GRASP and Clarke and Wright heuristics are introduced. In addition, implementation of Python is presented. The explanations are presented as videos in the Moodle course, and additional reading is recommended.

## 3 Didactical Concept

### Methodical Implementation

- The concept of chapters is presented in a video, where the problem and the heuristic to solve it are presented.
- The students are asked to be divided into groups with 2 to 3 students per group to work on the exercises; thus, the learning is collaborative.
- A bigger group discussion could be arranged for all students in some circumstances.

### Media

The material required is explained in videos (uploaded on the Moodle course). In the next version of the course, quizzes could be added there.

### Learning Organization

Students work in groups; thus, students interact with their colleagues in their group. Further discussion could be arranged between groups, especially for optional exercises. These students could use the video conferencing platforms for meetings and discussions. The students could contact the tutor if they do not find an answer to their question or need more help. The videos are about one hour long, and students require discussions after the video and to do experiments; thus, the lecture's content and exercises are scheduled to last two weeks.

### Feedback and Evaluation

Students should present their experiment results as plots/reports and explain their findings. Thus, the evaluation could be based on their analysis and understanding of the presented concept. Each chapter is evaluated after two weeks of its release, and the evaluation may include suggestions to improve the analysis. This feedback enhances students' learning and their analysis.

### Expert Tips

Similarly to the situation in any programming lab, students raise many basic questions regarding code implementation. Students should be advised to use the debug to understand the code and rectify their errors.

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*Jannicke Baalsrud Hauge and Wajid Khilji*

## Smart Production Logistics Concepts

### 1 Didactical Preface

#### 1.1 Overview of Didactical Fundamentals

Effort in lecture hours (given by the teacher and facilitator)	Theory: 90 min (if on site 2 classes, if remote 3x30) Safety introduction 45 min on site, 30 min remote Lab operation 60 30 min of debriefing after class
Effort Self-study (flipped classroom)	Preparation 10h incl. replay 10h for report analysis
ECTS	1 ECTS
Prerequisites	None, this is an intro course, but basic knowledge on actuators and sensors is an advantage
Additional information	To do the experiment, passing the safety test is required A facilitator and a technician need to be on-site in the lab
Adaptability	The students should submit lab reports afterwards The usage of the digital twin is flexible. We have a different set of theory if a class is on an advanced level

#### 1.2 Keywords

Internet of Things, CPS components, SoA, Barriers, CPS application in production logistics

#### 1.3 Learning objectives

- Understand the system architecture
- Know the different components of a CPS system
- Understand how CPS and its components can be applied to improve different aspects of logistics
- Know about the main barriers to implementation
- Know relevant frameworks for standardization in CPS

## 1.4 Target Group

The course is designed to introduce students at the undergraduate level to cyber-physical applications in production logistics as a part of a smart production concept. It is designed for students in sustainable product development, but it is also usable for students of business administration and for vocational training at different levels. We also use the same digital twin but a different chapter for the master's students in sustainable product development.

## 2 Use Case

### 2.1 User Story

The cost of logistics is often high, but with a minimal value-added contribution [3,4], and consequently, stakeholders are looking into how to use technology to offer the same or better services at a lower cost. The focus of this unit is to use digital twins either as an on-site lab or as a remote lab. The objective is to investigate how digital twins can contribute to supporting the decision-making process of selecting the right components for a specific company both in relation to the degree of automation and the digitalization of the operations. A summary of the lab environment is given below.

A core component is connecting equipment and RTLS, since these are a prerequisite for being able to realize transparent and efficient material flow from a warehouse to a production site. The initial demonstration scenario is to kit three different parts into two different kits by introducing a UR collaborative robot, an AGV, a Kinect vision system, and an RTLS. The AGV transports the parts from their storage position to the UR robot station, which performs the kitting with the help of the vision system. The digital twin is used both with pure simulation data as well as with data from what we already have in operation, which is currently mostly related to the integration and interaction of the AGV and picking robot, investigating how the AGV is doing its mission scheduling, and how this can be improved. A main action for the latter is to compare the simulated optimized route in the digital twin to the one the AGV actually chose in the physical environment, and investigate how to best realize the part of the physical environment for the quality checkpoints and how to embed this best in the material flow.

In order to investigate the problems mentioned in section 2, the physical objects and the digital twin are integrated into a single system, whose components communicate via a data streaming bus. This system interconnects all the components to make use of the digital twin in a real-world scenario. As a first step, communication between each component was realized. A data streaming bus, which will hold and send messages wherever needed was chosen for this purpose. Secondly, there is an application layer, which is required in order to write business logic or calculations. In addition, data storage and the digital twin ought to be connected through the application layer. Figure 1 shows the system architecture for the production logistics digital twin.

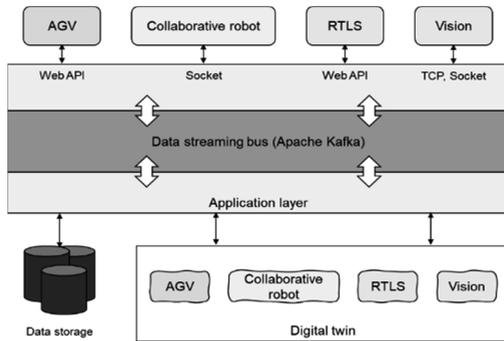


Fig.1. Production logistics digital twin system architecture

In the digital environment, replica components of the physical environment are defined. Each replicated component has to go through the data streaming bus and application layer to send and receive information from the physical environment since the operating systems, data formats, and communication methods are different in each component. The next paragraphs describe communication between the components in more detail: A) The AGV communicates via web API. The results of this API are not only location data, but also various parameters, such as battery status, speed, and orientation of the AGV, which may deliver additional valuable information for logistics operations. Of specific relevance is to know that the AGV uses its own coordinates system. This is translated into the digital twin model to align it with the physical environment. B) The collaborative robot uses a pre-defined language to program and communicate with the external world. In this case, the robot communicates via a TCP socket connection, in which

the robot is treated as a server and connected via a TCP client application. The robot sends six angular rotations to the unity model (digital twin), for simulation. C) The RTLS is used to identify various locations of the components in an indoor location system. The RTLS system uses API to retrieve location data on these various objects. D) The vision system is currently built by using Microsoft Xbox Kinect. The vision system is currently working via a C# program with the help of an OpenCV wrapper, called EM-GU. So far, we have been using Haar's classifier method for deep learning mechanisms to identify an object. The vision system elaborates coordinates from a recognized image, which Xbox Kinect contains in properties of an image object that have X, Y, and Z coordinates. Coordinates will be sent to a middleware that translates them into the collaborative robot coordinates. E) To visualize the digital twin, Unity is used. Along with some complex prefabs like the AGV and collaborative robot, delivered by the supplier or modeled using IPS Each controller is responsible for fetching data or controlling the machine. The digital twin can visualize the track of the AGV to analyze deviations. F) Data storage is used for the long-term data solution for data analytics or data mining. This will help to create a way to replay a particular scenario. Message brokers can be used instead, but later there will be a need to store data for a longer period of time. This layer is important to unify the data transport layer. It provides an opportunity for replication. In addition, there will be a single point of data disposal and retrieval, which makes it easier for many other devices that need data from a single point.

More information can be found in the referenced articles under additional material.

## 2.2 Tasks

Tasks for students:

- Read the chapter below
- Open the virtual lab and explore the different components (we can use inquiry-based, problem-based, or project-based learning here)
- Watch the two different videos on material handling—identify 10 changes in terms of changes
  - Operational processes
  - Safety issues
  - Efficiency
  - Personal integrity
  - Quality of operation

- Discuss with your co-students the changes you observed. How will this affect future needs in terms of
  - Working environment?
  - Skills development in the workforce?
  - Internal organization?

Self-test

- Define the components of the system to be deployed (e.g., sensors, devices, actuators, storage entities, mobile app);
- Define the functionalities of each component
  - e.g., sensors read data related to different operations, the devices collect data from sensors and forward them to the central entity and/or process them to control actuators
- Outline the data flow among the different components
  - e.g., sensor data goes from IoT nodes to the central entity, from the central entity to the mobile app.

Exercise

- Remote Lab exercise
- Deliver lab report

2.3 Learning Resources

- Script (see below)
- A set of articles
- Example articles:
  - Baalsrud Hauge, J.; Zafarzadeh, M.; Jeong, Y.; Li, Y.; Ali Khilji, W.; Larsen, C.; Wiktorsson, M (2021) Digital twin testbed and practical applications in production logistics with real-time location data
  - Barreto et al. Industry4.0 implication in logistics; [https://ac.els-cdn.com/S2351978917306807/1-s2.0-S2351978917306807-main.pdf?\\_tid=f5a8ca13-498d-4064-94f2-b945083ca1d4&acdnat=1553020335\\_a994bf025db102fd694707c668a1ca97](https://ac.els-cdn.com/S2351978917306807/1-s2.0-S2351978917306807-main.pdf?_tid=f5a8ca13-498d-4064-94f2-b945083ca1d4&acdnat=1553020335_a994bf025db102fd694707c668a1ca97)
  - H.Deramy: Architectural Design Principles For Industrial Internet of Things, Ch. 2–3 <http://www.diva-portal.org/smash/get/diva2:1199862/FULLTEXT01.pdf>
  - K.L.Goeddecke: Development of a Cyber-Physical Logistics System in an Industrie 4.0 Environment, Chapter 4 ;<https://www.iwi.uni-hannover.de>

/fileadmin/wirtschaftsinformatik/Abschlussarbeiten/K\_MA\_Goedecke.pdf

- Zafarzadeh, M., Baalsrud Hauge, J., Wiktorsson, M. (2019) Real-time data gathering in production logistics: A research review on applications and technologies affecting environmental and social sustainability; Full Paper Template (diva-portal.org)

### 3 Introduction: Smart Production Logistics

The term Industry 4.0 aggregately alludes to a wide scope of current ideas, whose reasonable order concerning control as well as their exact qualification is unbelievable in singular cases. In the following, accompanying basic ideas are recorded [1]

**Smart Logistics:** In the following five to 10 years, smart supply chains will exert a solid pull on the worldwide economy. The change in perspective is already in progress, as linear and sequential supply chain activities move to a digitized, open framework—part of Industry 4.0—that boosts machine abilities with high throughput and limited resources. [1]

**Cyber-physical Systems:** The physical and the computerized level blend. In the event that this covers the level of generation as well as that of the products, frameworks rise whose physical and computerized representation cannot be separated in a sensible way any longer. A case can be observed within the area of preventive upkeep: Handle parameters (stretch, beneficial time, etc.) of mechanical components and basic (physical) wear and tear are recorded carefully. The genuine condition of the framework comes about from the physical object and its computerized process parameters. [1]

**Self-organization:** Existing manufacturing frameworks are becoming progressively decentralized. This comes together with a deterioration of classic generation progression and a shift towards decentralized self-organization. [1]

**New systems in distribution and procurement:** Dispersion and acquisition will be progressively individualized. Associated forms will be taken care of by utilizing diverse channels. [1]

**New systems in the development of products and services:** Product and service improvement will be individualized. In this setting, the approaches of open development and item insights as well as item memory are of exceptional significance. [1]

**Adaptation to human needs:** New manufacturing systems should be designed to meet human needs instead of the reverse. [1]

**Corporate Social Responsibility:** Sustainability and resource efficiency are continuously at the center of the plans of mechanical manufacturing processes. These variables are principal system conditions for successful products. [1]

#### 4 ILO 1: Know the different components in a CPS

This course is embedded in a bigger context. The table below gives an overview of what we have in the different levels for different types of studies. The one in this chapter is bachelor-level engineering.

Topic	Bachelor's	Master's
Components of CPS system	Engineering, Business	Engineering Business
Computer and its different components	Engineering, Business	
Embedded Systems		Engineering, Business
Enterprise Software Systems		Engineering, Business
Real-time Information Processing		Engineering, Business
Software design	Engineering, Business	Engineering, Business
Modularization		Engineering
Software development		Engineering

##### 4.1 Components of a CPS System

A cyber physical system is comprised of cyber components and physical components. That is why it is known as a cyber physical system. A CPS is based on information processing in computer systems, which is embedded into many products, like a car, planes, microwave ovens, or other devices. These computer systems are used to perform specialized tasks.

For example, in a plane, an embedded system would be the autopilot system to control the trajectory of the aircraft or set the altitude, speed, and direction. This computer system interacts with the outside physical environment with the help of sensors and actuators. These embedded systems are no longer standalone; they share their data via communication networks such as cloud data Warehouses via the internet, where data from many embedded systems can be collected and processed, thus creating a system of systems. Connected embedded systems, moreover, can be controlled and decentralized by a computational unit.



## Embedded Systems [2]

### 4.1.1 Examples of physical Components

1. Actuators (Maybe can add images?) elbows of a robot—use videos
2. Sensors—accelerometer maybe—and usage.
3. Computer system—videos
4. Embedded System—videos
5. Visioning system—different types of them

**Actuator:** The pressure driven actuator consists of a barrel or liquid engine that uses hydraulic control to encourage mechanical operations.

[https://www.youtube.com/watch?v=5CkJGRsoBcs&ab\\_channel=Firgelli-Automations](https://www.youtube.com/watch?v=5CkJGRsoBcs&ab_channel=Firgelli-Automations)

TASK: What is the function of air in an actuator?

**Sensor:** A sensor is a device that measures physical input from its environment and changes it into information that can be translated by either a human or a machine.

[https://www.youtube.com/watch?v=5b5xJu8KYrc&ab\\_channel=RealPars](https://www.youtube.com/watch?v=5b5xJu8KYrc&ab_channel=RealPars)

TASK: What are the 4 industrial revolutions?

**Computer system:** A computer system is a set of integrated devices and peripherals that is used in many modern offices and industries. Its functions are to input, output, process, and store information and data.

**Embedded system:** A type of computer system that is installed in many electronic devices, such as microwaves, aircrafts, and cars.

**Visioning System:** Vision systems offer assistance; collaborative robots perform assignments such as assessing, recognizing, tallying, measuring, or

reading barcodes. Ultra-high-speed imaging and focal point quality encourage multi-operations in one process.

[https://www.youtube.com/watch?v=3Re8EV3jQ6o&ab\\_channel=CognexTV](https://www.youtube.com/watch?v=3Re8EV3jQ6o&ab_channel=CognexTV)

#### 4.1.2 Examples of Cyber Components

1. Networks—network diagrams—Add tasks—why they are important?
2. Database—Add tasks
3. Augmented reality (is not the focus in this unit)
4. Virtual reality (is not the focus in this unit)
5. Graphics

**Networks:** A computer network is a group of computers connected with each other. It allows all the computers to communicate with each other and share their assets, information, and applications.

[https://www.youtube.com/watch?v=cNwEYkx2Kk&ab\\_channel=NetworkDirection](https://www.youtube.com/watch?v=cNwEYkx2Kk&ab_channel=NetworkDirection)

Long video

**TASK:** What is the difference between a Switch and a Router?

**Database:** A structured set of data stored in a computer system, especially one that is accessible in different ways or locations.

[https://www.youtube.com/watch?v=Tk1t3WKK-ZY&ab\\_channel=LinuxAcademy](https://www.youtube.com/watch?v=Tk1t3WKK-ZY&ab_channel=LinuxAcademy)

**TASK:** What is the difference between a Relational and a Non-Relational Database?

**Augmented Reality:** This is a technology that is used to superimpose a computer-generated picture onto a user's view of the genuine world, hence giving a composite view.

**Virtual Reality:** a computer-generated environment with scenes and objects that appear to be real, making the user feel they are immersed in their surroundings. The computer-generated recreation of a three-dimensional picture or environment that can connect the user with the computer-generated object, individually using extraordinary electronic hardware, such as a protective cap with a screen interior or gloves fitted with sensors.

**Computer Graphics:** Computer Graphics include technology to present visual representations of graphical data. The Method transforms and presents data in a visual shape. Computer design has become a common component in client interfacing, TV commercials, and motion pictures. Graphical representation can be done using a web, desktop, or mobile applications, or by building a digital twin system using gaming engines.

## 4.2 Embedded Systems

As its title suggests, embedded in an embedded system implies something that is connected to another thing. An embedded system can be thought of as a computer equipment framework with a computer program embedded in it. An embedded system can be an autonomous system, or it can be a portion of a huge system. An embedded system may be a microcontroller or chip-based system, which is outlined to perform a particular task. To illustrate, a fire alert is an embedded system: it will immediately sense smoke, but it is limited to sensing smoke only.

A typical embedded system consists of three components:

- Hardware.
- Application software.
- Real-Time Operating system (RTOS), which is an operating system specifically designed to perform specific tasks. It lets the processor perform processes as per scheduling by following a chain of commands to control latency.

Apparently, we can describe an embedded system as a Microcontroller-centered, software driven, and reliable real-time control system.

### 4.2.1 Characteristics of an Embedded System

**Single-functioned**—An embedded system more often than not performs a specialized operation and does the same thing more than once, i.e., a pager continuously functions as a pager.

**Tightly constrained**—All computing systems have imperatives on design metrics, but those in an embedded system can be particularly tight. Design metrics could be the degree of a system's highlights such as its cost, measure, power, and execution. They must be able to fit on a single chip, must perform quickly enough to prepare information in real time, and devour least power to extend battery life.

**Reactive and Real time**—Numerous embedded systems must persistently respond to changes within the system's environment and must compute certain results in real time without any delay. Consider the case of a car cruise controller; it persistently screens and responds to speed and brake sensors. It must compute increasing speed or decelerations more than once inside a restricted time; a deferred computation can result in failure to control the car.

**Microprocessors based**—This embedded system must contain a microprocessor or microcontroller.

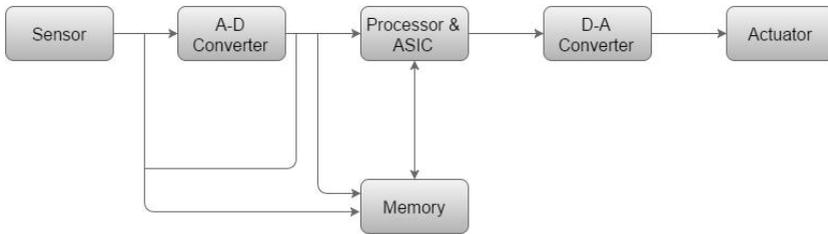
**Memory**—It must have a memory, as its computer program more often than not inserts ROM. It does not need any auxiliary memories within the computer.

**Connected**—It must have associated peripherals to associate input and output devices.

**HW-SW systems**—Program is utilized for more highlights and adaptability. Equipment is utilized for performance and security.

#### 4.2.2 Basic Structure of an Embedded System

The diagram below depicts the basic structure of an embedded system:



#### *Embedded System [8]*

**Sensor**—It measures the physical amount and changes it into an electrical signal which can be studied by a spectator or by any electronic instrument like an A2D converter. A sensor stores the amount measured in the memory.

**A-D Converter**—An analog-to-digital converter changes the analog signal sent by the sensor into a computerized signal.

**Processor & ASICs**—Processors handle the information to measure the output and store it in the memory.

**D-A Converter**—A digital-to-analog converter changes the computerized information bolstered by the processor into analog data.

**Actuator**—An actuator compares the output given by the D-A Converter to the real (anticipated) output stored in it and stores the affirmed output.

#### 4.3 Real-Time Information Processing

A real-time information processing system is able to take input of rapidly changing information and after that give output almost immediately so that change over time is seen promptly in such a system. To illustrate, a radar

system depends on a nonstop stream of input information which is prepared by a computer to uncover the number of various aircraft flying inside the extended area covered by the radar and after that show it on a screen so that anybody looking at the screen can know the real location of an airplane at that moment.

Real-time information handling is additionally called stream processing because of the nonstop stream of input information required to abdicate output for that minute. Good examples are online bookings and reservations, e-commerce order processing, and credit card real-time fraud detection. The greatest advantage of real-time information processing is immediate results from input information, which guarantees everything is up to date. Batch handling, on the other hand, implies that information is now not up to date.

#### 4.3.1 Digital Twin System as an Example of Real-Time Information Processing

A digital twin could be a virtual demonstration of a process, product, or service. This blending of the virtual and physical worlds permits information to be investigated and systems to be checked to head off issues before they even happen, anticipate downtime, develop new opportunities, and even plan for the longer term by utilizing simulations. It requires precise data exchange between different devices to work consistently. With the development of 5G, it will be conceivable to work in true real time.

#### 4.4 *Software Design*

Software design is a process used to convert client prerequisites into an appropriate frame, which enables the software engineer to program, code, and implement software. To survey client prerequisites, an SRS (Software Requirement Specification) document is compiled, while as far as coding and execution are concerned, more particular and point-by-point prerequisites are needed in computer programming terms. The output of this process can straightforwardly be utilized in programming languages. Software design is the primary step in an SDLC (Software Design Life Cycle), which moves the concentration from issue space to arrangement space. It tries to indicate how to fulfill the necessities specified in SRS.

#### 4.4.1 Software Design Levels

Software design yields three levels of results:

**Architectural Design**—The architectural design is the most noteworthy theoretical form of the system. It recognizes the software as a system with numerous components in connection with each other. At this level, the creators thought of a proposed arrangement domain.

**High-level Design**—The high-level design breaks the ‘single entity-multiple component’ concept of structural design into the less-abstracted view of subsystems and modules and delineates their interaction with each other. High-level design centers on how the system’s components can be executed in the form of modules. It identifies the measured arrangement of each subsystem and their linking and interaction among each other.

**Detailed Design**—Detailed design bargains with the implementation portion of what is seen as a system and its subsystems within the previous two designs. Detailed design is more detailed concerning modules and their execution. It characterizes the logical structure of each module and their interfaces to link with other modules.

#### 4.5 Modularization

Modularization could be a strategy to isolate a code into numerous discrete and independent modules, which are anticipated to be competent to carry out task(s) freely. These modules may work as fundamental constructs for the complete computer program. Creators tend to design modules in such a way that they can be executed and/or compiled independently. Modular design inadvertently follows the rules of the ‘divide and conquer’ problem-solving methodology, which is often since there are numerous other benefits connected with the modular design of software. [10]

##### 4.5.1 Advantages of modularization:

- Smaller components are easier to maintain
- Program can be divided based on functional aspects
- Desired level of abstraction can be included in the program
- Components with high cohesion can be reused
- Concurrent execution can be made possible
- Desirable from in terms of security

#### 4.5.2 Concurrency

All computer programs are designed to be executed consecutively. By consecutive execution we mean that the coded instructions will be executed one after another, inferring that one part of a program can be activated at any given time. Say, a software program has different modules, then only one of all of its modules can be active at any time of execution. In software design, concurrency is actualized by dividing the computer program into different autonomous units of execution, like modules, and executing them in parallel. In other words, concurrency enables the program to execute more than one portion of code in parallel with each other. It is essential for the software engineers and architects to recognize those modules which can be executed in parallel. [10]

#### 4.5.3 Example

The spell check feature in a word processor like MS Word is an individual module of software that runs together with the word processor itself.

### 4.6 *Software Development*

Software development is the process software engineers utilize to build computer programs. The process, also known as the Software Development Life Cycle (SDLC), incorporates a few stages that provide a strategy for building items that meet specialized specifications and client prerequisites.

The SDLC provides a universal standard that software companies can utilize to construct and improve their computer programs. It offers a characterized structure for development groups to follow during the design, creation, and support of high-quality programs. The point of the IT software development process is to construct viable products inside a defined budget and timeline.

#### 4.6.1 Key steps in the software development process

There are six major steps in the software development life cycle, including:

1. Needs identification
2. Requirement analysis
3. Design
4. Development and implementation
5. Testing
6. Deployment and maintenance

#### 4.6.1.1 Needs Identification

Needs Identification could be a market investigation and brainstorming stage in this phase. Before a firm builds a program, it must conduct a broad showcase inquiry about how to determine the product's practicality. Engineers must identify the functions and services the program ought to provide so that its targeted buyers get the most out of it and find it vital and valuable. There are a few ways to induce this data, using input from potential and existing clients and surveys.

#### 4.6.1.2 Requirement Analysis

In this stage, stakeholders concur on the technical and client prerequisites and details of the proposed product to realize its objectives. This stage gives a nitty gritty diagram of each component, the tasks, and of engineers and testing parameters to convey a quality product.

The requirement analysis process includes developers, clients, testers, project directors, and quality assurance. This is often also the stage where software engineers select the program development approach such as the waterfall or V model. The team records the result of this stage in a Software Requirement Specification document, which teams can continuously counsel during usage.

#### 4.6.1.3 Design

Design is the third stage of the SDLC. Partners will talk about variables such as risk levels, group composition, pertinent technologies, time, budget, project impediments, strategy, and engineering design. The Design Specification Document (DSD) indicates the engineering design, components, communication, front-end representation, and user flows of the product. This step gives a format for designers and analyzers and decreases the chances of imperfections and delays in the finished product.

#### 4.6.1.4 Development and Implementation

Another stage is the development and implementation of the design parameters. The developers' code based on the product's specifications and prerequisites coincides with the previous stages. Following company methods and rules, front-end engineers construct interfacing and back ends, whereas database administrators create significant information within the database. The software engineers, moreover, test and survey each other's code. Once the coding is complete, developers send the product to an environment

within the implementation stage. This permits them to test a pilot version of the program to create performance and coordinate the necessities.

#### 4.6.1.5 Testing

The testing stage checks the program for bugs and confirms its performance before delivery to clients. In this stage, expert testers confirm the product's capacities to make sure it performs according to the requirements analysis document. Testers utilize exploratory testing in case they encounter a computer program or a test script in order to approve the execution of individual components of the program. They notify engineers of defects within the code. On the off chance that designers affirm the imperfections are valid, they will improve the program, and the testers will rehash the method until the computer program is free of bugs and carries on meeting the desired requirements.

##### 4.6.1.5.1 Deployment and Maintenance

Once the computer program is defect-free, the engineers can supply it to clients. After the release of a type of software's production version, the IT program development company creates a support group to oversee issues clients experience when utilizing the product. Support can be useful if there is a minor issue, but serious computer program failures require an overhaul.

#### 4.6.2 Types of software

Software fit into three main clusters based on their usage and application. The popular categories of software are below.

##### 4.6.2.1 System software

Also known as an operating system or OS, system software is the program your computer uses to decipher input commands into machine-readable language. The operating system controls a computer's equipment. Examples of prevalent operating systems utilized in individual computers include the Windows OS from Microsoft, Mac OS utilized in Apple MacBooks, and the Linux-based Ubuntu. Web servers utilize the Apache OS, whereas the UNIX operating system is used to construct proprietary systems.

4.6.2.2 Application software

This type of applications is used by the general public to perform tasks on their computers and smartphones. Well-liked examples are word processing apps, web browsers, media players, picture editing tools, anti-virus software, and even software-as-service (SAS) products.

4.6.2.3 Programming languages

This is the programing language used to produce software systems. It is used solely by coders to make programs. Programming languages include Java, C++, PHP, and Simlab.

5 ILO 2: Understand the system architecture

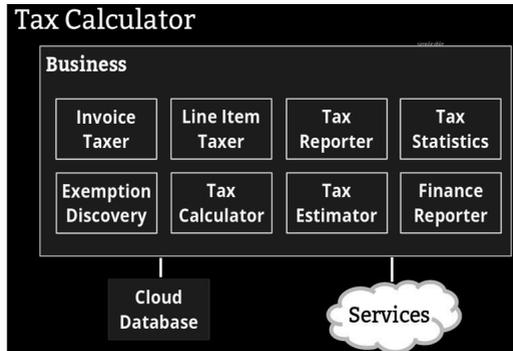
Topic	Bachelor's	Master's
Components of the system architecture	Engineering, Business	Engineering, Business
Basic Architecture types		Engineering, Business
Advanced Architecture types		Engineering

5.1 Components of the System Architecture

System architecture is the structural design of systems. Systems are a class of software that provide foundational service and automation.

5.1.1 Components

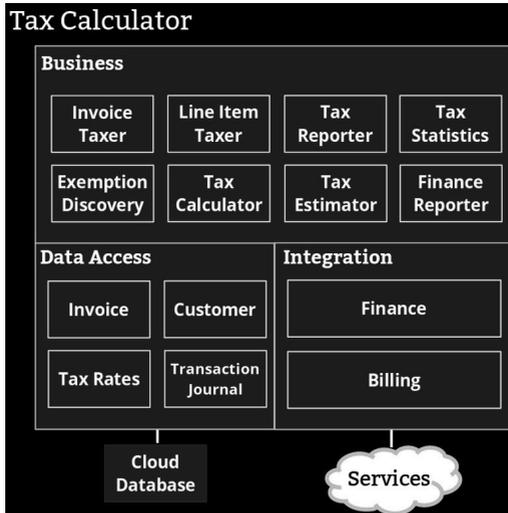
A basic approach to the design is to separate work into components, which are also designed to be reusable. Parts conjointly serve to scale back extraordinarily complicated issues into small, manageable issues. The distinction between a pricey, unstable, low-performance system and a quick, low-cost, and reliable system typically comes all the way down to how well it has been architected into components. For instance, a service for calculating tax for a commerce company may need the following parts. [11]



### Components [11]

#### 5.1.2 Layers

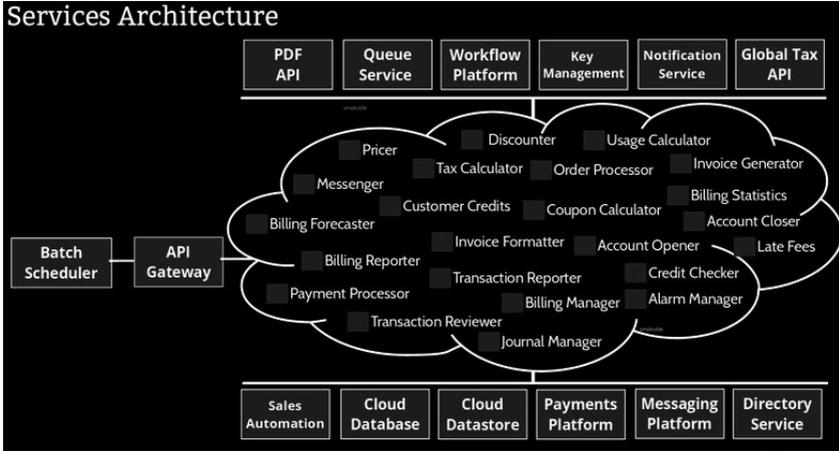
It is common to separate parts into layers. Individual components in numerous layers are loosely coupled so that their implementation is hidden behind an interface. This enables complexity reduction and may cut back the cost of future changes. For example, if a business layer is aware of nothing of how data is stored, then you will be able to change your information without any changes to your business layer.



Layers [11]

### 5.1.3 Services

A service could be a piece of functionality that may be deployed and managed on an individual basis. Services are loosely coupled so that you will be able to work on a service while not impacting the remainder of your architecture. For instance, the Tax Calculator service (above) may be one among dozens of services in a billing system.

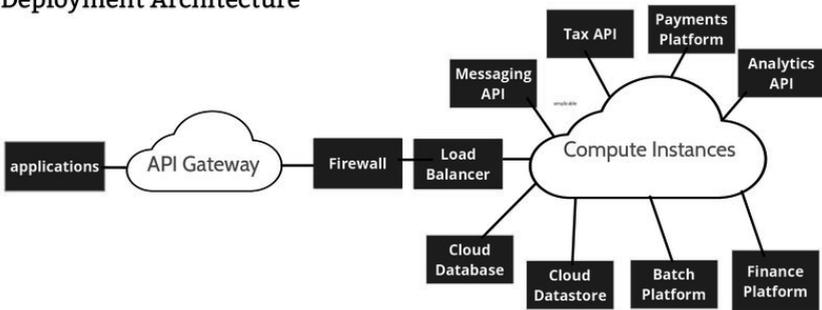


Services [11]

### 5.1.4 Deployment

As services are individually deployed, they permit extreme scalability and dependability. Services can even cut your computing costs as they permit massive systems to be deployed to several instances of cheap hardware.

### Deployment Architecture



Deployment [11]

In order to build and understand a CPS system, it is important to understand the software architecture or system architecture of CPS. In software engineering, there are many examples of software architecture. We will discuss some of the common software architecture patterns, which are also important for CPS.

## 5.2 Basic Architecture Types

- Layered (n-tier) Architecture
- Event-bus Architecture
- Microservices Architecture (SoA)
- Client-server Architecture

### 5.2.1 Layered (n-tier) Architecture

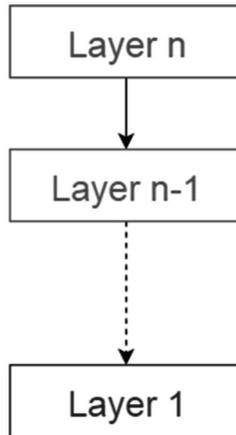
This software architecture pattern creates different levels of abstraction. Each architecture layer provides a service to the next higher-level layer.

The most commonly found four layers of general information are as follows:

- Presentation Layer (AKA UI layer)
- Application Layer (AKA service layer)
- Business logic Layer (AKA domain layer)
- Data access Layer (AKA persistence layer)

Usage:

- Desktop Applications
- E-commerce web applications



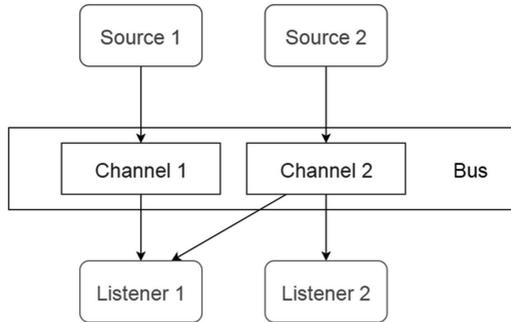
*Layered (n-tier) Architecture [12]*

### 5.2.2 Event-bus Architecture

This architecture type deals with various events and has four major parts. Event source, event listener, channel, and event bus. Sources publish messages to specific channels on an event bus. Listeners subscribe to specific channels. Listeners are notified of messages that are published on a channel to which they have already subscribed. [12]

Usage:

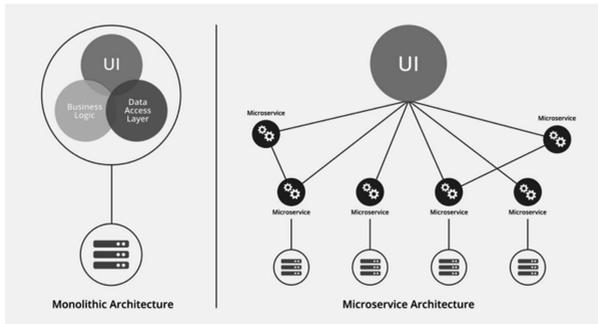
- Android development
- Notification services



Event-Bus Architecture [12]

### 5.2.3 Microservices Architecture (SoA)

This architecture has become the most accepted and well known within the past couple of years. It depends on providing tiny, autonomous modular services, where every service solves a selected issue or performs a special task. And these modules communicate with one another through well-defined API to serve the business objective. [13]



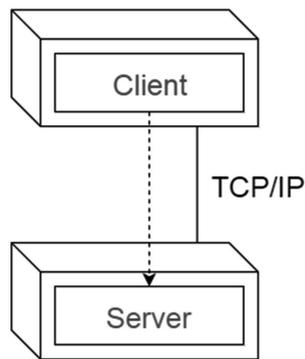
Microservice Architecture [13]

### 5.2.4 Client–Server Architecture

This design comprises 2 parties: a server and various clients. The server component can offer services to numerous client components. Clients ask for services from the server and also the server offers pertinent services to those clients. Besides this, the server proceeds to listen to clients' demands. [12]

Usage:

- Online applications such as email, document sharing, and banking.



*Client–Server Architecture [12]*

### 5.3 Advanced Architecture Types

- Model-View-Controller Architecture
- Broker Architecture

#### 5.3.1 Model-View-Controller Architecture

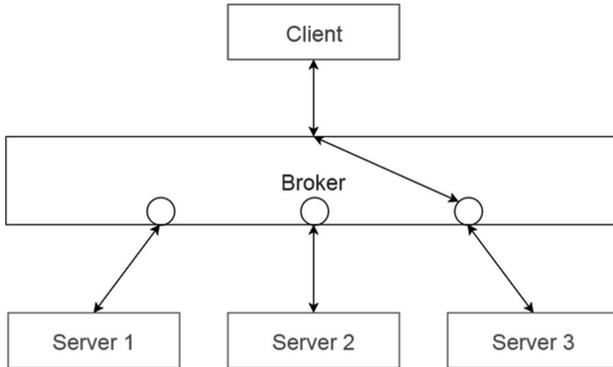
This architecture divides an interactive application into three parts:

- Model—Contains the core functionality of acquiring and storing data.
- View—Contains the functionality of designing and displaying information to the user.
- Controller—Handles the input from the user

This is often done to isolate inside representations of data from the way data is displayed to and acknowledged by the client. It decouples components and permits proficient code reuse.

Usage:

- Web applications



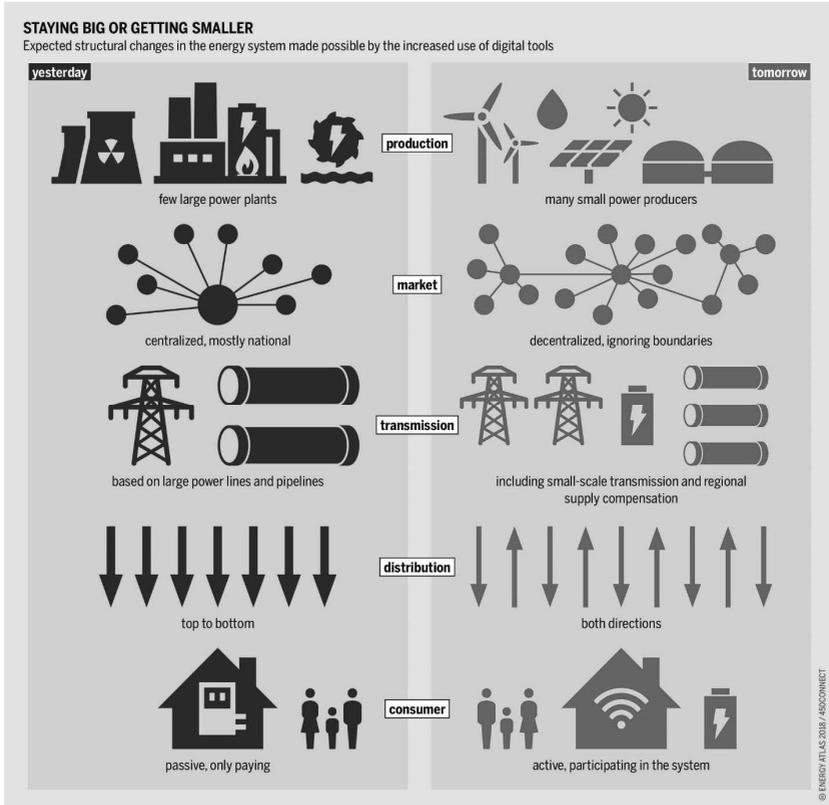
*Model-View-Controller Architecture [12]*

### 5.3.2 Broker Architecture

This design is utilized to structure distributed systems with decoupled components. These components can be connected to each other by remote service invocations. A broker component is usually responsible for the coordination of communication among various components. Servers publish their capabilities (Services and Characteristics) to a broker many times. Clients request a service from the broker, and the broker then directs the client to an appropriate service from its registry. [12]

Usage:

- Message broker software such as Apache ActiveMQ, Apache Kafka, and RabbitMQ



Broker Architecture [12]

**6 ILO 3: Get an overview of how it can be used in logistics — applications**

Topic	Bachelor's	Master's
Smart Grid	Engineering, Business	
Smart Supply Chain Management	Engineering, Business	
Autonomous Guided Vehicle	Engineering, Business	
Healthcare Logistics		Engineering, Business
Automatic Pilot in Avionics		Engineering

In CPS, using physical systems and connecting them via a cyber-system requires knowledge of various domains, such as Information technology, computer networks, software engineering, and robotics. There are various ways in which a logistics system can benefit from CPS. Some common ones are mentioned below: examples related to logistics

- Smart Grid (smart power consumption and distribution)
- Smart Supply Chain Management
- Autonomous automobiles

*6.1 Smart Grid*

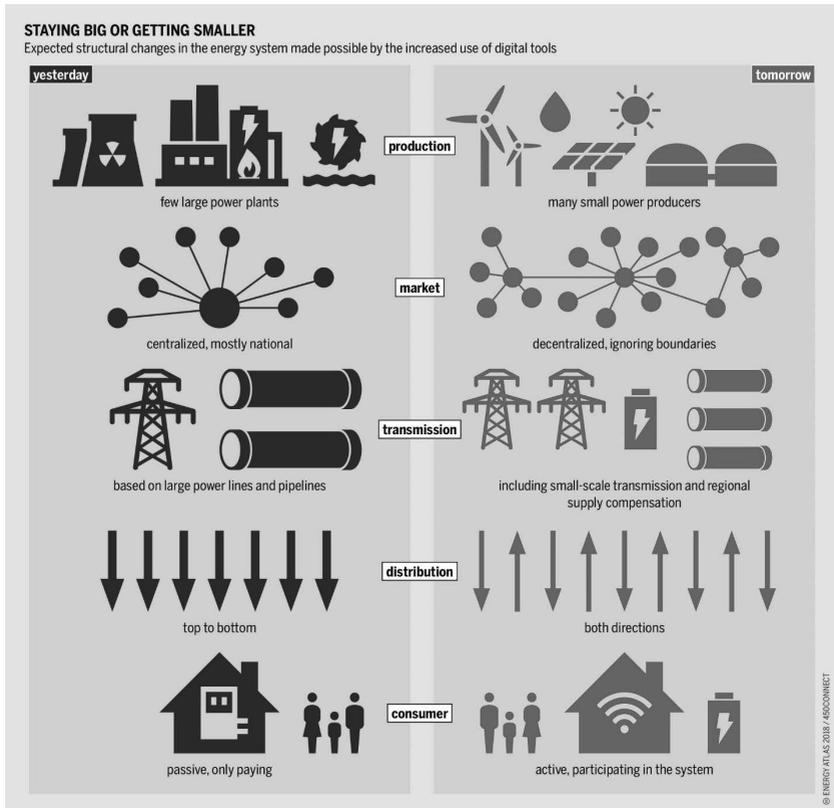
A smart grid is an electrical grid which has a range of operation and energy measures together with smart appliances, smart meters, renewable energy resources, and economical energy resources. [14]

[https://www.youtube.com/watch?v=JwRTpWZReJk&ab\\_channel=U.S.DepartmentofEnergy](https://www.youtube.com/watch?v=JwRTpWZReJk&ab_channel=U.S.DepartmentofEnergy)

TASK: What is Home Area Network?

*6.2 Smart Supply Chain Management*

The scope of supply chain management is vast—it has the potential to reinforce each supply chain function, from inventory prediction to demand and supply management. Applied properly, smart supply chain management may revolutionize strategic decision-making, creating a really agile and optimized ecosystem. Even simply an increase of a tenth in potency is well worth the effort, netting an organization the maximum amount of \$276 billion in fifteen years. Plus, analysis has shown that about 80% of corporations with leading supply chain operations achieve above-average revenue growth. [15]



## Smart Grid [14]

### 6.3 Autonomous Automobiles

An autonomous vehicle may be a vehicle which will drive itself with no input from a human driver. These kinds of vehicles are called self-driving cars, driverless cars, or robotic cars.

Computer-controlled and wheel-based, automatic radio-controlled vehicles (AGVs) are load carriers that follow the ground of a facility without an operator or driver on board. Their movement is directed by a mix of software systems and sensor-based steering systems. Because they travel a certain path with precisely controlled acceleration and deceleration, and

embody automatic obstacle detection bumpers, AGVs offer safe movement of loads. Typical AGV applications are the transportation of raw materials, work-in-process, and finished goods in support of creating production lines, and storage/retrieval or alternative movement in support of selecting in warehousing and distribution applications. [16]

There are several types of AGVs. These include:

- **Automated carts**—These are the simplest kind of AGV with the least features for the lowest-cost implementation.
- **Unit load AGVs**—This is the kind of individual vehicle that transports loads (typically bins, pallets, carts, or bundles) on forks or on the AGV's deck. Roll-handling AGVs explicitly handle heavyweight rolls of steel or paper.
- **Tugger AGVs**—This type of powered units can pull a series of non-motORIZED trailers that each carry a load.
- **Automated forklift AGVs**—The type of existing forklift trucks, whose controls have been altered to allow pilotless operation

Typically, battery-powered AGV systems incorporate multiple vehicles that navigate pre-defined paths. Vehicles navigate within the facility using many steering technologies together with floor-surface mounted magnetic tape or bars, lasers, optical sensors, and magnets/gyroscopes primarily based on inertial navigation. These steering technologies make it simple to alter the routes and expand the AGV system in response to facility changes for a versatile and scalable material handling solution. [16]

For real-time control and observation of multiple AGVs, computer-based software systems use wireless connections to gather information concerning every unit's current location, and then interface with a software system for destination and routing logic. The software package directs the vehicles by wirelessly communicating specific tasks to the AGVs via radio frequency (RF). Directions include stops, starts, dynamic speed, lifting, lowering, multi-point turns, reverses, diversions from the prescribed path, and interfacing with alternative material-handling instrumentation and systems—both machine-controlled and static.

AGVs are used in a range of areas to support handling and processing throughout a facility:

- **Assembly:** AGV moves products through production processes
- **Kitting:** AGV collects parts for assembly
- **Transportation:** AGV loads and reloads loading pallets and loose parts

- **Staging:** AGV delivers pallets for production processes
- **Warehousing:** AGV moves items from stretch wrappers to docks or storage

**Order picking:** AGV moves ordered items to trailer-loading zone for delivery, and moves a platform for a picker to place designated items on

**Parts/just-in-time (JIT) delivery:** AGV tows trailers carrying parts or materials to consumption zone

**Transfer/shuttle:** AGV transfers loads across high traffic aisles

## 7 ILO 4: Know about the main barriers to implementation

Topic	Bachelor's	Master's
Barriers to Smart Manufacturing	Engineering, Business	
Barriers to AI adoption		Master's

### 7.1 Barriers to Smart Manufacturing

Technology is not a roadblock to the present endeavor; in fact, the technology is already here. On discussing the barriers to smart manufacturing throughout the session, the audience unanimously agreed that technology was not an element in this respect. They provided the subsequent list of barriers: [19]

**Economic:** Decision makers cannot always see the benefits of actualizing innovation into the manufacturing process. Whereas some decision makers can be paralyzed by the investment and exertion of procuring modern innovation, specialists must see past the starting investment, considering the time and money that will eventually be gained by joining such an environment.

**Social/Cultural:** This is often the more common complaint that encompasses most developments. It is often related to different aspects, like lack of organizational preparedness, reluctance towards technology implementation and uptake. This happens when there is an uncovered need for direct implementation and execution of new technology from a technical perspective, but appear to be working fine with the status quo to the users or decision makers. One audience member referenced the popular quote from Jim Collins, “Good is the enemy of great,” to summarize the acknowledgment of keeping the manufacturing plant in its current state.

**Security:** The expanding utilization of connected devices inside plants and along supply chains causes numerous clients to inquire, “Is our data safe?” Avoidance of security risks begins with quality merchants and analy-

zing vulnerabilities at each “touchpoint”. An audience member referenced a “Hack-a-thon” that their plant had conducted to test zones of weakness inside their connected systems. Once these boundaries were recognized, the discussion at that point turned to a dialog on how they can start a journey toward Smart Manufacturing. [19]

## 7.2. Barriers to AI adoption

**Fear of AI:** Whereas the fear of terminators invading the office is one take, the genuine fear of AI relates to gigantic work losses and unemployment due to robotization. This is an issue that the world must address incrementally as innovation progresses. The automation being utilized presently is centered on monotonous assignments like mail reminders, information extraction and entry, upgrading spreadsheets, and other administrative chores. Coupled with AI and machine learning, contract supervisors, paralegals, and others get instant information investigation on contracts and other records, which improves productivity and gives them more time to deal straightforwardly with clients. [19]

It is presently essentially inconceivable for administrators and other business leaders to manually oversee all requests, contracts, sellers, compliance, and other obligations. AI and computerization complement today’s burdensome workload to grant time back to workers, and rather than doing their occupations for them and making them nonessential, AI makes their workday more effective and compelling. When done right, this eventually leads to more joyful workers and a more advantageous bottom line.

**Mountains of data:** Another obstruction is the enormous amounts of information that companies have collected over the last few decades or more. Where do you start? What can you do with it? How do you keep it secure and compliant with directions? The arrangement here is to not get scared into inaction, as each business can use the information on hand to conduct profitable, predictive analyses. The great news is the more information, the better prepared the AI will be. And as for security, information kept in a single secured system is always more secure than information scattered over a few machines or put away in record cabinets. [19]

**Picking the right algorithm:** Although this is a critical step in creating AI, it is not one that will be made in the starting stages of setting up an AI strategy, unless the company develops their AI completely in house, typically likely a choice to be made by an AI computer program provider. Whether it is an out-of-the-box AI apparatus or a custom-built AI application, businesses can presently actualize AI with as much or as little customization as they need.

**Shortage of data scientists:** This can be a huge problem for the future of AI programs, and there are numerous thoughts on how to unravel the issue. As companies ramp up their efforts to utilize machine learning and AI, data science is becoming a critical component of a successful strategy. But when executing any program, the most vital steps are building up the business's needs which the program will solve and then conveying those needs. Data science plays an imperative part in turning raw information into business value, but current workers that already know the information can be trained, experts can be utilized, and outsourcing this work to sellers is becoming commonplace. [19]

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*Jan Seedorf, Kazim Mazhar,  
Florian Schwabe and Irman Omerovic*

## **Applied Cryptography in the Internet-of-Things**

### Abstract

The educational chapter at hand provides a three-week practical educational unit that aims at teaching students how to apply, enhance, and benchmark state-of-the-art symmetric cryptography in an actual Internet-of-Things (IoT) operating system in a locally virtualized lab environment as well as in an actual remotely deployed lab environment. Existing open-source code will be provided to participants as a starting point. This code essentially applies AES encryption in a basic block cipher mode to IoT messages. The students will then be provided a chain of challenges to enhance this code with more advanced block cipher modes and to execute their enhanced code in a virtualized environment as well as on actual IoT hardware in a remote lab.

The high-level learning objectives for this educational chapter are for students to a) get practical hands-on experience in programming, compiling, and running C programs on an actual IoT operating system, b) learn how to use, optimize, and enhance existing C code (which is provided as open-source code) that applies symmetric AES encryption to IoT messages, and c) learn how to execute and interpret scientific experiments with the goal of benchmarking various AES block cipher modes on different IoT hardware located on a remote IoT test bed.

### Keywords

Applied Cryptography, Advanced Encryption Standard (AES), RIOT-OS

## **Part A—Educational Considerations**

### **1 Preface**

#### *1.1 Didactic Fundamentals*

The target group for this educational chapter is computer science students at the end of their bachelor's degree program. As prerequisites, the students are

required to have essential knowledge in i) Linux-based operating systems, ii) computer programming, and iii) cryptography. Particular knowledge of the C programming language is beneficial but not strictly required as a prerequisite for this educational chapter. Students will be organized into groups that stay the same for the whole educational chapter.

The following further didactic fundamentals are envisioned for this education chapter: i) Effort in lecture hours (i.e. solving challenges in the presence of an instructor/lecturer): 12; ii) Effort for self-study material (i.e. solving challenges without the presence of an instructor/lecturer): 12; iii) Suggested Credit Points (CP): 30% of 5CP.

## *1.2 Learning Objectives and Competence*

### 1.2.1 Competence

The main high-level skills envisioned for students to gain are:

- The ability to write and run C programs that apply symmetric encryption algorithms in an actual IoT operating system
- The ability to execute and interpret scientific experiments in an IoT setting

### 1.2.2 Learning Objectives

The overall learning objectives of this educational chapter are for students to

- get practical hands-on experience programming, compiling, and running C programs on an actual IoT operating system,
- learn how to use, optimize, and enhance existing C code (which is provided as open-source code) that applies symmetric AES encryption to IoT messages,
- learn how to execute and interpret scientific experiments with the goal of benchmarking different AES block cipher modes on various IoT hardware located on a remote IoT test bed.

## 2 Overview

The educational chapter at hand provides a three-week practical educational unit for teaching students how to apply, enhance, and benchmark state-of-the-art symmetric cryptography in an actual Internet-of-Things (IoT) operating system in a virtual—as well as a remote—lab environment.

## 2.1 Practical Teaching Approach

In the course of this educational chapter, existing open-source code will be provided to participants as a starting point. This code essentially applies AES encryption in a basic block cipher mode to IoT messages. The students will then be provided with a series of challenges to enhance this code with more advanced block cipher modes and to execute their enhanced code in a virtualized environment as well as on actual IoT hardware in a remote lab.

The operating system (OS) chosen for this education chapter is RIOT-OS (Baccelli et al., 2018). Experiments will be conducted in two kinds of lab environments by the students:

- running code under RIOT-OS locally, on a virtual Linux machine
- running code under RIOT-OS in a remote IoT test bed on actual IoT hardware (Adjih et al., 2015)

## 2.2 Technical and Methodical Considerations

### 2.2.1 Technical Considerations

Technical requirements for this educational chapter concern only virtualization, as for the remote lab technically an existing IoT lab will be used as a basis<sup>1</sup>. Hence, some form of Linux virtualization environment must be provided for the students, either as a virtualized server environment<sup>2</sup> or as a local virtualization environment running on the students' host OS<sup>3</sup>. The chapter will assume the latter, i.e. Debian Linux as an operating system and Oracle Virtual Box as a local virtualization environment. Adapting the chapter to a virtualized server environment should be straightforward.

### 2.2.2 Methodical Considerations

In terms of the project's methodical implementation, the exercises (referred to as "challenges") are suggested to be provided to students via the online learning platform Moodle<sup>4</sup> (or via a similar learning platform). Participants can then provide feedback via Moodle through a survey that is conducted at the end of the educational chapter. For an overall evaluation of the appropriateness and difficulty of the challenges, time tracking for each indi-

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1 <https://www.iot-lab.info>

2 Such as e.g. VMWare ESXi-Server (<https://www.vmware.com/products/esxi-and-esx.html>)

3 Such as e.g. Oracle Virtual Box (<https://www.virtualbox.org>)

4 <https://moodle.org>

vidual challenge can be provided by participants, e.g. via an Excel timesheet uploaded to the Moodle learning platform.

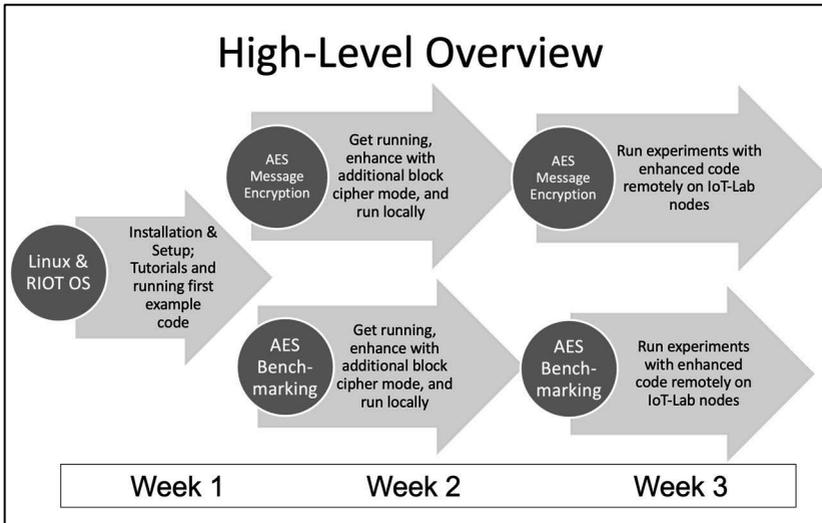


Figure 1: Weekly Overviewed of Lecture Chapter

### 3 Lecture Chapter Outline

The complete lecture chapter with concrete challenges for participants will be provided in the following sections. Here, a short summary of the content of the lecture chapter for each week is given (see Figure 1 for an overview):

- Week 1: Installation and setup of virtual Linux machine and RIOT-OS; Compiling first programs under RIOT-OS and conducting selected RIOT tutorials
- Week 2: Understanding and getting to run existing code (which is provided as open-source code) that applies a) AES encryption and b) AES benchmarking to IoT data in a virtual machine; modifying both types of code to automatize experiments; enhancing the existing code so that additional block cipher modes can be used with AES encryption
- Week 3: Running modified, enhanced code on remote hardware in an IoT lab; executing experiments (with enhanced code) on remote hard-

ware in an IoT lab; scientifically interpreting the results of the experiments

## Part B—Educational Chapter

### 4 Challenges Week 1

The high-level objectives for week 1 are:

- Getting more familiar with RIOT-OS by conducting some basic RIOT tutorials
- Getting RIOT-OS running as a virtualized working environment
- Being able to configure and compile a basic RIOT application with Make-Files

The content in a nutshell for week 1 is:

- Linux VM Installation & Setup
- RIOT Installation & Setup
- RIOT Tutorials

#### 4.1 Challenge 1.1—Linux VM Installation & Setup

##### 4.1.1 Preparation

- Download and install Oracle Virtual Box as a virtualization environment on your host OS<sup>5</sup>.
- Download the current stable version of Debian Linux as a DVD ISO Image<sup>6</sup>.

##### 4.1.2 Installation and configuration

- Install Debian from the ISO Image as a virtual machine under Virtual Box with the following settings:
  - Virtual Box settings: 1GB Ram, Virtual HD Size: 25GB
  - Debian settings: Install with Apache web server and SSH Server
- Configure virtual network settings in Virtual Box to NAT, restart your new Debian virtual machine, and confirm that you have Internet access (e.g. by opening a random webpage of your choice in a browser).

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<sup>5</sup> Available at <https://www.virtualbox.org>

<sup>6</sup> Available at <https://cdimage.debian.org/debian-cd/current/amd64/iso-dvd/>

### 4.1.3 Installing packages

- Get familiar with the apt-get command.
- Verify that you are able to install packages with the apt-get command, e.g. by installing the Firefox browser (if not, check e.g. that your Apt sources are configured correctly<sup>7</sup>).

## 4.2 Challenge 1.2—RIOT Installation & Setup

### 4.2.1 Preparation & repository Cloning

### 4.2.2 Configuring a first test project

- Look at the Make-File in your first\_test directory and try to understand each line in it.
- Configure the Make-File so that the absolute path to the RIOT base directory is correct and that the executable output of your Make-File will be called first\_test.
- Configure the main.c file in your first\_test directory so that it contains a shell command named “whats\_up” that will print out “the roof” when run in the shell<sup>8</sup>.

### 4.2.3 Running a first test project

- Set up your network with the tapsetup command.
- Make and run your first\_test project in two instances, each connected to a different tap device.
- Try out your whats\_up shell command.
- Try sending messages from one RIOT instance to the other RIOT instance with the txtsnd command.

## 4.3 Challenge 1.3—RIOT Tutorials

### 4.3.1 Preparation

- Read the ‘readme’ for the official RIOT tutorials and ensure that your environment is properly prepared for the RIOT tutorials<sup>9</sup>.

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7 See e.g. <https://wiki.debian.org/SourcesList>

8 Similar to the example in <https://github.com/RIOT-OS/RIOT/wiki/Creating-your-first-RIOT-project>

9 See “Preparations” at <https://github.com/RIOT-OS/Tutorials>

### 4.3.2 Task execution

- Conduct tasks 1.1, 2, 3, and 4 from the official RIOT tutorials<sup>10</sup>.

## 5 Challenges Week 2

The high-level objectives for week 2 are:

- Being able to encrypt and decrypt messages with AES in RIOT
- Benchmarking AES with different configurations

The content in a nutshell for week 2 is:

- Using and enhancing existing code that uses AES under RIOT for message confidentiality
- Using and enhancing existing code for benchmarking AES under RIOT

### 5.1 Challenge 2.1—Enhancing AES message encryption with an additional block cipher mode of operation

#### 5.1.1 Repository cloning, running and understanding existing code

- Clone the repository at <https://github.com/flori-schwa/IT-Sec2>.
- Read and reproduce the following tutorials from the README.md on your local system:
  - *Part 4: AES in Electronic Codebook (ECB) mode*<sup>11</sup>
  - *Part 5: AES in Cipher Block Chaining (CBC) mode*<sup>12</sup>.
  - Hint: You may have to make small adjustments in the Make-Files (e.g. RIOT path) to get everything working on your system.
- Try to understand how AES block cipher modes are being used and applied in the code to encrypt short messages.

#### 5.1.2 Enhancing code with an additional block cipher mode

- Besides AES-ECB and AES-CBC, RIOT also supports the following cipher modes by default:

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10 Located at <https://github.com/RIOT-OS/Tutorials> under “Tasks”

11 i.e.: [https://github.com/flori-schwa/IT-Sec2/blob/master/Tutorials/Chapter\\_2\\_Crypto/04\\_AES\\_ECB\\_en.md](https://github.com/flori-schwa/IT-Sec2/blob/master/Tutorials/Chapter_2_Crypto/04_AES_ECB_en.md)

12 i.e.: [https://github.com/flori-schwa/IT-Sec2/blob/master/Tutorials/Chapter\\_2\\_Crypto/05\\_AES\\_CBC\\_en.md](https://github.com/flori-schwa/IT-Sec2/blob/master/Tutorials/Chapter_2_Crypto/05_AES_CBC_en.md)

- CTR (Counter Mode): SP 800-38A<sup>13</sup>
- OCB (Offset Codebook Mode): RFC7253<sup>14</sup>
- CCM (Counter with CBC-MAC): SP 800-38C<sup>15</sup>
- Choose one of the modes above and write a program to encrypt + decrypt string messages with AES in that particular mode.
- Any code in the repository may be freely used as a starting point.
- The RIOT crypto documentation<sup>16</sup> provides an overview of all library functions necessary to solve this challenge.

## 5.2 Challenge 2.2—*Enhancing AES Benchmarking with an additional block cipher mode of operation*

### 5.2.1 Repository cloning and understanding existing benchmarking code

- Clone the repository at <https://github.com/deus778/riot-aes-benchmark>.
- Familiarize yourself with the code and get an understanding of how the benchmarking of the AES algorithm works.

### 5.2.2 Enhancing benchmarking code with an additional block cipher mode

- Extend the existing benchmark code to include your AES block cipher mode implementation from challenge 2.1. Note that you do not want to encrypt/decrypt messages here, instead, you want to fill the input with random bytes.
- When running the benchmark, you should be able to choose between AES-ECB, AES-CBC and the mode you implemented.

### 5.2.3 Running first experiments

- Run multiple benchmarks using different configurations and note how it affects the performance and significance (e.g. standard deviation) of your results.

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13 <https://doi.org/10.6028/NIST.SP.800-38A>

14 <https://datatracker.ietf.org/doc/html/rfc7253>

15 <https://doi.org/10.6028/NIST.SP.800-38C>

16 [https://api.riot-os.org/group\\_\\_sys\\_\\_crypto.html](https://api.riot-os.org/group__sys__crypto.html)

## 6 Challenges Week 3

The high-level objectives for week 3 are:

- Getting enhanced AES message encryption to run in a remote IoT-Lab
- Executing scientific AES benchmarking experiments in a remote IoT-Lab
- Presenting and interpreting results

The content in a nutshell for week 3 is:

- Migrating enhanced AES code to the remote IoT-Lab
- Running experiments in the remote IoT-Lab
- Creating graphs from results and discussing the results observed

### 6.1 Challenge 3.1—Running enhanced AES message encryption in a remote IoT-Lab

#### 6.1.1 Account Creation and SSH access

- Create an account<sup>17</sup> for accessing the remote FIT IoT-Lab test bed<sup>18</sup> (hereafter referred to as “IoT-Lab” or “remote IoT-Lab”).
- Generate SSH keys, associate your SSH key with your IoT-Lab account, and test your SSH access to the IoT-Lab SSH front end at a site of your choice<sup>19</sup>.

#### 6.1.2 Running first experiments

- Read the introduction<sup>20</sup> of the FIT IoT-Lab<sup>21</sup> in order to understand how to run your code on a remote node in the test bed.
- Get to run your AES message encryption code<sup>22</sup> in a selected block cipher mode on a remote node via the web portal<sup>23</sup>.

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17 <https://www.iot-lab.info/testbed/login?next=%2Fdashboard>

18 <https://www.iot-lab.info/docs/getting-started/user-account/>

19 <https://www.iot-lab.info/docs/getting-started/ssh-access/>

20 <https://www.iot-lab.info/docs/getting-started/introduction/>

21 <https://www.iot-lab.info>

22 i.e. your modified and enhanced version of the code from <https://github.com/flori-schwa/IT-Sec2> from last week’s challenges

23 <https://www.iot-lab.info/learn/>

### 6.1.3 Running more experiments

- Run your AES message encryption code with different selected block cipher modes on different remote nodes (i.e. on different board types) via the web portal.

## 6.2 Challenge 3.2—Running enhanced AES benchmarking in an IoT-Lab and executing scientific experiments on a remote test bed

### 6.2.1 Running first manual experiments

- Get your enhanced AES benchmarking code<sup>24</sup> to run on the remote IoT-Lab, e.g. on different selected nodes with various selected block cipher modes.
- You can execute your code in the remote IoT-Lab either via the web portal or via SSH access.

### 6.2.2 Automizing experiments

- Find a way to automate the execution of a multitude of different settings to be run on different boards sequentially.
  - One way of achieving this could be to compile your code in multiple teams with different settings (e.g. with AES-128-CBC, AES-256-CBC, AES-128-ECB, AES-256-ECB, etc.) for each board and then automate the sequential execution of experiments via shell scripts
  - An alternative to achieve automated experiments could be to re-factor the benchmarking code so that it can run multiple AES block cipher modes and different key sizes in a single run, and then compile this re-factored code on different selected hardware boards
  - Hint: A combination of the methods above is certainly possible.
  - Hint: For automation of your experiments, SSH access seems to be the preferred method of code execution in the remote IoT-Lab.

## 6.3 Challenge 3.3—Presentation and discussion of results

### 6.3.1 Graph generation

- Generate result graphs from your results (e.g. by importing .csv-files into Excel).

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24 I.e. your modified and enhanced version of the code from <https://github.com/deus778/riot-aes-benchmark> from last week's challenges

### 6.3.2 Result analysis

- Interpret and discuss your results and graphs. What can you observe and conclude?<sup>25</sup>

## 7 Conclusion

This educational chapter provides a practical three-week course for computer science students with the objective of learning in depth how to apply, enhance, and benchmark state-of-the-art symmetric cryptography in an actual Internet-of-Things (IoT) operating system. Experiments are conducted in a locally virtualized lab environment as well as in an actual remotely deployed lab environment. The basis for this educational chapter is existing code as a starting point, which has been developed specifically for this course and is provided as open-source code. During the course, students enhance this code and run experiments with their enhanced code in weekly challenges, which have been presented in detail.

This educational chapter was successfully conducted in the winter term 2021/2022 at the University of Applied Sciences Stuttgart, Germany (HFT Stuttgart). The detailed challenges provided here contain the experiences of executing this educational chapter in practice, i.e. are aligned and adjusted based on experiences gained, in particular with respect to the time needed by students and, hence, the allocation of challenges to weeks. In general, all challenges were solvable for the students.

Additional resources such as a challenge-evaluation Excel sheet or virtual machines with intermediate states for the individual challenges will be provided by the authors upon request.

## Acknowledgments

This work has been supported by the Digilab4U (Open Digital Lab for You) project<sup>26</sup>, funded by the German Federal Ministry of Education and Research (BMBF) under No. 16DHB2112.

The authors are deeply grateful to Peter Kietzmann, Cenk Gündogan, Matthias Wählich, Thomas Schmidt, and the whole RIOT team at HAW

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<sup>25</sup> For an example of a scientific paper that presents and discusses such scientific results in relation to running cryptography on IoT hardware, refer to (Kietzmann et al., 2021).

<sup>26</sup> <https://digilab4u.com>

Hamburg and FU Berlin for their help in getting us started with cryptography under RIOT-OS and in developing this educational chapter.

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## **Online-MQTT: Online Lab for Basic and Advanced Features of the MQTT Protocol**

### Abstract

The Message Queuing Telemetry Transport (MQTT) application layer protocol is the de-facto first choice in building Internet of Things (IoT) applications. Accordingly, MQTT is being increasingly deployed and configured by experts as well as non-experienced application designers. Furthermore, MQTT is being increasingly used for Industrial IoT (IIoT) use cases, where even mission-critical measurements and commands are shared by machines through MQTT. Being a fundamental component in virtually all (I)IoT projects, a wrong MQTT configuration or use may lead to critical loss or damage. This remarkable popularity of MQTT has resulted in a tremendous need for problem- and task-driven MQTT training with hardware-in-loop, which well suits a wide range of qualification degrees. Precisely, application designers require a remote lab that is scalable, accessible anytime, and involves low-cost machine models. Consequently, we propose Online-MQTT, an online lab for MQTT with hardware-in-loop. Online-MQTT is designed to be used by a wide range of learners while pinpointing selected crucial research gaps and possible solution strategies for spontaneous and/or real-time MQTT communications for machines.

### Keywords

Industrial Internet of Things (IIoT); Message Queuing Telemetry Transport (MQTT); Online-Lab-based IoT Education

## **1 Introduction**

Message Queuing Telemetry Transport (MQTT) is a popular publish-subscribe messaging protocol in the Internet of Things (IoT). MQTT is frequently used by IoT system and application designers in virtually all application

domains, from smarthome to smart agriculture, smart city, Industrial IoT (IIoT), etc. As machines increasingly act as publishers and subscribers, spontaneous communication across machines, i.e., without an explicit pre-configuration at the commissioning phase, is required more and more in IIoT. In addition, the need for real-time communication via MQTT became apparent. Accordingly, relevant MQTT features need to be further developed and in particular made automated and machine-ready. MQTT is easy to use and is consequently being used and configured more and more, even by non-IT users. This makes MQTT a fundamental but critical component in IoT. A wrong configuration by a non-experienced user may lead to serious damage in mission-critical use cases. Therefore, it is essential to offer labs where participants from various education and technical levels can safely experiment with basic and advanced MQTT features. Obviously, such a lab needs to be low-cost, extensible, and trustworthy to scale globally.

Offering a physical MQTT-driven IoT lab requires remarkable personal and monetary efforts. Furthermore, these labs are per se not designed for remote access. Subsequently, they do not scale globally, though such a scale would make the efforts invested more justifiable. Accordingly, it is fundamental to digitalize these labs and offer them to remote users. Unfortunately, enabling meaningful remote access to a physical lab may also be time and cost-intensive.

Besides the publicly available specification of the MQTT standard, some online MQTT learning platforms exist. Some blogs such as (Eclipse Foundation, 2021a), (HiveMQ, 2021) and MQTT.org offer valuable tool recommendations and examples for self-learning. Furthermore, some online (mostly cloud-based) MQTT brokers and clients offer an infrastructure for quick trials with MQTT. In addition, some simulation environments exist, such as the MIMIC MQTT Simulator (Gambit Communications, 2021). Obviously, these resources are rather for experts and require a long self-learning phase for beginners. Additionally, they insufficiently pinpoint the limitations of the current MQTT standard and how to address them in research.

A few digital IoT labs already exist. The partners of the DigiLab4U Project (the DigiLab4U Project, 2021b) offer some of them. The FIT Lab (French Ministry of Higher Education, 2021) focuses on networking and wireless communication aspects. Unfortunately, these labs do not provide a digital lab on MQTT. Only a few online task-based MQTT courses exist, such as the hands-on introduction to MQTT (Manzoni, 2021). However, they do not provide access to hardware assets in a physical lab. To the best of our knowledge, there is no online lab that covers standardized as well as Work in Progress (WiP) features while being suited to all education

levels. We propose Online-MQTT, which represents our first steps towards a multi-purpose MQTT online lab.

Besides standardized features (client, broker, testbed), we decided to teach WiP features that enrich the semantic and real-time properties of MQTT so that designers become aware of the limitations which the current standard versions, MQTT 3.1.1 (Oasis, 2021a) and MQTT 5.0 (Oasis, 2021b), suffer from. These WiP features may inspire advanced learners for future business and research opportunities. DigiLab4U provides an appropriate infrastructure to enable educational remote access to physical IoT Labs. We are building on this opportunity to realize Online-MQTT lab.

The remainder of this paper is organized as follows. In Section 2, we detail the requirements of an Online-MQTT digital lab. The implementation of Online-MQTT and its integration into the open DigiLab4U infrastructure is discussed in Section 3. In Section 4, we revisit our requirements and qualitatively assess the quality of the proposed digital lab. Section 5 concludes the paper and gives a brief overview of our next steps.

## 2 Requirements

The key drivers to allow remote access to a given physical lab are (1) allowing current users to further use the lab anywhere and at any time, and (2) reaching as yet unreachable users worldwide.

As the number of unreachable users is unknown in advance and lab providers usually desire to maximize the worthiness of the digitalization of their labs through a larger number of users, scalability with regard to (simultaneous) number of users is a crucial requirement in the design of Online-MQTT.

In order to allow for scalability and simultaneity of use, it is essential to base the basic instance of Online-MQTT on low-cost, multi-purpose and Commercial-Off-The-Shelf (COTS) components. This would allow operating expenses to be reduced and new demands to be responded to very fast.

The hardware and software lab architecture should be legolized in such a way that some parts are easy to interchange, and some new requirements are easily implemented. The extensibility of the online lab is essential for its longevity and evolvability in the fast-growing (I)IoT world.

Finally, the ecosystem of the online lab should be trustworthy so that no significant harm is caused to any lab asset through remote access. In particular, the attack surface of the infrastructure should not be increased,

the privacy of lab users should be protected, and safety in the lab should be maintained.

### 3 Our Approach for an Online-MQTT Lab

Opening a physical lab to external users is usually challenging. Opening it for a remote user is even more challenging. This complexity depends directly on the experiment to be shared. In the introduction, we laid out several virtually simulated MQTT experiments a student could run on his/her own or on a provided machine. To further enrich the learning process, it was important to us that a student could experiment with physical instruments in our lab. A physical demo that can be accessed and experimented with in real-time, even remotely, should be a great didactic tool to help the student, through his/her own experimentation with the robots, observe and understand the limitations of MQTT and the need for its support of RT-protocols. With these considerations, the aim of this project is to emulate an IIoT scenario, where MQTT is used to transmit commands to machines. Our major steps toward an Online-MQTT lab that fulfills the requirements above consist in:

- Making use of the DigiLab4U infrastructure for COTS standard digitalization modules (Sec. 3.2).
- Utilizing the popular LEGO EV3 robots while enabling MQTT for them to realize a low-cost but powerful machine model (Sec. 3.3).
- Implementing a real-time loop for immersive user interaction, i.e., experiment control and result visualization (Sec. 3.4).
- Supporting simultaneous access to the lab through spatial and time redundancy considerations in the design (Sec. 3.5).

#### 3.1 Technical Architecture

Figure 1 illustrates the technical architecture that we deployed to allow remote access to the Online-MQTT lab. The main logic of the Online-MQTT lab is implemented as a Virtual Machine (VM). The entry point of the user to our lab is the Moodle course of DigiLab4U, which, upon successful authentication, forwards the user to the web app instance running in the VM. This web app allows the user to control the experiment as well as receive real-time feedback through the camera live stream.

In order to ensure that only authorized participants access the remote lab, we use the open-source Learning Tools Integration (LTI) middleware

(IMS Global Learning Consortium, 2021), sharing a cookie for each user’s web session of the experiment. Both LTI and WebApp instances (LabMS 1..n) run within Docker containers. In addition, we isolated the whole lab environment in its own Demilitarized Zone (DMZ).

The external DMZ defines the communication between the public Internet and Landshut university networks. The internal DMZ defines the communication between the virtual machine network (eth0) and the university network. Within the VM, we deploy scalable docker containers for each necessary module. Each hosted experiment runs in its own LabMS container and manages two robots (one RT and one non-RT) and one camera (eth1 and access point). The robots are restricted to communication with MQTT brokers only, whereas the camera streams are forwarded via WebRTC to the user’s web session.

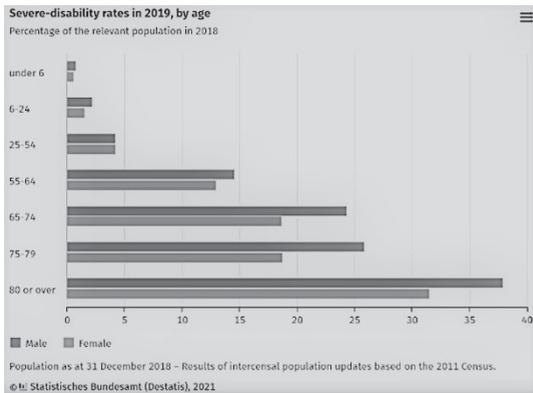


Figure 1. Hardware and Software Architecture of Online-MQTT

### 3.2 Integration with the DigiLab4U Infrastructure

There are several ways to implement remote lab access such as that Online-MQTT.

The open DigiLab4U (The DigiLab4U Project, 2021a) is one way that already provides for accounting, scheduling, booking, and billing using a very convenient interface. In addition, there is the virtual lab example code (LabMS), which offers a suitable template to start using DigiLab4U. Accordingly, DigiLab4U seems to be a unique opportunity for our Online-MQTT remote lab.

Using the DigiLab4U interface allows us to mainly focus on the implementation of lab-specific aspects. In detail, we do not have to handle (1) Moodle (Moodle, 2021), (2) its user registration and administration, (3) accounting incl. booking and scheduling, (4) billing, and (5) lab session handling.

The open and established LTI middleware manages the authorization of DigiLab4U Moodle-User to access our remote lab. This allows any authorized user to access our proposed lab at any time without implementing their own user management. Next, the RESTful LabMS software presents a plug & play method to manage our virtual lab sessions. The live feedback needed for users during their experiments can be easily realized by using this RESTful interface. No further session management is required. Also, scalability regarding multiple simultaneous virtual labs is easily provided by design. A simple configuration will add each virtual lab session to the open DigiLab4U infrastructure.

### 3.3 Enabling MQTT for LEGO EV3 Robots

We use robots that are based on LEGO MINDSTORMS EV3 due to their low cost and their ability to be easily rebuilt to simulate a wide range of machines in IIoT. Unfortunately, there is no MQTT support yet from LEGO. In addition, the EV3 processing and storage capabilities are very limited. Raspberry Pi, on the other hand, is an established multi-purpose, low-cost platform that supports MQTT well. Since there is an adapter to bridge EV3 and Raspberry Pi, i.e., the PiStorms, we decided to go for the following composition: robots are controlled by a Raspberry Pi via a PiStorms controller. The Raspberry Pi hosts an MQTT client and is connected to an open-source established MQTT broker on our VM, i.e., Mosquitto (Eclipse Foundation, 2021a). Publishers are then able to send commands to the robot. The main components of one robot are:

- EV3 LEGO parts used to build a 4-wheeled vehicle with two servomotors to drive the rear axle (actuators) and one obstacle detector (sensor).
- One Raspberry Pi (model 3B) implements the MQTT subscriber and controls the robot's movement through a python script depending on received MQTT messages. To this end, the Paho MQTT library (Eclipse Foundation, 2021b) is required. The Raspberry Pi connects to the Mosquitto MQTT broker via WiFi
- The PiStorms controller is the intermediate component between the LEGO platform and the Raspberry Pi platform, translating Python commands into EV3 commands.

A command to a robot is an MQTT published message, upon whose reception the robot moves a certain distance straight forward, referred to as one step.

### 3.4 Live Loop for Immersive User Interaction

From a User Experience (UX) perspective, it is essential to provide a live feeling to the user, where possible. Obviously, an interface that can be used to interact in real-time with the experiment is fundamental. In addition, a camera live streaming of what happens during the experiment is a powerful method with which to enhance the UX. In the following, we present our approach to building real-time interaction with our experiment while fulfilling the requirements above.

#### 3.4.1 Enabling Web-based Interaction with the Experiment

The user interacts with the proposed lab through a web app dashboard implemented in Java, HTML, CSS, JavaScript, and Bootstrap (Figure 2). In order to start an experiment, the user specifies the values of the following three parameters:

1. *Number of Steps* each robot is supposed to move forward; the value should be  $\in [1, 10]$  steps.
2. *Time Between Steps in ms*; value should be  $\in [500, 2000]$  ms.
3. *Deadline in ms*—the latest time by which the message should be received—(Subscriber Reception Timestamp—Publish Timestamp) < Deadline; value should be  $\in [1, 2000]$  ms.}

The number of steps is equal to the number of MQTT published messages that are going to be transmitted to each robot via a pre-specified topic on the broker. The user may publish the command to a robot instructing it to move the specified number of steps by clicking the button "start experiment" (Figure 2). After completion of the experiment, the student can visually observe the results in a plot.

#### 3.4.2 Enabling GDPR-Compliant and Real-Time Control Feedback

At first glance, a camera seems to be the best fit for lively interaction between a remote user and the physical lab. However, camera deployment is subject to stringent data protection rules and such deployment should be compliant with the European General Data Protection Regulation (GDPR). To keep privacy protected, we decided to deploy the robots in a closet so that the camera's view was restricted and did not capture any human inside

the lab. The user could observe only the robots with the camera live stream. In addition, no microphone was used along with the camera.

For an emergent UX, it is essential to implement a streaming solution performing with low latency. Low-cost LAN accessible cameras are hard to configure for low latency streaming, as they usually make access to the stream only available through proprietary software (e.g. Smartphone App) and do not support open protocols such as the Real-time Transport Protocol (RTP) or Real-Time Streaming Protocol (RTSP). Other low-cost cameras offer a cloud-based stream, which unfortunately shows high or fluctuating latency, which massively degrades the quality of the UX. The Raspberry Pi Camera module is a low-cost but customizable alternative. Thanks to the open-source multimedia framework GStreamer (GStreamer Team, 2021), we succeeded in implementing real-time streaming using Web Real-Time Communication (WebRTC) from a Raspberry Pi camera. To this end, we deployed an instance of the open-source Janus WebRTC Server (Meetecho s.r.l, 2021). Access to Janus was secured via Stored Tokens on the Janus server.

A Token is interchanged every 24 hours. A Cronjob sends an API request to Janus to delete old tokens and generate new ones. To establish WebRTC connections, a Session Traversal Utilities for Network Address Translation (STUN) server has been integrated. In order to further enhance privacy protection, we connected the robots and cameras to the server via a dedicated and isolated WiFi Access Point, which is only reachable inside our experiment VM and has no connection to the Internet or to the campus network.

### 3.5 Considerations for Parallel Access to the Lab

We are providing access to shared physical resources with movement behaviour that requires mutual exclusion and prevents simultaneous access to a robot. Basically, an experiment can start only if both robots involved in the experiment are in a starting position. Given this hard restriction and in order to still accommodate multiple users simultaneously, we implemented two replication strategies, i.e., one in space and one in time.

We allow for many experiments that are independent of each other. Currently, we offer two experiments; however, due to our modular design and the support of LabMS, it is easy to scale to any number of experiments on demand (Redundancy in Space).

We keep experiments short and reset them automatically shortly after they are completed. Users that start a running experiment are informed from LabMS that the experiment is running and cannot be started now (Re-

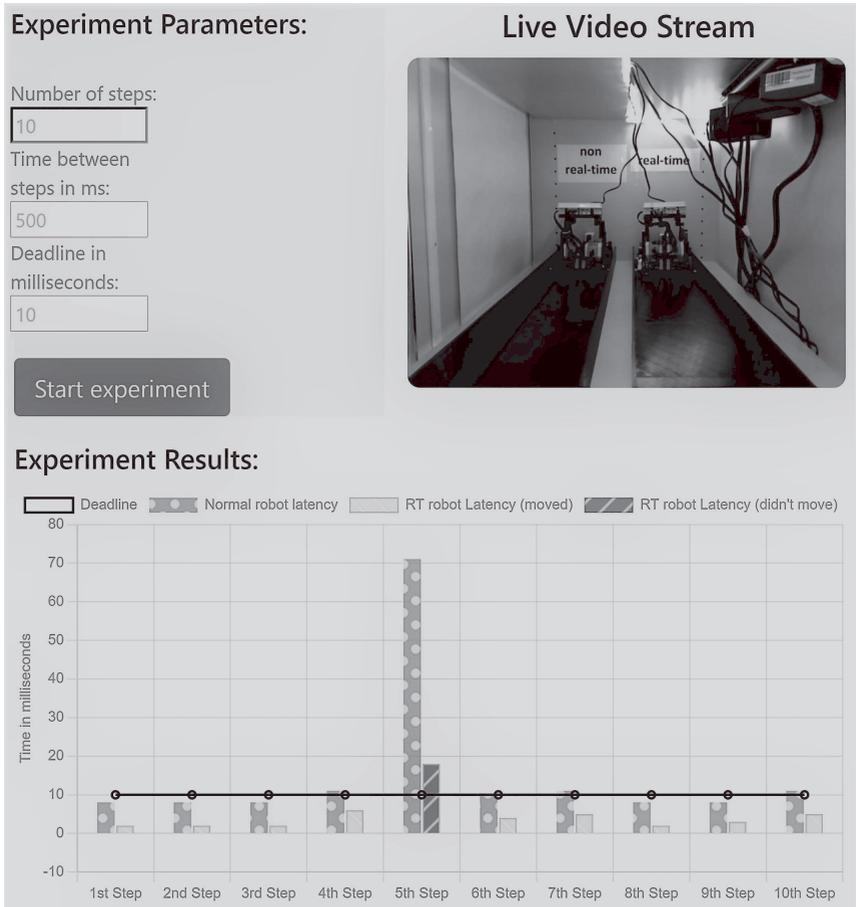


Figure 2. Control Dashboard for the Experiment

dundancy in Time). A shared calendar/scheduler in Moodle allows slots to be reserved to run the experiment. In addition, we isolated the experiments from each other in order to avoid failure propagation across experiments. Currently, we implement the isolation through software virtualization and MQTT settings, such as different topics for different experiments.

## 4 Evaluation

Now, we briefly revisit our requirements and assess to what extent our proposed Online-MQTT lab meets them.

Being web-based, all user interfaces, i.e., DigiLab4U and our lab interfaces, allow access from anywhere and anytime (24/7). In addition, for better scheduling of the physical resources, the DigiLab4U scheduler in Moodle allows convenient time slots to be reserved.

Through its modularity the proposed lab architecture containerization allows our experiment to be cloned within some hours. Given the two robots built as detailed in Section 3.3, the effort required to offer a new instance of the MQTT experiment is easily manageable, i.e., to create, deploy, and configure a new LabMS docker image, to configure LTI with shared keys, and add a web link to the new experiment in the Moodle course. Our software architecture is containerized where possible, allowing it to be scaled easily with regard to software. Being low-cost supports the scalability potential of the Online-MQTT lab. This highlights the scalability potential of Online-MQTT depending on user demands.

We built Online-MQTT using only low-cost, COTS components in order to easily scale it. This is mainly achieved through the selection of open-source hardware and software components such as Raspberry Pi, LEGO EV3, Docker, Mosquitto, Paho, etc. Being established with a rich and active ecosystem, the selected components require reasonable maintenance efforts. In addition, the components have a socket power supply, so that no batteries fail or need to be replaced. We decided to go for multi-purpose hardware platforms and architectures (Raspberry Pi and PCs) to run all elements of the MQTT protocol, i.e., clients and brokers. This allows us to overcome dependencies on the "machines", which then just need to have a bridge to a Raspberry Pi or a PC in order to be integrated into our lab. The containerization of the software simplifies efficient interchange of the components deployed and their extension. These design choices significantly enhance the extensibility of the Online-MQTT lab.

Through physical isolation of the online lab (its own closet, observed by cameras, and physical access for authorized personal only) and its cyber isolation (implementation of all the required cybersecurity countermeasures for opening resources such as DMZ and use of resilient open software like LTI), we achieved an appropriate trustworthiness level with regard to security, privacy, and safety that is satisfactory worldwide.

## 5 Conclusion

We proposed a novel lab that offers participants a journey from basic features up to advanced features of MQTT to address current research gaps. The proposed simulation of an RT scenario with the capability of live feedback enriches the learning experience for a broad range of participants. In this project, the unique DigiLab4U infrastructure has offered valuable support in overcoming the complexity of opening physical labs to remote users and one step toward the vision of an MQTT lab as a service. Nevertheless, some technical lab-specific barriers had to be overcome, which we briefly outlined in this paper. Fortunately, these solutions may be easily adopted by other (I)IoT labs for their digitization.

The online lab realized represents the basis for building a legitimized architecture, where different protocols such as Sparkplug (The Eclipse Sparkplug Working Group, 2021), OPC-UA (The Open Platform Communications (OPC) Foundation, 2021), and CoAP (The Internet Engineering Task Force (IETF), 2021) can be selected by the user before running the experiment. This would allow for easy comparison and technology selection for the community. In addition, our lab architecture is open and safe so that WiP protocols can be tested and offered to the community. In particular, we will keep updating the current lab according to our future research findings so that students are able to try different RT classes and various approaches for automated and spontaneous subscriptions.

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# Understanding the Impact of Measuring and Choosing RFID-Transponders for Applications in Logistics

## Abstract

Automatic identification (Auto-ID) is the fundament of the Internet of Things. Besides barcodes and 2Dcodes, Radio Frequency Identification (RFID) is used. In the different applications in logistics, the objects to be identified consist of different materials, and therefore this chapter provides basic knowledge about testing and selecting the right RFID-transponders for specific substrates.

## Keywords

RFID, Transponder, Measurement

## 1 Preface / Overview

### 1.1 Didactic fundamentals

Effort in lecture hours:	<ul style="list-style-type: none"><li>theory: 2 x 45 minutes</li><li>lab experiment: 60 minutes</li></ul>
Effort for self-study material	<ul style="list-style-type: none"><li>reading (1.5 hours)</li><li>VR-game (20 minutes)</li></ul>
Suggested Credit Points (CP)	the lab experiment is part of a 2CP lecture
Necessary background	<ul style="list-style-type: none"><li>physics related to radio frequency communication</li><li>fundamental knowledge about Auto-ID technologies</li></ul>
Additional information	student teams of 2–3 people suggested

## 1.2 Learning Objectives

After completing this unit, students will be able to:

- name the components of an RFID-transponder,
- state the advantages of testing in a closed measurement cabinet,
- apply the basic measurement settings for RFID testing,
- analyze basic measurements from an RFID measurement cabinet
- list the influence of different carrier materials on reading behavior.

## 2 Introduction to RFID-Transponder Testing

### 2.1 Use-case Introduction

On March 3<sup>rd</sup>, 2022 there was a job offer from Porsche AG in Stuttgart, Germany on the Web (<https://jobs.porsche.com>) asking for a specialist on Auto-ID in logistics to work on “*Design and planning of automation solutions in logistics based on process requirements from project start to acceptance with a focus on Auto-ID and IIoT [Industrial Internet of Things]*” and requesting fundamental technical knowledge on Auto-ID, especially RFID. One of the important technical topics for an RFID specialist to understand is the behavior of different RFID-transponders on different materials, which will be called substrates in the following. RFID-transponders are designed to work in specific frequency ranges and are quite often optimized for specific applications. Substrates may detune the RFID-transponders, so that poor read results are achieved. Therefore, RFID-transponders should be tested on those substrates which will be used in real logistics scenarios. If, for example, an RFID-transponder is supposed to produce good reading results on a propylene box, it should be tested on polypropylene and compared with other transponders to identify the appropriate transponder.

### 2.2 How to Identify the Right RFID-Transponder for a Given Application

#### 2.2.1 Basics of RFID frequencies

There are different frequency ranges available for RFID. A distinction is made between LF (Low Frequency), HF (High Frequency), UHF (Ultra High Frequency), and MW (Microwave). The frequency ranges have different characteristics, such as the maximum possible read range between a reader

and a transponder. Therefore, the appropriate frequency range is selected depending on the respective application.

While high-frequency (13.56 MHz) transponders are used for applications such as access control or identifying books in libraries, in logistics applications the ultra-high frequency range is used. Unfortunately, the ultra-high frequencies allowed are different around the world (Fig. 1) due to country-specific regulations. RFID-readers must comply with the frequencies allowed in the different regions and countries, and RFID-transponders need to be designed to work in the frequency ranges where they will be used.

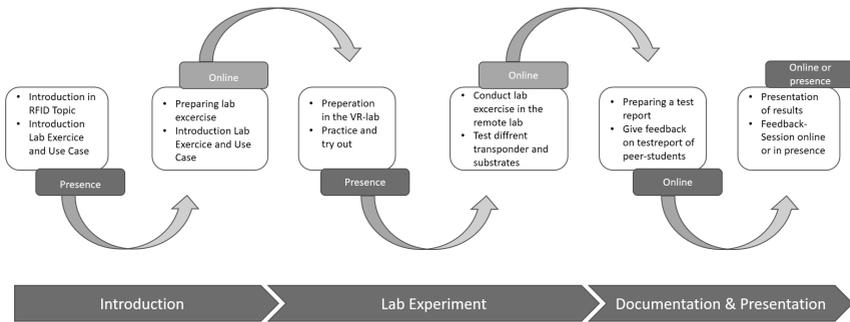


Figure 1: Overview of some of the UHF ranges for RFID, for details see: [https://www.gs1.org/docs/epc/uhf\\_regulations.pdf](https://www.gs1.org/docs/epc/uhf_regulations.pdf)

Consider a ship with RFID-equipped goods traveling from Tokyo to Hamburg. The RFID-transponders should thus be readable in both frequency ranges. They should have similar read results using frequencies 865–868 MHz (Europe) and 916–923 MHz (Japan). This requires specially designed broadband transponders.

### 2.2.2 RFID-transponders for Logistics Applications

As RFID is getting more and more popular, there are numerous different RFID-transponders available from different manufacturers for specific applications. Special attention is needed if liquids (an RF-absorbing material) or metals (an RF-reflecting material) are in close proximity to the RFID-transponder.

Typical examples in logistics include transponders for substrates such as

- Returnable polypropylene boxes (e.g. as specified in VDA 4500 for the German automotive industry)
- Electrostatic discharge (ESD-)boxes (which have a strong negative impact on RFID-transponders, e.g. as specified in VDA 4504)
- Cardboard (beware, the moisture level of the cardboard may impact the read results)
- Wood (e.g. pallets)
- Metal (so-called on-metal transponders are needed for good read results)
- Glass

All these substrates have a different impact on the reading results. Other aspects to consider are environmental influences (e.g. dry retail environments or wet outdoor environments) and usage (e.g. open-loop one-time application vs. closed-loop long-time application (see section 5.1). Transponders can be optimized for these different substrates and usage requirements, by using, for example, different chips, antennas, housings, or fixtures.

RFID-transponder manufacturers provide data sheets that show the most important data for their different products (Table 3).

*Table 3: Typical specification data provided in a transponder data sheet*

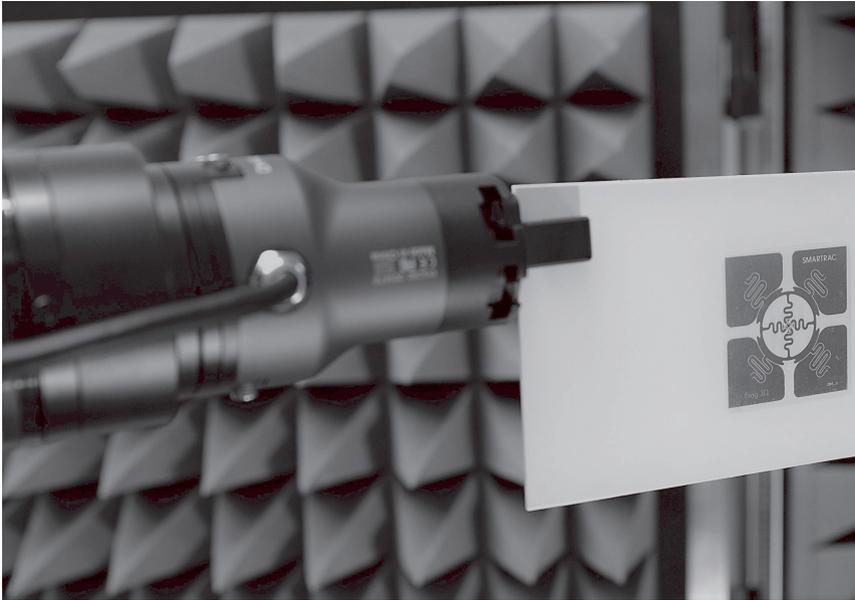
Specifications of the transponder	Example	Comments
Transponder type / specification	UHF RFID EPCglobal Gen2V2	Refers to the general frequency range and communication standard
Operational Frequency range	860–960MHz	Specific frequency range
Chip manufacturer and specification	Impinj Monza 4QT	The chip is responsible for processing and storing the data
Memory	EPC: 128 bit User: 512 bit TID: 96 bit	The chips have different memory sizes. The memory is divided into different memory banks, which contain for example the TID (Tag ID), EPC (Electronic Product Code), and user memory
Antenna design	Omnidirectional, (radiation pattern)	The radiation pattern indicates the readability from different angles
Read range (ETSI regulation)	Plastic: <10m Cardboard: <4m	This example shows the impact of different substrates on reading distance

Specifications of the transponder	Example	Comments
Designed for substrate / surface material	Non-metallic surfaces	A little generic in this example, as probably ESD-boxes may cause problems but are not made of metal
Mechanical specification	White, printable, PET, self-adhesive, dimensions, installation instructions	
Environmental specification	Temperature range, water resistance, chemical resistance, expected lifetime, ...	Influenced largely by the housing

### 2.2.3 How to find Missing Information about Unknown Transponders

If data sheets are missing, the transponder and its specifications need to be identified.

- Visual check: Does the transponder show written data (e.g. manufacturer, type)? What are the dimensions of the transponder? Does the housing tell you something about the transponder (e.g. antenna polarization, fields of application)?
- Identifying the chip manufacturer: The Transponder ID (TID) contains information about the chip manufacturer and the type of chip (see, e.g. a corresponding JSON-file for chip identification at [https://www.gs1.org/docs/epc/mdid\\_list.json](https://www.gs1.org/docs/epc/mdid_list.json) with corresponding HEX and binary values).
- Antenna layout: Sometimes in RFID-label transponders, the antenna layout can be seen, for example, by holding it against a light source. Some of these layouts are well known and can be searched for on the Web (search term: UHF RFID inlays).



*Figure 2: A UHF RFID-transponder ready for testing—a visual inspection shows information about the manufacturer (Smartrac) and the antenna design (Frog 3D). The square layout indicates orientation insensitivity to horizontal or vertical usage.*

#### 2.2.4 Comparison of Different RFID Test Methods

While the transponder data sheets provide basic data about the transponder specifications, application-specific testing still remains a state-of-the-art procedure to ensure reliable operation.

There are two easy, commonly used “quick and dirty” static test procedures for RFID-transponders using standard RFID-readers. The first easy approach is to fix transponders onto a substrate, set up a corresponding RFID-reader and antenna, and measure the maximum reading distance at a given power setting. Starting from a far distance outside the antenna field, a linear movement at walking speed toward the antenna is carried out. The threshold distance when the RFID-transponder is read by the reader is recorded. Multiple measurements need to be performed. Usually, the transponder which offers the longest reading range is considered to be the best for logistics applications, as the chip, antenna, transponder housing,

fixing, and substrate will work well together, thus enabling these long reading-distances. Writing distances are shorter than reading distances, as a more stable connection is needed.

However, the reading field is not homogeneous, ambient conditions, reflections from the ground or surrounding objects, and interference from other RF devices may influence the results. Thus, the accuracy and repeatability are questionable. On the other hand, these tests show the reading results in a real environment.

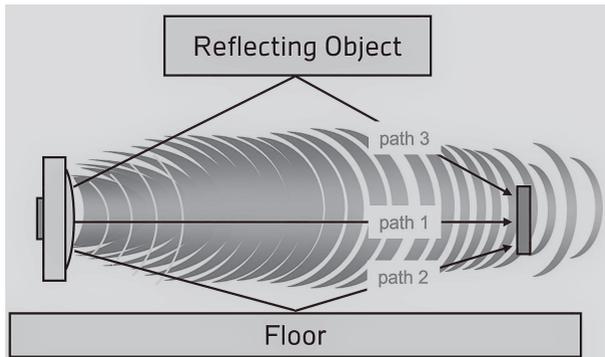


Figure 3: Antenna on the left, reflections from the floor and reflecting objects lead to positive or negative interference

The second method is based on keeping the same distance between the RFID-transponder and the reader’s antenna. In this case, the power-settings on the reader are changed from high to low power levels, and the threshold value is recorded when communication is lost. For this method, a table-like structure made of rigid foam plates, as used in the insulation of buildings, can be used (Fig. 4). The rigid foam has minimal effects on the test results. The reader’s antenna is placed on the bottom layer of the table structure, while the RFID-transponder is placed on the top layer. Unfortunately, RFID-readers usually limit the power settings, e.g. from 15 dBm to 30 dBm. Sometimes RFID-transponders are even read at a 2m distance from the antenna at a minimum 15 dBm level. Antennas with a low gain may be used in order to avoid further amplification of the reader’s signal.

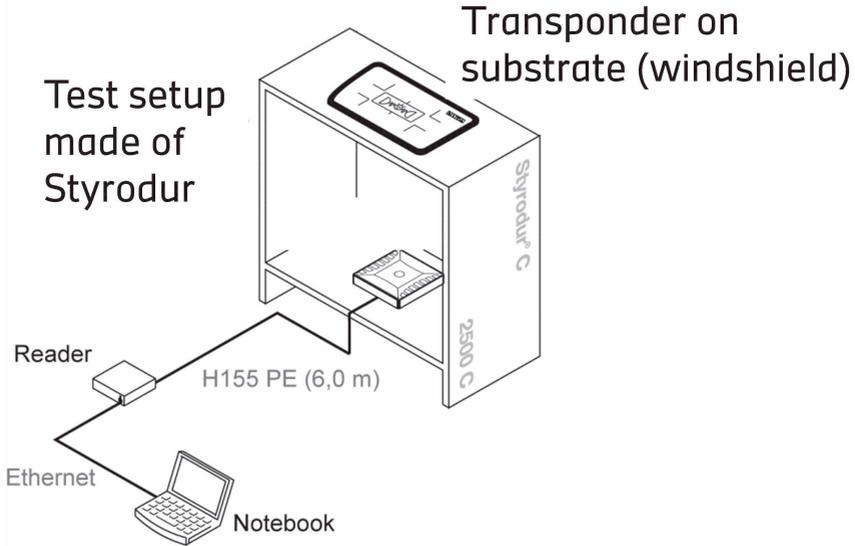


Figure 4: Test setup to measure towards the sky in an outside environment to avoid reflections from the ground or from walls

Both test scenarios mentioned have their advantages. The cost of the equipment is low and the transponders can be tested in a real-world environment. However, the accuracy and repeatability of these setups are limited, and the testing may be quite time-consuming. Therefore, testing and comparing RFID-transponders for specific substrates in an RFID measurement cabinet is recommended to improve accuracy, repeatability, and speed of testing and to perform other tests of interest (e.g. rotation testing). Additionally, a closed chamber allows the transponder to be tested in frequency ranges that may be used in other regions (e.g. USA, Asia, Europe), which is otherwise not allowed. However, an RFID measurement cabinet is costly and still needs to be complemented by real-world testing scenarios (see chapter *Applied RFID in Logistics*). Transponders in movement can be tested (dynamic testing) on a conveyor belt in a real-world scenario in this lecture.

Table 2: Comparison of different test methods for RFID-transponders

	1. Changing the reading distance, vertical setup	2. Changing the power settings, horizontal setup, reader antenna facing the sky	3. Measurement cabinet
Test scenarios	Threshold (distance)	Threshold (power)	Automated threshold (power) and orientation testing, ...
Distance between reader (antenna) and transponder	Changing	Fix	Fix
Power-setting on RFID-reader	Fix	Changing	Changing
Frequency range	Fixed or variable within the regionally allowed frequency band (usually secured by the RFID-reader manufacturer)		Broad frequency range (e.g. 800–100 MHz)
Reflections	High in reflective environments	Low	None
Interference from other RF equipment	Depends on sources of interference in the environment (maybe measured with a spectrum analyzer if available)		None
Equipment needed	RFID-reader and antenna, a stand for RFID-transponder	RFID-reader and antenna, a structure to place the RFID-transponder horizontally over the antenna at a minimum distance of 1m	RFID measurement cabinet (costly)
Measurement accuracy and repeatability	Poor	Better, fewer reflections	Very good
Speed of testing	Slow, numerous tests at different distances need to be performed	Fast, if RFID-reader has an automatic threshold test	Very fast

### 3 Measurements with an RFID measurement cabinet

A typical RFID measurement cabinet resembles an anechoic chamber (Fig. 5) in a small package.

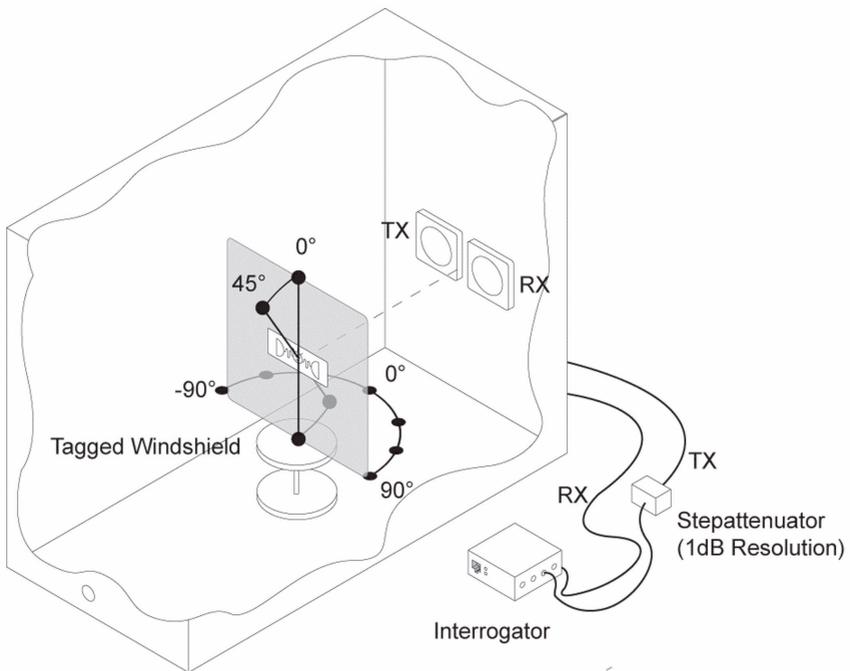


Figure 5: An anechoic chamber with shielded walls, a turning stand for probes, transmitting (TX) and receiving (RX) antennas, a measurement device (interrogator), and a step-attenuator to reduce the signal step by step

The RFID measurement cabinet at HFT Stuttgart uses a single antenna for transmitting and receiving signals. The measurement device controls the integrated step-attenuator and the rotation of the stand to enable automated threshold and orientation testing. Please refer to guidelines: *Perform RFID test series with the Remote Measuring Chamber of the HFT Stuttgart* on how to run the measurement.



Figure 6: The RFID measurement cabinet inside, turntable with a blue RFID-transponder on a white plastic substrate to the left; linear polarized reader-antenna on the right; surrounding absorbers

### 3.1 Threshold Measurement

The goal of this test is to identify the threshold (minimal power setting) for the transmitted power needed to communicate with the transponder at each frequency of interest. This value can be converted into a theoretical read range. The cabinet allows testing between 800 and 1000 MHz. Frequency range, frequency steps, and power-steps for testing should be chosen to get a meaningful data set at an appropriate time. The data is visualized as a graph and a downloadable data set. It is easy to identify the optimal frequency for the transponder and the frequency range it is suited for (all frequencies in a 3 dBm range from the optimal frequency). The threshold power is recorded in a logarithmic value, dBm (decibel milliwatts). 3 dBm corresponds to doubling the power.

### 3.2 Orientation Measurement

The rotation test measures the orientation sensitivity at a predefined frequency, while the turntable with the RFID-transponder is rotating. Again, the power steps and the angle steps to control the turntable need to be set appropriately. The results tell us how well the transponder can be read

at different angles. On-metal transponders on a metallic substrate usually cannot be read from the back. Transponders for non-metallic applications of materials such as cardboard should produce an 8-shape. If the transponder cannot be read at all, please check the right orientation of the transponder, as the reading antenna in the RFID measurement cabinet is linearly vertically polarized (please refer to the chapter *Applied RFID in Logistics* for more information).

### 3.2.1 Questions you Should ask Yourself

Think of the Porsche job offer mentioned at the beginning. Let's consider you have an RFID specialist in the job interview who wants to test your RFID knowledge. Do you feel confident in answering these questions during your job interview?

- How would you choose the right RFID-transponder for a logistics application?
- What is the information you need about the specific logistics application to choose the right transponder?
- What types of (static) tests would you choose to identify the best transponder?
- What values would you measure?
- What do these values tell you about the usefulness of the transponder tested for the specific logistics application?

## 4 Summary

Successful RFID deployment requires choosing the right equipment such as RFID-readers, antennas, and transponders. Transponder data sheets provide useful information concerning the transponder. However, for specific applications, the impact of the substrate on the reading results should be tested. Simple tests may be performed using a standard RFID-reader. More accurate and repeatable results may be achieved in an anechoic chamber or a smaller measurement cabinet with specialized measurement interrogators. The data obtained from the measurements can be used to

- select the best transponder out of a set of transponders,
- analyze the useful frequency of the transponder range for regional or global applications,
- analyze the orientation sensitivity of the transponder,

- evaluate the usability of a transponder for a specific application in logistics and beyond.

## 5 Further Resources

### 5.1 Definitions

Closed-loop applications: Within the context of RFID for supply chains, this term is used to describe that the RFID-transponders are used in a loop such as in combination with returnable transport items. The transponders are used, again and again, thus ensuring the longevity of the transponders.

Open-loop applications: Within the context of RFID for supply chains, this term is used to describe that the transponders leave the boundaries of a closed loop, such as e.g. in retail applications. Transponders used in open-loop applications are very price-sensitive, as the benefits of their repeated usage are lacking.

### 5.2 Recommendations for Additional Resources

- Guidelines: Perform RFID test series with the Remote Measuring Chamber of the HFT Stuttgart (on Moodle)
- Measurement Report Template: RFID Test Report Use Case (on Moodle)
- Follow-up: Chapter on “Applied RFID in Logistics”
- Scientific RFID testing: This chapter is focused on the educational basics of RFID transponder testing. Please read VDI/AIM 4472 Part 10 on *Requirements to be met by transponder systems for use in the supply chain—Test methods to check the performance of transponder systems (RFID)* as well as ISO/IEC 18046 series on *Information technology—Radio frequency identification device performance test methods* if you are planning to do scientific tests.

## Acknowledgements

The DigiLab4U project, on which this paper is based, was funded by the Federal Ministry of Education and Research (BMBF), Germany under the funding code 16DHB2112. The responsibility for the content of this publication lies with the authors.

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## **1 Didactical Considerations for Understanding the Impact of Measuring and Choosing RFID-Transponders for Applications in Logistics—Handout for Lecturers Lab environment**

(Remote) RFID Measurement Cabinet at HFT Stuttgart

## **2 Didactical Analysis**

**Short Description:** This unit explains the theoretical background and fundamental basics of testing RFID (Radio Frequency Identification) transponders. It focuses on the frequency range UHF (Ultra High Frequency) and passive RFID transponders, as they are used in many applications in logistics and production. The basic knowledge acquired in this chapter will be necessary for the later practical laboratory exercise.

**Target Group:** The unit addresses bachelor's students in engineering disciplines such as production engineering, computer science, logistics, and related engineering degrees in their first two years of studying. Some prior knowledge of physics is helpful but not mandatory. The lab experiment is targeted at groups of two students. 60 minutes of exclusive lab time should be reserved per group.

**Institutional Requirements:** The lab experiment requires professional measuring equipment (e.g. Voyantic Tagformance). However, as part of the DigiLab4U research project, the measuring equipment has been digitalized and is remotely accessible. As the project funding ends in 2022, access cannot be guaranteed. Please send an email to [info@digilab4u.com](mailto:info@digilab4u.com) if you are interested in remotely accessing the RFID measurement cabinet at HFT Stuttgart.

**Subject matter:** The chapter is recommended as preparation for the practical laboratory exercise with the remote RFID Measuring Chamber. On the learning platform, students will find templates for the systematic preparation of the lab exercise, informative video resources on the topic, quizzes for self-assessment, and supporting methodological handouts for self-directed work and working in teams.

In addition, the chapter and laboratory exercise from the University of Parma “Applied RFID in Logistics” can be completed afterwards to deepen the topic.

### 3 Didactical Concept

**Methodical implementation:** We (HFT lab-team) recommend the method of case-based reasoning (CBR) for the use of the (Remote) RFID Lab in a university course. Particularly in areas where complex problems arise and no recipe-like solutions are available, this kind of methodical approach can be beneficial for students. Industry-related laboratories in universities, like the RFID measuring cabinet, especially can provide these kinds of open learning environments, which are particularly suited to CBR. The CBR method relies on solutions to authentic cases and it supports students in deriving solution steps for similar future problems. In lab-based learning scenarios, case studies are bridges between theoretical models and practice. The goal is to use the method to develop, extend, and consolidate generalizable findings for a specific use case from the industry. The close interlinking of expert knowledge, methodical process know-how, and action-guiding values and standards ideally lead to professionally relevant solutions.

The chapter use case is based on a real job offer from well-known automotive manufacturer Porsche AG and can be found on the DigiLab4U learning platform. A complementary specific use case on selecting the right RFID-transponder for different transport-box materials is used for the experiment itself.

**Media:** The complete laboratory exercise is accompanied with Moodle, and all the required information and learning resources are available to students on this platform. To prepare for the RFID lab, a VR environment resembling the real RFID measurement chamber is offered. This may be used in a browser-based way or live in university VR labs. In general, all media resources can be used to make the case authentic, promote the use of scientific methods, and support analytical thinking.

**Learning Organization:** For the lab exercise, it is advisable to have the students work together in small groups of two people. Currently, a hybrid learning concept is appropriate for the use of the case-based learning method in the laboratory.

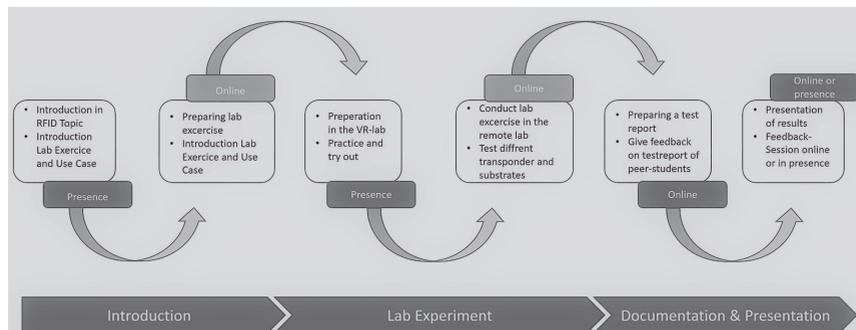


Figure 1: Phases of the lab exercise and organization of the hybrid lab-based learning scenario: lab phases

1. **Introduction:** The lecturer or lab assistant introduces the topic and presents the laboratory process and use case. Additionally, the students receive all the required resources and a detailed description of the use case on the learning platform.
2. **Analyze phase 1:** The students engage with the learning resources and use case scenarios in advance, and in groups prepare a hypothesis for their planned measurements in the laboratory.
3. **Lab preparation:** The students use the VR measuring chamber to prepare their work in the real or remote laboratory. The virtual measurement chamber also allows them to look into the measurement chamber while the measurement is running, which is not possible in real-world testing.
4. **Lab experiment:** The students carry out their measurements on certain substrates with transponders; they document each result and have the opportunity to test disturbance factors in the measurement chamber. The goal is to gain a deeper understanding of RFID measurements in the RFID lab (iconic chamber).
5. **Analyze phase 2:** The students create a test report, compare their results, and make a recommendation for the use case. They have to justify their recommendation based on their measurement results and the theoretical knowledge they have acquired.
6. **Presentation:** Finally, they present and discuss their findings and receive feedback on their test report.

A contact person (lab expert, lecturer, lab assistant) should be available during all lab phases to answer questions, give feedback, and support the students if technical issues occur. A total of three weeks should be planned

for this lab experience, which means one week for each section (introduction, lab-experiment and documentation/presentation).

**Feedback and Evaluation:** In the context of the evaluation of laboratory-based courses, an evaluation in the form of a Teaching Analysis Poll (TAP) is useful.

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## **Data-Driven Warehouse Logistics Concepts**

### **1 Didactical Preface**

#### *1.1 Overview of Didactical Fundamentals*

*Table 1 Overview of didactical fundamentals*

Effort in lecture hours (given by the teacher and facilitator)	Theory: 60 min (if on-site, 2 classes; if remote, 3x20) Safety introduction 15 min on-site, 15 min remote Lab operation 120 min (2x3x20 min) 3x20 min of debriefing after class
Effort Self-study (flipped classroom)	Preparation 4 h 4 h for report analysis
ECTS	0.5 ECTS
Pre-requisites	Needs to have completed a basic course on introduction to smart logistics, introduction to CPS or similar. However, this is an intro course with a focus on application and experiential learning.
Additional information	To carry out the experiment, passing a safety test is required A facilitator and a technician need to be on-site in the lab
Adaptability	The students should submit lab reports afterwards The usage of the mixed reality environment is flexible. We have a different set of theories if class is on an advanced level

#### *1.2 Keywords*

Sensor, actuators, augmented reality, mixed reality, warehouse operations, risks, production logistics

#### *1.3 Learning objectives*

- Know the function and specifications of different types of sensors and actuators

- Understand how sensors and actuators can support data-driven logistics
- Understand the opportunities and limitations of the implemented technology in a warehouse operation
- Apply methods to analyze how the technology affects warehouse operations
- Evaluate how the different technologies can support the decision-making process in warehouse operations
- Create an understanding of how the knowledge gained can be transferred to one's own working environment (only for VET and LLL settings)

#### 1.4 Target Group

This MR game environment is designed to support everyone who wants to understand better how different sensors and actuators can be used in a warehouse environment.

It is designed as a sandbox game and can therefore be used both for those with basic knowledge and practical skills as well as those with advanced skills in ICT supported warehouse operations.

## 2 Use Case

### 2.1 User Story

Damage to goods and loss of goods are significant issues within warehouse operations [1]. In addition, there is also a risk that the operators may be exposed to various risks like forklift crashes, collapsing pallet racks, spillage of hazardous materials inside the warehouse, etc. [2]. Even though the likelihood of such events is low, the impact is high, and thus avoiding them is given a high priority. The implementation of the Internet of Things technology to continuously track goods [3] and for better visualization [4] can help to reduce both the likelihood as well as the impact of those risks [5]. To implement, use and rely upon this supportive technology, there is a need for qualification and training of warehouse operators [6, 7] as well as of the management involved in the decision-making process of selecting the right technology for its implementation, taking infrastructural boundaries into account [5, 8]. A gamified mixed-reality environment can be more than a testing environment [6, 9,10]; it encourages the ideation process and helps researchers to analyze problems from different perspectives. During the exploration phase, draft solutions are tested with mock-ups or prototypes

and the results are transferred into real environments for experimentation. The usage of gamification techniques in production and logistics has some evidence of effectiveness regarding the understanding of complex processes and systems. This challenge brings into focus the fact that gamification tools need to be capable of adapting to the situation: they should enable real-time dynamics and be open to adaptation and personalization to answer to the user’s needs better.

The game environment presented is planned to be the experiential learning part of a course on warehouse operations and management in the current setting. The mixed-reality environment is, however, adaptable and can be used in different settings. In Table 2, we have designed the following description of the learning scenario.

Table 2. Learning Scenario Technology-supported decision-making

Course title	Decision-making technology implementation
Possibility of distance learning	Yes, as a part of the shared lab infrastructure or through access to the games and/or simulations and digital twins
Abstract	The module will be used in both strategic and operative decision-making. The main objective is that the participant should get a deeper understanding of how different technologies can support seamless and transparent information flow and material handling in a warehouse, but also on factors that influence the decision-making process because they are not changeable At the operative level, this will be a decision-making process related to daily operations The KPIs used are those from a first and second-level SCOR model.
Goals and objectives of the course in terms of competence and skills	Apply methods for strategic and operative decision-making for technology introduction (S) and usage (O) Apply knowledge & methods on how to analyze risks and opportunities related to technologies in a warehouse in a supply chain Assessment Design layouts of WMS Understand and assess in-stocking and out-stocking technologies Understand how to implement automated material movement in an existing warehouse area Safety issues related to HCI.

The corresponding game uses an open narrative, where the players get a set of tasks related to typically operational processes in a warehouse, like in- and out-stocking, ordering, picking, and placing, etc. In the current gameplay, the players are first asked to become familiar with the logistics operations and then to evaluate how different IoT technologies can support the operational process in terms of process quality, and efficiency, as well as

cost and time reduction versus the implementation and operational costs of the technologies. The narrative then broadens to differences in the goals for individual players—i.e. it can also be used for assessing privacy and ethical issues. It is possible to solely focus on technical implementation, be more specifically related to how to select what types of sensors depending on what we are interested in (humidity, tilt of forklift, temperature, real-time tracking, etc.) and depending on what types of goods we have or to focus more on the flow of materials.

More information can be found in the articles referenced under additional material.

## 2.2 Tasks

The goal of this unit is that you will experience how different types of sensors and actuators can support your warehouse operations. You will also be able to test how the usage of augmented reality (AR) can support the same operations, but an important takeaway is also to identify the limitations of both sensor and actuator usage as well as AR support.

Before you start your lab exercise:

- Read the introductory article
- Open the video of the forklift operation and start by reflecting on what information you would like to receive. Base your analysis on what you have learned in your previous lessons on warehouse operations and cyberphysical systems
- Read the fact sheet about the different sensors. It is especially important here that you reflect on the details and analyze the warehouse environment you will play in the mixed-reality environment
- Analyze the problem description (we currently have 10 different descriptions of problems)
- Based upon the problem description, design your experimental setup related to
  - Improving overall operational processes
  - Safety issues
  - Efficiency
  - Data-driven warehouse management
- Design the protocol for your experiments and select the choices of sensors and actuators in terms of expected impact they will have on warehouse operations
- Carry out the experiments in the sequence and complete the debriefing (with all your classmates) before you carry out the next experiment.

- Use the replay function in the unity model to analyze the results in terms of the planned and expected results
- Identify any deviations and look for possible reasons.

#### Self-test

- We have a self-test on safety and risks which you need to pass
- We offer a test on sensors and actuator knowledge, which you may take before you start the experiments
- Define what the functionalities of each component are
  - e.g., sensors read data related to different operations, the devices collect data from sensors and forward them to the central entity and/or process them to control actuators

#### Exercises

- Analyze the video material
- Remote/physical lab exercise
- Deliver lab report

### 2.3 Learning Resources

- Introduction to warehouse operations (lecture)
- A set of articles
- Fact sheets
- A set of illustrative videos

## 3 Introduction to a mixed-reality environment for warehousing operations

Due to changes in the working requirements for people working within production and logistics operations, there is a need for training and educational offers that prepare current and future employees for these requirements. During this lab exercise, you will have the opportunity to try out how different technologies (in this case, sensors, actuators, and augmented reality) can support operations and provide a safer working environment. This introduction describes the mixed-reality environment you will use. It is complemented by a video that gives a more practical overview of the environment. The environment you will use is described in more detail in [5, 6, 8].

### 3.1 Overview of game flow

The part of the MRLift mixed-reality sandbox game, which is the focus of this lab, is illustrated in Fig. 1.

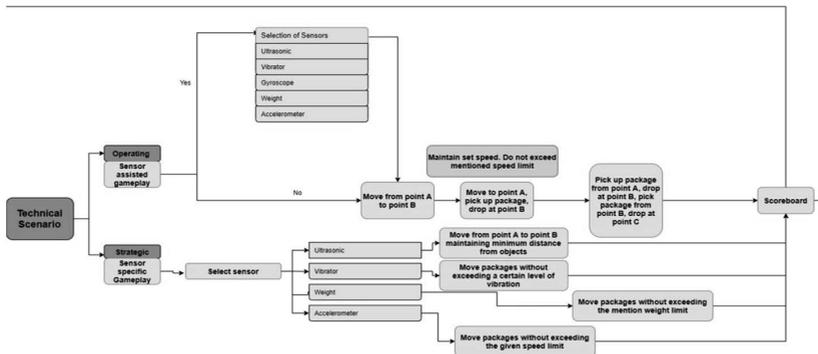


Figure 1 Gameflow Diagram MRLift Sandbox game.

In a lab (remote or physically on-site) or a test bed, gamification approaches can be applied to both the virtual and the physical environment. A part of the purpose of the lab is that you as a student can experiment with different settings. In some cases, you will do that by changing the sensor, while we also foresee that you will deal with the manipulation of data from the physical environment in the virtual (unity model) to support the planning process. The intention is to foster a deeper understanding of how the accuracy of a sensor may be affected. For this purpose, in the virtual part (i.e. the DT), we only map the relevant processes, with the data either imported directly from the physical demo area or reused from a database.

Table 3 shows the design of one of the scenarios realized in line with [9]

		First Feedback on # bumps	Discussion on sensor selection	Move the pallet	Second Feedback on # bumps	
Gaming	Action	See performance evaluation	Plan Select	...	See performance evaluation	
	Tools	Performance meter	Multiplayer List of components	...	Performance meter	
	Goals	Collect information	Carry out task	...	Collect information	
Learning	Actions	Assess	Compare Discuss	Compare	Assess	
	Tools	Tips	Group discussion	Simulation Demonstration	Tips	
	Goals	Evaluate the performance	Learn about different sensor applications	Show differences with and without sensors	Evaluate the performance	
Intrinsic Instructional	Actions	Quantitatively assess feedback	Present material	Repetition	Quantitatively assess feedback	
	Tools	Performance measure	Limited set of choices	Simulator Checklist	Performance measure	
	Goals	Provide feedback	Elicit performance	Elicit performance	Provide feedback	

We have integrated different kinds of mechanics into the decision-making process of a simulation. This includes information on time spent on movement, on how the vehicle has moved, the quality of the service delivered, the selection of different sensors or actuators, etc. The mechanics implemented depend on the specific aim of our investigation, so you may use it in different ways, depending on the problem in question. For a focus on the operating processes, other KPIs (like mistakes, bumps, etc.) would have been of more interest than mechanics. To realize the current prototype, we created the digital twin of a warehouse in which IoT technologies are used.

Figure 2 shows the physical test bed and illustrates one main cause of damage—the in-stocking process. To reduce component size, the demons-

trator is not full-scale. Since the purpose of this digital twin is to support learning by using experimental learning methods, we only need sufficiently detailed processes rather than exact physical mapping. However, this also places boundaries on the usability of the twin for different learning goals.



*Figure 2 The physical test bed from which we import the real-time sensor data*

The digital twin scenario teaches whether and how IoT technologies can improve and enhance warehouse operations. The pedagogical method used is problem-based learning (PBL). This approach calls on the learner to face a real-world problem, analyze it, and present a possible solution. It has been demonstrated to positively affect the learning outcomes of engineering students. The students need to use the digital twin, either with data from the database or from the demonstrator, to assess which technology is best for which problem and to explore the limitations of the technology. As an example, we use an RC-forklift with environmental sensors, e.g., temperature and humidity, and tilt sensors to detect the tilt of the forklift.

### *3.2 Introduction to the physical lab environment*

These sensors are connected with Arduino. Xbee modules send these processed bytes wirelessly to a computer terminal. The user can monitor Xbee frame packets using XCTU software. We use Unity to model 3D data from the data sensed, which requires an interface that shows the data in real-time. It is also possible to do this the other way around—i.e. instead of collecting data from the real-world sensors, we can manipulate the data (perhaps collected from moving objects and sensor data in the first step) and spin

them back in the real world, in order to validate the module. However, this has some restrictions—that we need to have the same equipment, so we have not tried it out for the planning process. In addition, in our case, we have objects which pose a certain risk of accidents and injuries—in this case, the import of manipulated data in a real-world need to undergo a safety assessment process before being tested. The idea of the physical scenario is to develop a working replica of the scenario that will be created in the games. To develop that in the physical world, we use a model forklift and add sensors and motors to it. The forklift is then operated, and the data collected by the sensors is transferred back. The sensors used, the reason for the selection of the sensors, and how the sensors can assist the use of the forklift will be discussed in detail by you and your classmates during the debriefing sessions. This is just the basic idea of how the sensors will be implemented on the forklift; more sensors might be added later to enhance its performance.

The objective of extending the digital game with physical components is to increase the players opportunities to experiment with different components (like sensors, actuators, or tracking technologies). The player may then investigate what impact small differences might have on the overall results in a more practical way, and still have the opportunity to visualize, manipulate, and replay the game (in the digital part). To develop that in the physical world, we use a model forklift and add sensors and motors to it. The forklift is operated, and the data collected by the sensors is transferred back. The basic concepts of the physical model are discussed here. The sensors used for this purpose are:

1. Ultrasonic sensors,
2. Vibration sensors,
3. Touch sensors.

Different sensors have different purposes and are installed in the forklift to assist its performance. The sensors are described below.

### 3.2.1 Ultrasonic sensors

Ultrasonic sensors (also known as transceivers when they both send and receive, but more generally called transducers) work on a principle similar to radar or sonar, which evaluate the attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high-frequency sound waves and evaluate the echo, which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.



*Figure 3 Example of an ultrasonic sensor*

This type of sensor will be used on all four sides of the forklift to determine the distance of the forklift to any surrounding object. The more area the ultrasonic sensors cover, the more accurate the measurement will be. The main purpose of installing the sensor is to alert the forklift driver to nearby surrounding objects.

### 3.2.2 Vibration Sensors

A vibration sensor's internal structure is like a metal ball that is fixed in a special spring as a pole; around it is the other pole. When the vibration gets to a certain extent, the two poles are connected so as to judge the shock that occurs. A vibration sensor emits a digital signal and is used for vibration detection. This sensor has two contact pins. When an external force is acted upon either by movement or vibration, the sensor's two contact pins are closed, and contact is made between the two pins. When the force is removed, the sensor's terminals return to open contacts.

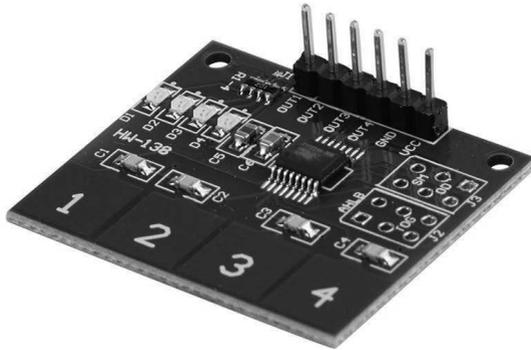


Figure 4: Example of a vibration sensor

The vibration sensor can be installed on the forks of the forklift to measure any kind of vibration. If the vibration limit given is exceeded, an alert system can be installed to alert the driver of the forklift to certain vibrations or irregularities. The vibration sensors can be installed on the forks of the forklift, where most of the vibrations will occur due to the lifting of materials. If the materials create vibrations that exceed the limit, the sensor can create an alert. A vibration sensor can also be installed at the rear end of the forklift for extra safety measures.

### 3.2.3 Touch Sensors

Touch sensors work like a switch. When they are subjected to touch, pressure, or force they are activated and act as a closed switch. When the pressure or contact is removed, they act as an open switch. A capacitive touch sensor contains two parallel conductors with an insulator between them. These conductor plates act as a capacitor with a capacitance value  $C_0$ . When these conductor plates come into contact with something, they act as a conductive object. Due to this, there is an uncertain increase in the capacitance. A capacitance measuring circuit continuously measures the capacitance  $C_0$  of the sensor. When this circuit detects a change in capacitance, it generates a signal. The resistive touch sensors calculate the pressure applied on the surface to sense the touch. These sensors contain two conductive films coated with indium tin oxide, which is a good conductor of electricity and separated by a very small distance. Across the surface of the films, a constant voltage is applied. When pressure is applied to the top film, it touches the

bottom film. This generates a voltage drop which is detected by a controller circuit and a signal is generated, thereby detecting the touch.



*Figure 5: Touch Sensor*

In this scenario, the sensors can be used to activate certain switches or can be installed on the forks to automatically control the fork's movement after the materials to be lifted come into contact with the touchpads of the sensors. The touch sensor can also be placed under the seat of the forklift, which will signal if a driver is present on the seat. If not, the forklift will not start.

Other sensors can also be incorporated into the model. Infrared sensors can be installed along with ultrasonic sensors. Although they will serve the same purpose, the output of the sensors will be different and will give the user a different perspective on the model. The infrared sensors can also be installed on the sides or on the four corners of the forklift to maximize its coverage area. Weight sensors can be installed under the forklift and a weight limit can be set to avoid carriage of excess weight on the forklift.



Figure 6 the integration of the different sensors in the physical devices

In the above image, dots of three different colors are visible. The different colors signify different sensors. The blue dots signify the ultrasound sensors, the red dots signify the touch sensors, and the green dot signifies the vibration sensor. The dots denote where the sensors will be positioned. The sensors will be programmed using an Arduino, and if the Arduino is used to set up the model, a portable battery will also be installed along with it. A motor is also planned to be installed to be able to run the forklift without human interference. That will require more sensors and accuracy in measurement. Human supervision will always be necessary.

### 3.3 Currently available sensors and actuators (March 2022)

For each of the sensors and actuators, you will find a fact sheet in the course learning management system. You will also find information on how to use them as well as how to replace the sensors with others if you are in the physical lab environment. If you are in the remote lab, please set up your experiment in advance so that the technician can change it for you.

#### List of sensors used/can be used for the Forklift

1. Ultrasonic sensors (used)(HC-SR04)
2. RFID sensor (used)(RC-522)

3. Camera (used)
4. Time of flight sensors (used)(VL5310X)
5. Gyroscope (used)(GY-521)
6. Proximity sensors
7. Pressure sensors
8. Vibration sensors
9. Accelerometer sensors.
10. Touch sensors

#### **Actuator used**

1. L298 H-Bridge

## **4 Evaluation**

The usage of this DT is different from the previous examples in which the twins are used for planning and operation. Our evaluation also reflects this difference. The accuracy of the DT is of relevance but not on a level similar to applications used for monitoring and control. Furthermore, since the mixed-reality environment is used for learning, we have to consider different constraints, like the capacity of the human brain to just follow a few variables. The evaluation of one of the first prototypes is described in [6]. This was evaluated by master's students, while the first results of the new mixed-reality environment at the design stage and first prototypical implementations are described in [12, 13] and have so far only been tested by research assistants and researchers. However, the potential users of the sandbox game are an inhomogeneous group both in terms of their experience of warehouse management and operations and of their technical skills. It is therefore imperative that the game can be adapted to suit different learning needs. In the first testing with prototype 2, as shown in Fig.7, we identified the need for an introduction to the topic that is adapted to the player's knowledge, i.e. if a player has no experience in logistics operations, he/she will get a different introduction, support, and feedback while playing than one with more experience. The same would be the case in terms of the technologies used, i.e., the current mock-up related only to sensor selection. A player with little knowledge of sensor technologies, he/she might only choose between the three types of sensors described in the previous section. In contrast, a more advanced player would get the chance to select different types of sensors in the same category to emphasize their deeper understanding. The mock-up testing also revealed the need for better-customized feedback (in our case via tablets) to keep track of what is

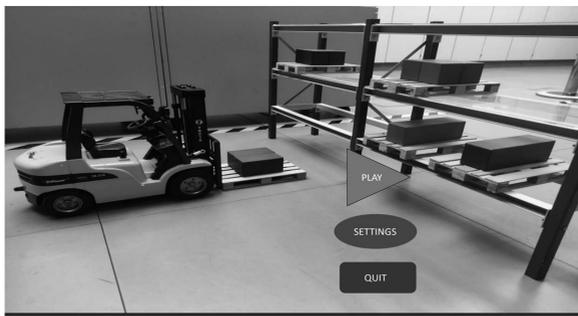


Figure 7 Prototype

relevant and what is not. Based on our experiences with the mock-up, we also introduced (as an integral part of the game) a tutorial. The tutorial's sole objective is to teach players about the game's basic topology and controls. This will broaden the players' general understanding and understanding of warehouses. We also think that, in some cases, it would be suitable to let the player acquire prior knowledge by exploring sensor technology and the interfaces by free roaming in the sandbox mode.

As regards the use of Augmented Reality (AR) with a tablet, we identified in which processes it had the most supportive effect. AR interaction and controls with tablets engage players significantly in terms of interactivity in the learning process while playing games. The realization of this is shown in Fig.8

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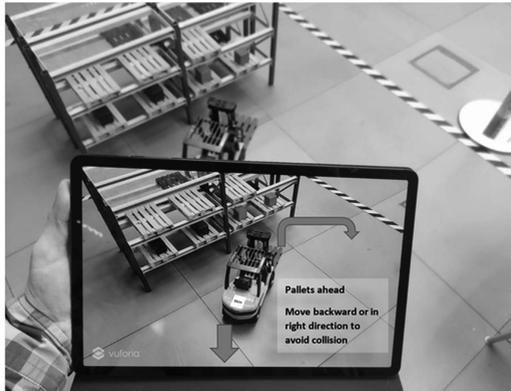


Figure 8 AR supported interaction and feedback GUI

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## **Applied RFID in Logistics Testing RFID Technology for its Application in the Fast-Moving Consumer Goods and Apparel Industries<sup>1</sup>**

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Keywords

Radio-frequency Identification (RFID), Logistics, Retail, Received Signal Strength Indicator (RSSI)

### **1 Preface**

*Overview*

In this chapter, a research-oriented lecture on RFID application in logistics is provided. The chapter explains the theoretical background of UHF RFID and is driven by a user story, based on an industry-like scenario in a food & beverages supply chain. Indeed, the second section of this chapter will deep dive into the user story, allowing the reader to personify a supply chain management consultant into a pilot implementation of RFID technologies in the food & beverages sector. Also, the lecture presented in this chapter is strictly connected with practical lab experience. By means of QR codes, in fact, readers might be linked to supplementary resources, such as data repositories or even experiments, performed either in batch (i.e. readers specify the experimental settings, and then the experiment is performed and the results are provided at a later time) or remotely (i.e. readers become experimenters by remotely accessing and operating lab resources). When carrying out the lab experience, readers are encouraged to work in groups

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of 2–4 people to set and/or perform the experiments, and to analyze experimental results. The aim of this group work is to foster cooperative learning, especially when this chapter is adopted in higher or vocational education classes or courses.

### *Didactic fundamentals*

Target group	Master's students in industrial, electrical, or computer engineering disciplines or professionals in supply chain management or logistics who want to deepen their knowledge of the topic of industrial RFID applications
Effort in lecture hours	16
Effort for self-study materials	34
Suggested Credit Points (CP)	2
Prerequisites	General: computer with online access, MS-Excel or compatible spreadsheet Specific: The experiment needs to be booked one month in advance
Necessary background	The reader is strongly advised to go through the RFID-tag testing chapter first
Additional information	Before the reader starts with the user story, we suggest leafing through the sections 2–4. If the reader feels confident about those topics, we suggest start with the user story in section 1 immediate. Conversely, a deeper look into the theory in sections 2–4 could provide the reader with the necessary theory to perform the experiments and analyze their results.

### *Learning Objectives and Skills*

The goals of this learning chapter are that the students:

- know the components of an RFID system
- have an overview of the frequency ranges of the RFID technology
- understand how the backscatter communication of UHF RFID works and the difference between near field and far field antennas
- know which antenna polarizations exist and what is meant by ERP, EIRP, and RSSI
- acquire knowledge of the modulation, encoding, and anti-collision methods of UHF RFID systems
- know which factors influence the communication of an RFID system
- can measure RSSI curves to find out the influence of power and substrate on an RFID system
- are able to measure and calculate alpha and beta errors in different system configurations
- can determine the best system configuration from antenna type, antenna orientation, and performance
- can perform an economic evaluation of RFID systems

## 2 Theoretical Background of UHF RFID

The abbreviation RFID stands for Radio Frequency Identification. RFID is part of the automatic identification procedures (Auto-ID). RFID technology has attracted increasing interest in the business environment by virtue of its ability to improve many industrial practices, mainly logistics, typically made with effective but inefficient technologies (Riemenschneider et al., 2007). The early literature on this subject area (Hardgrave et al., 2005; Riemenschneider et al., 2007) has proven that RFID brings four main advantages when compared with other identification technologies (e.g. barcodes and acousto-magnetic systems), namely: (i) the reader and tag do not need to be aligned for RFID readings (non-line of sight), (ii) it is possible to read a huge amount of tags in a short time frame, up to hundreds of readings per second, (iii) the data storing capacity of the tag, potentially provides more memory space than linear barcodes, (iv) it allows re-writing and managing the data written on the tag. In the following sections, the use of RFID in the industry is explained, the components of an RFID system are described, the communication between the reader and transponder is explained, and the factors influencing an RFID system are mentioned.

## 3 Use of RFID in Industry

In recent years, because of the increasing need for tracking and tracing products in supply chains, the use of RFID has increased. Large organizations such as Walmart and Tesco have been pushing their suppliers to tag products. In 2010, Walmart announced the decision to start using RFID technology to track such items as men's jeans and underwear. Today, RFID technology is used for all shipments and locations in the United States. More in general, studies on the fashion and apparel industry have proven that RFID adoption in environments using suitable platforms and standards can improve the whole supply chain (SC), for instance allowing coordination of players (Bindi *et al.*, 2016, 2018). Of course, such an approach also involves customers who have to share information suitable to SC coordination (i.e. customer demand). In this sense, Novotny *et al.* (2015) have proven the willingness of consumers to share information with SC via RFID, which eventually leads to providing better services to customers (Heim *et al.*, 2009). Fashion and apparel retailers especially have been driving the adoption of RFID for the last 10 years (Cilloni *et al.*, 2019). Among other advantages, an important focus of the fashion and apparel industry is on the existence of counterfeit products, which causes a huge amount of revenue

loss as high as 26.3 billion euros annually in Europe. RFID can be used to optimize store practices, also because the usefulness of the technology is well recognized by company staff, who are generally willing to use the technology in their tasks (Bertolini *et al.*, 2018). Still, the interest of the fashion and apparel retail sector is not limited to counterfeiting or the grey market: in 2016, Rizzi *et al.* (2016) identify 18 possible RFID use cases in this industry, further extended and used to realize an observatory of RFID adoption in the fashion and apparel industry (QR code to: <http://www.rfidlab.unipr.it/rfid-barometer/>), as well as to provide specific key performance indicators to improve retail and distribution practices (Bertolini *et al.*, 2017 ; Cilloni *et al.*, 2019).

Many other industries, however, have adopted RFID technology. Typically, RFID is adopted to improve logistics and SC flows (Baars *et al.*, 2009 ; Cao *et al.*, 2018; Gladysz & Santarek, 2015), as well as manufacturing operations (Cao *et al.*, 2017 ; Jiang & Cao, 2013 ; Ruppert *et al.*, 2018 ; Xiang *et al.*, 2017). Digital SC, leveraging RFID, can yield better and faster decisions, better visibility and quality of information, improved processes and productivity, reduced operating costs for logistics, and improved competitive positions (Attaran, 2020). RFID usage in this industry is estimated to grow from 3.6 billion in 2018 to 9.8 billion in 2025 (even though such forecasts do not always become reality).

The construction industry has been continuously interested in RFID adoption over the last 10 years. Its main applications relate to asset tracking and inventory management, and life cycle management of assets for buildings as well as infrastructures (Iacovidou *et al.*, 2018; Li *et al.*, 2020; Motamedi *et al.*, 2016 ; Prakash Chandar *et al.*, 2016 ; Valero *et al.*, 2015). Also, other important uses of RFID in the construction industry related to sharing information for controlling projects, and coordinating company departments and partners (Sun *et al.*, 2013), as well as tracking operators for the sake of their safety (Bugg *et al.*, 2018).

Beyond retail, manufacturing, and the construction industry, RFID has also gained attention in the past decade from service industries, mainly healthcare (Kereri & Adamtey, 2019). RFID has successfully been adopted for asset tracking and providing information to decision-makers about patients, hospital personnel, and hospital processes (Caredda *et al.*, 2016 ; Figueroa *et al.*, 2019; Ma & Yang, 2013 ; Manzoor, 2016). Other successful applications relate to (i) transportation, such as parking management and traffic surveillance (Nahian & Rana, 2020), (ii) tourism, such as enhancing museum expositions by providing additional information to operas (Handojo *et al.*, 2018), (iii) natural resources management, mainly to track assets (Keefe *et*

al., 2019), as well as (iv) academia to trace student attendance of courses and library operations (bin Mohd Nasir *et al.*, 2015).

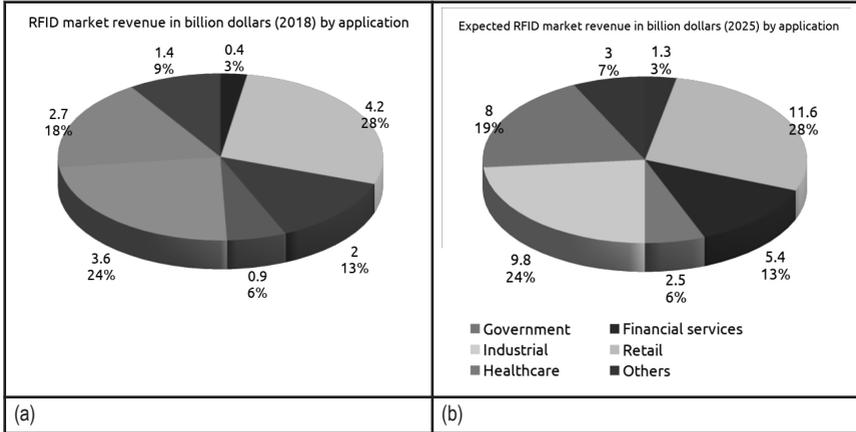


Figure 1: (a) market revenue of RFID adoptions in 2018, and (b) revenues forecasted for 2025. Data from [www.statista.com](http://www.statista.com)<sup>2</sup>a\_1.pdf

Finally, some considerations on the evolution of RFID applications. Previous research studies mostly focused on enhancing the security of radio frequency identification (RFID) protocols for various RFID applications that rely on a centralized database (Sidorov *et al.*, 2019). The reliability achieved has allowed researchers to enlarge the view of the big picture of the Internet of Things (IoT) (Da Xu *et al.*, 2014 ; Shammar & Zahary, 2019) and other related technologies, such as Wireless Sensor Networks (Landaluce *et al.*, 2020) and Blockchain (Ahamed *et al.*, 2020 ; Sidorov *et al.*, 2019 ; van Hoek, 2019). Surely increasing stress on security has to be applied for suitable trustworthiness of systems (Alotaibi, 2019 ; Ibrahim & Kamalrudin, 2018 ; Niraja & Rao, 2020).

2 Retrieved from: <https://www.statista.com/statistics/781314/global-rfid-technology-market-revenue-by-application/>. [Access available]. Last access: 2020.09.24

### Components of an RFID System

An RFID system consists of a transponder, which is attached to the object to be identified, and a reader, with which this information can be read or written to the transponder, as shown in Figure 2.

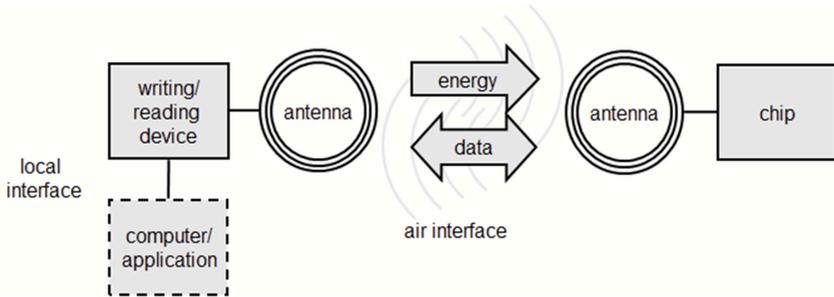


Figure 2: Components of an RFID System (Finkenzeller, 2010)

### Transponder

The term transponder is a combination of “transmit” and “respond”. Quite often the term tag is used synonymously for transponders. The transponder has a microchip to process and store data and an antenna to communicate with the reader. Tags can be very compact, measuring only 0.05 x 0.05 mm, and thus are thin enough to be embedded in a sheet of paper. The antenna connected to the chip, however, is larger. Transponders are divided into active, semi-active, and passive types. The active ones have their own battery to power the microchip in the transponder and generate radio signals, and therefore these tags can achieve the greatest reading range. Semi-active tags have a battery to power the microchip, and passive tags use only the energy of the reader. Due to the absence of a battery, passive tags are the cheapest ones and are the most widely used; therefore, the focus of this chapter is also on passive tags. The electrical current induced in the antenna by an electromagnetic signal from the reader provides sufficient power for the CMOS (an acronym for complementary metal-oxide semiconductor) silicon chip located in the tag to operate and transmit a response signal. Therefore, the chip’s low sensitivity threshold level is important for high reading ranges. The read sensitivity of an Impinj Monza R6 chip is as low as -22.6 dBm, while the write sensitivity is at -18.8 dBm. In order to write data to an RFID tag, a closer distance is required.

### Readers

There are different types of readers, classified on the basis of their characteristics. As far as the tag typology (active/passive) to read is concerned, readers for active tags are different from readers for passive tags. The main difference relates to the need for coping with severe standards on RF signals and, hence, passive tags are strictly normed. For instance, passive tags' signals working at UHF are normed by the standard ISO/IEC 18000 Type C (otherwise known as EPC Gen2, Class 1), in terms of modulation method, as well as bandwidth and the frequency range emitted. Of course, signals 'activating' passive tags come from the readers, and thus radio frequency (RF) signals of readers are normed. As regards reader typology, three main typologies exist:

- Portals: items pass through antennas equipped on fixed structures
- Handheld (mobile) readers: similar to remote controllers or scanners for barcodes
- Fixed readers: small devices fixed in specific positions of facilities or buildings

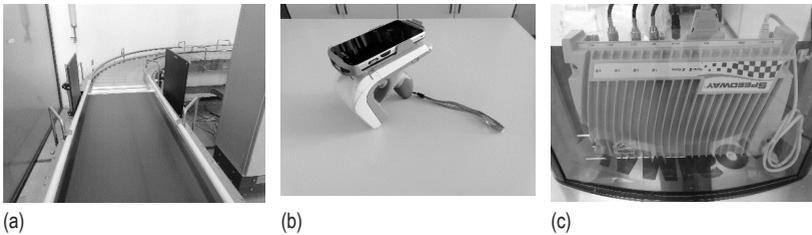


Figure 3: (a) Near Field/Short Range UHF Antenna—A1030 Times-7 Gateway, (b) Zebra RFD8500 RFID (UHF) Mobile Reader, (c) Impinj IPJ-R1000-AS11M3 RFID Reader

### Antennas

One of the main components of a reading system (the same applies to a tag) is one or more antennas. Antenna layouts differ and their usage depends on the type of application. An antenna is linked to an important value, the antenna gain  $G$ , indicating 'the factor by which the radiation density  $S$  is greater than that of an isotropic emitter at the same transmission power' (Finkenzeller, 2010, p. 117), which is shown in Figure 4 using the example of a dipole. Short-range readings require antennas with a negative antenna gain to limit the signal output of the reader. While medium- and high-range

applications require antennas with a positive gain to amplify the reader output.

Electromagnetic interference needs to be considered when designing antennas (e.g. eddy currents, signal fading) and their entity depends on the frequency range. For a more in-depth analysis, please refer to Dalla Chiara (2011), Souryal et al. (2010), and Ying et al. (2009). RF signals (waves) pass through many solid materials (though their strength will be reduced due to absorption). Therefore, they cannot be easily contained within the desired space, nor can we ignore the effects of radio signals transmitted by devices located a long distance, even thousands of feet away.

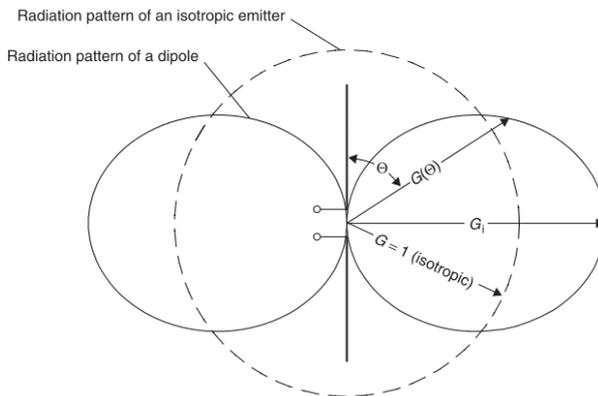


Figure 4: Radiation pattern of an isotropic emitter and dipole (Finkenzeller 2010, RFID handbook, p. 117)

### RFID Frequency Ranges and their Characteristics

Various frequency ranges can be used for data transmission via RFID, which are dependent on country-specific laws and regulations. Depending on the frequency range used, the technological characteristics and thus the possible applications of RFID systems vary. Basically, the RFID frequencies are divided into the ranges Low Frequency (LF), High Frequency (HF), Ultra High Frequency (UHF), and Microwave (MW)<sup>3</sup>. The table below shows the typical working frequencies, the read range, the type of coupling, the

3 (Bundesnetzagentur, RFID, das kontaktlose Informationssystem, p. 3)

reading speed, and examples of applications. Since this chapter deals with RFID in logistics, the focus is on the UHF frequency range.

*Table 1: Frequency ranges and their characteristics<sup>4</sup>*

	Low Frequency (LF)	High Frequency (HF)	Ultra-High Frequency (UHF)	Microwave (MW)
Working frequencies	125–135 kHz	6.78 MHz 13.56 MHz 27.125 MHz 40.680 MHz	433.92 MHz 868 MHz (EU) 915 (USA)	2.45 GHz, 5.8 GHz
Read range	Up to 1m	Up to 3m	Up to 9m	> 10m
Type of coupling	inductive	inductive	electromagnetic	electromagnetic
Reading speed	slow	slow to medium	fast	very fast
Examples of application	animal identification	access control, time recording, theft protection	warehouse, logistics	vehicle identification

As far as the worldwide principles of RFID are concerned, there are two main reasons to adopt the corresponding regulations. RF signals (waves) travel almost forever, pass through many solid materials, and cannot be easily held within the desired space. Radio devices can interfere with your RF system, and your system can interfere with them. These types of interference affect the performance of an RF system, i.e. can reduce the read range of a system or render it inoperable. The second reason to control RF transmission is to avoid injuries to humans and animals. RF devices operating at 2.4 GHz range and higher can seriously damage human tissue. A regulation must be established as to the level of safe exposure, and some mechanism has to be created to certify and monitor compliance. In Europe, UHF RFID systems are assigned a frequency range of 865 to 868 MHz and a 2 W max power. As a result, a tag designed for the US will have problems being read in Europe and vice versa, since in the USA frequency range is assigned between 902 and 903 MHz, while max power is normed at 4 W. To overcome these problems, RFID systems must be designed to incorporate all the frequency ranges (within the UHF band) used all over the world. This has been accomplished by EPCglobal Gen-2 and ISO 18000-6C standards. Readers and tags designed according to these standards will interoperate anywhere in the world.

4 (Bundesnetzagentur, RFID, das kontaktlose Informationssystem p. 5), (RFID, Tamm und Tribowski 2010, pp. 18–19)

### *Backscatter Communication*

For data transmission in the UHF range with passive tags, the backscatter method is used. The RFID reader generates an electromagnetic (EM) field with which it supplies the transponders located in the reader's reading field with energy and activates them. The RFID reader sends its data to the transponder via electromagnetic waves. The transponder reflects these electromagnetic waves to send its data to the reader. By means of a load resistor, the transponder can modulate its data and the reader interprets the backscatter signal received. If the object that the electromagnetic waves hit, here the tag antenna, is in resonance with the waves, then the backscatter will be especially good.

### Near and Far Field Regions of Antennas

Since the basis for transmission in this respect are electromagnetic fields, the near and far field regions of antennas are discussed here. The electromagnetic field characteristics vary as a function of distance from the antenna. They are broadly divided into two regions, the near-field region, and the far-field region.

*Table 2: Overview of near and far field*

Near field radius $\ll \lambda/2\pi$	Far field radius $\gg \lambda/2\pi$
<ul style="list-style-type: none"> <li>nature of waves depends on source characteristics</li> <li>high current, low voltage, the source is mainly magnetic</li> <li>low impedance</li> </ul>	<ul style="list-style-type: none"> <li>nature of the wave depends on the propagation medium</li> <li>electric and magnetic fields are both planar waves</li> </ul>

### Near-field region antennas

A distance less than  $\lambda/2\pi$  ( $\lambda$  - wavelength of the EM waves) between a standard UHF patch antenna (antenna with one emitter) and an RFID tag is called near field (see Figure 5), and there are specialized near field antennas. Near-field antennas solve the problem of using tags in difficult climatic and operating conditions and in hard-to-reach places. At the same time, they are compact and powerful. When we are determining the registration distance between the tag and the near field antenna, the size of the loop (the antenna pattern is depicted in the form of a loop) that is created by the emitter is important. By adjusting this parameter, the near field antenna is able to read UHF tags from a distance of 1 cm or less, since at a smaller distance the

signal from the tag is not shielded by the near field of the antenna and the influence of magnetic or dielectric permittivity is excluded.

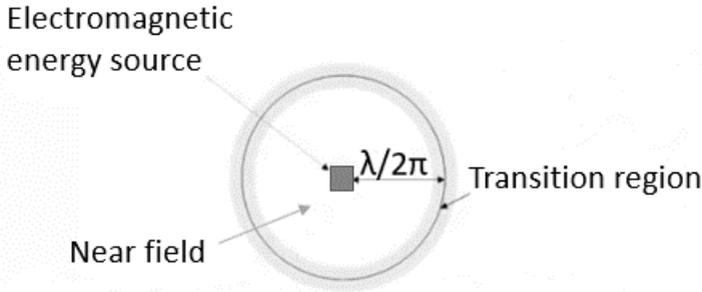


Figure 5: Near field

### Far-field region antennas

Far-field antennas are used to create registration zones for UHF tags up to 15 meters and are used at the entrances to the warehouse and production facilities when assembling RFID gates, portals, or frames on a conveyor. Far-field antennas have a pronounced directivity, and the readout range of such antennas depends on gain and polarization. Despite the fact that RFID antennas are not the main device in the RFID system, the correct operation of the whole system depends on their performance and correctly chosen settings. One condition that must be met when conducting measurements in the far-field region is that the distance from the antenna must be much greater than the size of the antenna and the wavelength.

### Antenna Polarization

RFID antennas polarization is one of the crucial parameters for setting up an RFID system. The communication is based on electromagnetic waves, which travel in two manners: linearly polarized (vertically or horizontally) or circularly polarized (see Figure 6). When EM waves propagate in a single plane either horizontal or vertical, it is called linear propagation. And when EM waves propagate in a manner where the amplitude of the waves is constant but rotates with time, it is called circular polarization. The orientation of the antennas for both the tag and the external device should be such that both antennas have the same polarization. Linearly polarized antennas should be used when the tag antenna orientation is known and does not

change over time. However, if the tag antenna orientation is unknown or changing, circularly polarized antennas should be used, as the tag antenna orientation has less impact on the reading results. However, circularly polarized antennas reduce the power transmitted (for details, see the next subsection) when compared to linearly polarized antennas, which may be compensated for by the antenna gain and higher power output settings in the reader. Also, the reader and tags can be placed on different planes and at different heights. In the use case in Chapter 2, right-hand circularly polarized (RHCP) antennas are used.

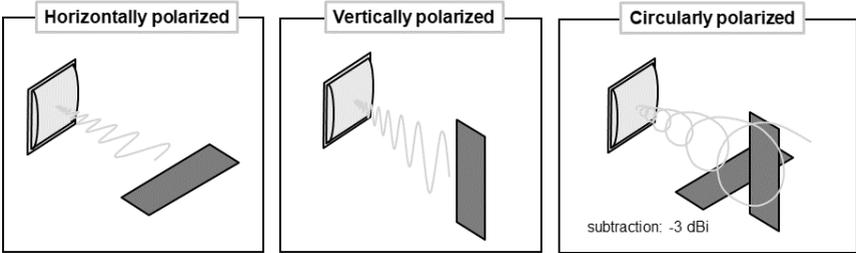


Figure 6: Antenna polarization

### Power Emitted at the Antenna

Not only does polarization have an influence on the communication, but so does the power emitted at the antenna because it affects the reading range. Calculating the emitted power at the antenna is necessary, as conformity to the maximum allowed the power of 2 Watts of effective radiated power (ERP) according to European regulations needs to be ensured. ERP values are based on half-wave dipoles, while American regulations use effective isotropic radiated power (EIRP) based on isotropic antennas. 4 W (EIRP) equal 3.28 W (ERP) or 35.15 dBm. New regulations in Europe will allow 4 W (ERP) in a different frequency range. However, using the upper band frequency ranges (915–921 MHz) is not yet allowed in all member states (e.g. Germany). Details are reported in Table 3.

Table 3: Measurement reference and characteristics

	Measurement Reference	Standardization body	Max Radiated Power Allowed	Antenna Gain Reference Value	Frequency range
ERP	Effective Radiated Power	ETSI (Europe, Lower Band)	2W (33dBm)	dBd	865–868 MHz
		ETSI (Europe, Upper Band)	4W (36dBm)	dBd	915–921 MHz
EIRP	Effective Isotropic Radiated Power	FCC (US)	4W (36dBm)	dBi	902–928 MHz

The power settings in the reader are given in milliwatts (mW) or decibels in relation to a milliwatt (dBm). Watts can be converted to dBm using the following formula:

$$P(\text{dBm}) = 10 \times \log_{10}(P(\text{W})) + 30$$

The power is increased by the antenna gain and reduced by the cable loss between them. The loss of the connectors is low and usually ignored in power setting calculations. The cable loss depends on the frequency, the quality of the cable, and its length. If a circularly polarized antenna is used, the signal strength is reduced by 3 dBi (decibels in relation to an isotropic antenna). Antenna gains are often given in dBi, dBic (decibel isotropic circularly polarized), or dBd (decibel dipole). The units dBi, dBic, and dBd can be treated just like dB, because they quantify the gain of an antenna relative to a corresponding antenna with a gain of 1 (0 dB) and they can be added to or subtracted from dBm values for power calculations. The following conversions apply:

$$\text{dBd} = \text{dBi} - 2.15\text{dB} = \text{dBic} - 5.15\text{dB}$$

According to ETSI EN 302 208, the calculation of the radiated power in dBm for a circularly polarized antenna is calculated as follows:

$$P_{\text{ERP}} = P_{\text{C}} + G_{\text{IC}} - 5.15\text{dB} - C_{\text{L}}$$

Where

$G_{\text{IC}}$  = antenna gain of a circular antenna in dBic

$C_{\text{L}}$  = total cable loss in dB

5.15 = 3 dBi loss for the circularly polarized antenna plus 2.15dBm to convert dBi to dBd

Example calculation of the radiated signal power for a reader with a power setting of  $P_{\text{C}} = 1000\text{mW}$  (30dBm), antenna with 5dBic (thus circularly polarized), and a cable loss of 1.5dB:

ERP calculation = 30 dBm + (5dBic -3dB) - 2.15dB - 1.5dB = 28,35dBm (684mW)

EIRP calculation = 30 dBm + (5dBic-3dB) - 1.5dB = 30,5 dBm (1.125W)

*Table 4: Data settings for the Use Case*

Power settings reader	Far-field antenna
Antenna gain	15–30 dBm (0.03-2W)
Cable loss	7 dBic
Antenna type (circular) and dBd/dBi conversion	1.5 dBm
Possible output at the antenna	5.15 dB
	low: 15 + 7 - 5.15 - 1.5 = 15.35 dBm
	high: 30 + 7 - 5.15 - 1.5 = 33.35 dBm
Maximal allowed emitted Power according to European regulations	2 Watts (ERP, lower band)
	4 Watts (ERP, higher band)

Table 4 shows the data for the settings in the given use cases, focusing on far-field antennas.

### Received Signal Strength Indication (RSSI)

As already mentioned, the electromagnetic signals emitted by the reader are reflected by the transponder. To indicate the signal strength of the back-scattered tag signal, the Received Signal Strength Indication (RSSI) is used. RFID readers provide RSSI values when reading RFID tags. A higher RSSI value is interpreted as a better connection and as more reliable communication. The RSSI decreases with a greater distance between the tag and reader; thus, it has also been used for locating tags in an RFID read zone. However, the RSSI is also affected by absorption, reflections, frequency, and relative tag orientation (angle and height difference) to the reader antenna. If the tag moves closer to a reader antenna, the RSSI increases, and it declines if the tag moves further away from the antenna. RSSI values may differ between readers from different manufacturers. Additionally, the gain of the reader antenna and cable loss influences the values measured. Thus, a comparison of RSSI values should be made with the same reader and antenna setup.

### *Modulation and Encoding*

In the communication between the reader and tag, the transmission rate, method of modulation, and coding/encoding are important parameters for transmission, which are described below:

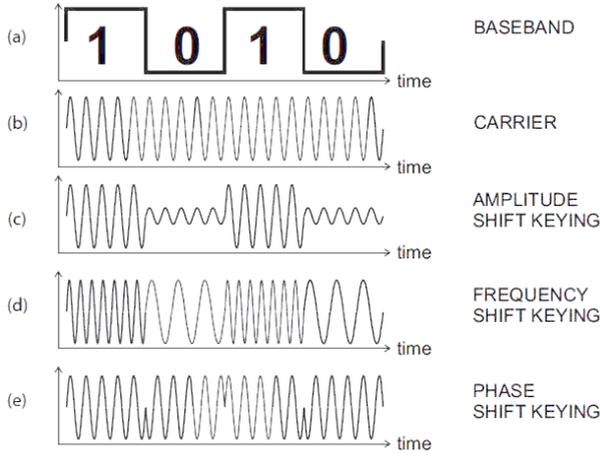


Figure 7: Methods of modulation (Kaur & Kaur, 2015)

Transmission rate

Baud rate of a data communications system is the number of symbols transferred per second. A symbol may have more than two states, so it may represent more than one binary bit.

Bit rate dimension for the efficiency of data transmission is an indication of the correct number of bits transmitted per second.

Methods of modulation

Amplitude modulation: Amplitude Shift Keying (ASK) is an easy technical application that does not need high bandwidth but is interference prone.

Frequency Shift Keying (FSK) needs a higher bandwidth, for example: communication by telephone.

Phase Shift Keying (PSK): complex demodulation, almost fail-safe.

According to the standard EPCglobal UHF Class 1 Gen 2, for the reader-to-tag link the modulations ASK, FSK, and PSK can be used, and for the tag-to-reader link, the modulations ASK or PSK can be used.

## Methods of coding

Figure 8 shows the different methods of coding.

NRZ-L (non-return to zero level) coding  
 uses the absolute voltage level for coding  
 fixed signal level during an interval  
 signal changeover at the bounds of an interval  
 possibly problems in detecting the clock  
 example: standard in digital devices (PC, ...)

Manchester coding

using a change in voltage in the middle of an interval  
 bit 1 = change in voltage in one direction (direction is freely definable)  
 bit 0 = change in voltage in the other direction, good detection of the clock

example: IEEE 802.3 (Ethernet, low-high = 1, high-low = 0, *not corresponding to the figure below*)

FM0 coding

using a change in voltage at every boundary of an interval  
 bit 1 = no change in voltage in the middle of an interval  
 bit 0 = change in voltage in the middle of an interval  
 example: EPC Class 1 Gen 2 (Tag to Reader), optional Miller

Miller coding

no change in voltage at every boundary of an interval  
 bit 1 = change in voltage in the middle of an interval  
 bit 0 = no change in voltage

pulsing is a problem, but good data transmission rates  
 example: EPC Class 1 Gen 2 (Tag to Reader), optional FM0

Pulse Interval Encoding (PIE)

Tari = reference time for '0' ( $6,35 \mu\text{s} - 25 \mu\text{s}$ )

time for '1' =  $1,5$  to  $2 * \text{Tari}$

example: EPC Class 1 Gen 2 (Reader to Tag)

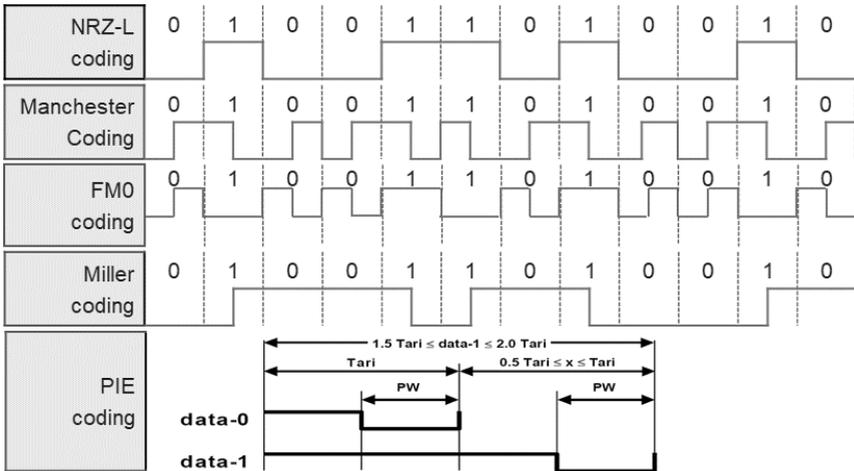


Figure 8: Methods of coding (Source: Rizzi et al., 2011)

Anti-collision Methods

If several tags are in the reading field of one RFID reader and simultaneously send data to it, collisions will occur, and the reader will not be able to identify the single tags. To avoid these collisions, anti-collision methods are used. Table 5 shows the two basic anti-collision methods: Query tree and Slotted Aloha.

Table 5: Methods of anti-collision

Methods used to avoid collisions of transponder signals	
<p>Query tree</p> <ul style="list-style-type: none"> <li>- the transponder ID uses a scheme according to ISO 15693</li> <li>- the Tag-ID is queried starting from its end digit until each tag can be uniquely distinguished</li> </ul>	<p>Slotted aloha</p> <p>EPC Class1 Gen2 standard</p> <p>the reader assigns random numbers to the tag until each tag has been uniquely identified</p> <p>the amount of available random numbers (<math>2^Q</math>) is based on the Q-value, which can be assigned to or may be automatically chosen by the reader</p> <p>if the number of tags to be read is known, assigning an appropriate Q-value can increase the performance</p>

*Data on the Transponder*

After the anti-collision has been successful, the reader can read or write data to the tag. Each tag has a transponder identification number (TID), which is written onto the tag by the chip manufacturer. Well-known manufacturers are Impinj, NXP, and STMicroelectronics. They provide chips with different memory capacities and functionalities (see Table 6). Passive tags can contain rewritable non-volatile EEPROM-type memory.

*Table 6: Memory capacities and functionalities*

Manufacturer	Chip Type	TID	Ull	User Memory
Impinj	Monza 4QT	32/96 bit	128 bit	512 bit
	Monza 4E		496 bit	128 bit
	Monza 4D		128 bit	32 bit
	Monza 5		128 bit	-
	Monza R6		96 bit	-
	Monza X-2K		128 bit	2176 bit
	Monza X-8K			8192 bit
NXP	G2XL	64 bit	240 bit	0 bit
	G2XM	64 bit	240 bit	512 bit
STMicro-electronics	XRAG2	64 bit	176 bit	128 bit
		64 bit	304 bit	0 bit
		64 bit		

The chip, which constitutes the intelligence of the tag, contains the power supply and signal transmission stage (by modulating antenna impedance), the control logic, and the memory. The memory of an ISO/IEC 18000-6c tag is divided into four memory banks, of which three are always present, and an optional one, which is present only on tags equipped with an EEPROM type user memory. The first three banks are used to contain the EPC (Electronic Product Code) numbering, the passwords to lock and kill the tag, and the information of the tag producer, while the fourth bank, the optional one, is intended for possible further user memory. The TID (Tag ID) is a unique code relating to the chip and the manufacturer that can only be read, as it is written in ROM (Read Only Memory) during the chip manufacturing process. Some manufacturers, in addition to their own unique company code, also report a unique serial identifier of the single chip produced in this bank. The EPC is a globally unique identifier that is designed to allow the automatic identification of objects. It contains an identification number for the product manufacturer, the product, and

a unique serial ID. However, as the EPC is provided by GS1, the main field of application is retail applications. This memory space, however, can alternatively be used to store unique identifiers based on ISO standards. The technology provides for assigning a unique identifier to each product according to the ‘license plate principle.’

Table 7: Memory banks

Memory bank	Functions	Comments
bank 00	'kill' password	each 32 bit
	'access' password	
bank 01	Cyclic Redundancy Check (CRC-16)	check sum method
	Protocol Control	incl. length of the EPC; numbering pattern (e.g. application family identifier / ISO 15961)
	Electronic Product Code (EPC)	ID assigned by the product manufacturer according to GS1 or ISO standards
bank 10	Tag Identification	ID assigned by the chip manufacturer (cf. ISO 15963)
bank 11	User memory	optional free memory

*Desired and unwanted readings*

Errors in the data collected can diminish the advantages of using RFID or even increase costs as compared to not using RFID systems. The two major origins of data collection errors are: (i) false positives, i.e. reading a tag that is unexpected or unwanted, also called ghost tags, and (ii) false negatives, i.e. missing the read of an expected RFID tag. A false negative result in no collected data: the identifier stored on the tag is not collected by the reader. A false positive result in wrong data: specifically it is read and reported by the identifier of a tag attached to a product that is not the object of the analysis but is within the reader’s field. Both forms of erroneous data collection can have a significant impact on the benefits of using RFID systems; therefore, they must both be minimized (Engels, 2005).

Alpha and Beta Errors

Alpha and Beta errors are two concepts adapted from statistical hypotheses testing that can be used as indicators of the reliability of the RFID system. We can therefore adapt  $\alpha$  and  $\beta$  errors to an RFID system. Error  $\alpha$ , or type I error, is the rejection of a true null hypothesis, i.e. a false negative or not rea-

ding expected tags. In contrast, error  $\beta$  or type II error is the non-rejection of a false null hypothesis, i.e. a false positive or reading unwanted tags.

### Alpha Error

The Alpha error indicates the reliability of the system. Indeed, having a list of tags that pass through an RFID gate, the Alpha error represents how many tags that should be read have not been read. It can be represented with the following formula:

$$\text{error } \alpha = \text{no. of expected tags not read} / \text{total no. of expected tags}$$

This concept of reliability must be integrated into the minimum lifecycle of a tag. Indeed, it is required that a tag guarantees at least 100,000 reading/writing cycles without damage. In this lifecycle, it has to attest to reading reliability of 99.99%, which can be translated into one missing read each 10,000th reading cycle, which equals an Alpha error of 0.01%. Also, accuracy of 99.998% is required, which can also be read as no more than two wrong lectures for every 100,000 readings.

### Beta Error

The Beta error indicates the noise of the system. In fact, it is useful to calculate how the other tags in the environment are read even if the focus should not be on them. Actually, it indicates how many tags that must not be read have been read during the measuring. It can be summarized in the formula:

$$\text{error } \beta = \text{no. of unexpected tags read} / \text{total no. of unexpected tags}$$

Both Alpha and Beta errors are directly influenced by the type and orientation of the antennas, their power level, and the distance between the antennas and the tag. The objective is to minimize the two errors. However, they react in different ways to the variables. Indeed, having a higher power level, the Alpha error will be reduced, but it will be more possible to read unwanted tags. Moreover, having desired products closer to the antennas, and distancing the unwanted ones, the Alpha error will decrease in accordance with the first solution, while the Beta error will decrease due to the second.

### *Factors in Performance Limitations and Testing*

The relevant factors defined by the regulations that affect performance, in terms of read rate and range, can be referred to as (Rizzi *et al.*, 2011) (i) the reading system (frequency and transmission power, antenna gain and

polarization, receiver sensitivity, modulation characteristics), (ii) the tag (activation energy, antenna gain and polarization, modulation characteristics), (iii) the material onto which the tag is applied (paper, wood, glass, plastic, metal, see also HFT chapter on tag measurement), and (iv) the external environment (reflective or absorbent surfaces for radio frequency, presence of water in the form of moisture, condensation or ice, chemical materials, electrical or RF noise).

Tests are carried out to determine the influencing factors in an RFID system and determine the best system configuration.

However, despite the standard ISO/IEC TR 18046 describing in detail the test conditions for the RFID tags, the operating conditions of industrial logistics, which is a particularly attractive area for passive UHF RFID technology, are very different from the test conditions described in the standard. It is therefore useful to move from a standard and standardized approach to a more pragmatic one, which is close to typical logistics situations, in order to qualitatively and quantitatively assess the performance of RFID systems in such scenarios.

The following are some results related to the execution of tests to investigate the behaviour of RFID technology in the presence of commercial products. In order to have a complete vision of the performance of the technology applied to real products, it was decided to perform a testing protocol with products with different characteristics, in compliance with the guidelines presented in the standard ISO/IEC TR 18046.

From the results of reading tests under static conditions, it can be seen that reading performance is strongly influenced by (i) the presence of metal in the primary packaging (coffee, milk in a carton, oil in tin), (ii) a product containing water (milk, fruit juice), (iii) the position of the tag on the box for products containing metal or water. In particular, it is possible to identify a position for which performance is maximized, a position that allows you to distance the tag from the metal surface of the package or the product containing water. It has to be underlined that in an industrial environment, where products pass through the RFID gate on a conveyor belt, if the speed of passage under the gate increases, performance tends to decrease in terms of instalments and, sometimes, accuracy.

The results obtained do not have an absolute value, because if the boundary conditions change, the performance could be substantially different.

*Material to which the transponder is attached*

The material to which the transponder is attached has a significant influence on the performance of an RFID system in terms of reading range and detection rate.

A large amount of research on the topic shows that care must be taken when RFID interference is present in an RFID operation. Covering materials of products can be categorized into two groups based on their interference in RFID operation: (i) those that have no effect on the operation, i.e. polyethylene stretch wrap and corrugated boards; (ii) and those that have an effect on the operation, i.e. aluminium surfaces, glass. However, this does not mean that the materials from the second group cannot be used in RFID operations. Typical substrates are metal, glass, and polyethylene.

1. **Metal**, common packaging material in the food and beverage industry, has a very large impact on the transmission of radio frequency. Metal does not allow radio frequency to pass through it. It also changes the inductance of antennas (on both reader and tag) and retunes its resonance frequency. In UHF, this may increase the read range of an RFID system if enough air gaps between the metal and tag are provided. There is some data reported that a metallic substance in front of the tag reduces the RFID system's operating range by 30–50%. The effect of metal behind the tag depends on the distance between the tag and the metal. A distance between 3–6 cm (or more) will minimize the effect of a metallic substance behind the tag. Another possibility is to use special On-Metal tags designed for this material.
- a) **Glass** is an inert and high barrier packaging material and is used extensively in primary packages. Glass can cause the resonance frequency to be detuned (VDA 5500).
- b) **Polyethylene (PE)** is a commonly used pallet stretch wrap material. The impact of stretch wrap on radio frequency is very important to pallet level tracking. It is important to know beforehand if the stretch wrap material will interfere with the pallet's readability. This will determine if the pallet tag needs to be placed on the outside of the stretch wrap or if it can be placed under the stretch wrap. In terms of pallet load tracking, the tags can be placed under PE stretch wrap without it interfering with an RFID operation. Placement of the tag under pallet stretch wrap is more desirable in order to prevent tags from being damaged, lost, or stolen during shipping/handling.

Besides these three materials, there are others that influence RF signals. Table 8 shows an overview of some materials and their effects.

Table 8: Materials and their effects on RF signals

Materials	Effects on RF signals
Cardboard	<ul style="list-style-type: none"> <li>• Absorption (humidity)</li> <li>• Detuning (dielectric)</li> </ul>
Conductive liquids (shampoo)	<ol style="list-style-type: none"> <li>a) Absorption</li> <li>b) A (tiny) layer of salt water (1mm or more) block tag emission</li> </ol>
Plastic	<ul style="list-style-type: none"> <li>• Detuning (dielectric)</li> </ul>
Metals	<ol style="list-style-type: none"> <li>1. Reflection</li> </ol>
Group of aluminium cans	<ol style="list-style-type: none"> <li>a) Complex effect (slow, filter)</li> <li>b) Reflection</li> </ol>
Human or animal body	<ul style="list-style-type: none"> <li>• Absorption</li> <li>• Detuning (dielectric)</li> <li>• Reflection</li> </ul>
Aluminium foil (27 μm or more)	<ul style="list-style-type: none"> <li>• Blocks tag emission</li> </ul>

Noise and interference

The main interference relates to operations carried out with other radio communication devices and applications (Talone & Russo, 2006): this aspect is regulated by norms about frequency ranges and bandwidth at both an international (International Telecommunications Union) and a European level (European Conference of Postal and Telecommunications Administrations). Furthermore, interference also occurs because of other sources working at the same frequency and bandwidth. For instance, Zhang et al. (2013) have analyzed how to solve interference between two or more readers working concurrently. Their study has proven that interference is higher in powerfully noisy environments. It is important to mention that noise is different from interference, since interference is generated by other signals, whereas noise is everything that is not a useful signal and can thus occur due to uncontrolled parameters, such as temperature as well as moon phases<sup>5</sup>. As a result, noise has to be considered and taken under control, but it is not possible to avoid it. A different approach is needed for interference with an electrostatic charge: the focus is on the protection of RFID tags more than avoiding bias (Blitshteyn, 2005), and lots of patents do exist to

5 Source:[https://eng.libretexts.org/Bookshelves/Electrical\\_Engineering/Book%3A\\_Electrical\\_Engineering\\_\(Johnson\)/06%3A\\_Information\\_Communication/6.08%3A\\_Noise\\_and\\_Interference](https://eng.libretexts.org/Bookshelves/Electrical_Engineering/Book%3A_Electrical_Engineering_(Johnson)/06%3A_Information_Communication/6.08%3A_Noise_and_Interference). Available for access. Last access: 2020.09.29

address this issue<sup>6</sup>. If the basic nature of interference is electromagnetic (radio communication signals as well as electric signals), nonetheless the buildings and other elements located in the environment in which reading operations are performed can affect the readings themselves. For instance, Holland et al. (2011) have discussed artificial neural network algorithms for device localization by means of RFID, overcoming interference from metal (i) walls and (ii) structural elements, as well as human presence. More in general, studies have proved that (i) correctly setting the layout of readers, (ii) tagging the items to be identified in a suitable manner, as well as (iii) preferring passive tags to active ones can ease this kind of interference to the extent that readability is not affected (Kolarovszki, 2014 ; Kolarovszki et al., 2016).

#### 4 Use Case

In this section, the use case and the practical exercises are explained.

George is a supply-chain-management consultant working for a renowned food and beverages company. He has been requested to manage a pilot project to implement automated identification (Auto-ID) on one production line of the company that produces cases of different food and beverage products. George decides to use Radio-Frequency Identification (RFID) to improve inventory accuracy in its warehouse because with RFID no line of sight is needed, hundreds of readings per second are possible, and the RFID tags can be used in other areas of the supply chain. George heard of several examples of RFID implementation that significantly improved inventory accuracy at a recent exhibition. However, he wants to test the usability of the RFID system in a realistic scenario, before suggesting the solution to his client. He is especially interested to see how metallic cans and bottles with liquids can cause problems in the identification process. The simple RFID system George is planning to test is composed of one reader and two antennas, tagged product cases, and a system with which to gather and transmit data (as shown in Figure 9). To relieve his burden, George decides to entrust the RFID testing to a group of four students working in part-time positions. He asks the students to report the findings in a management report so that George can forward the results to his customers and take an informed decision about the further rollout of the RFID solution.

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6 Source: Google patents. An example of query: 'RFID electrostatics discharge protection.' Results: 6,100 on 2020.09.29

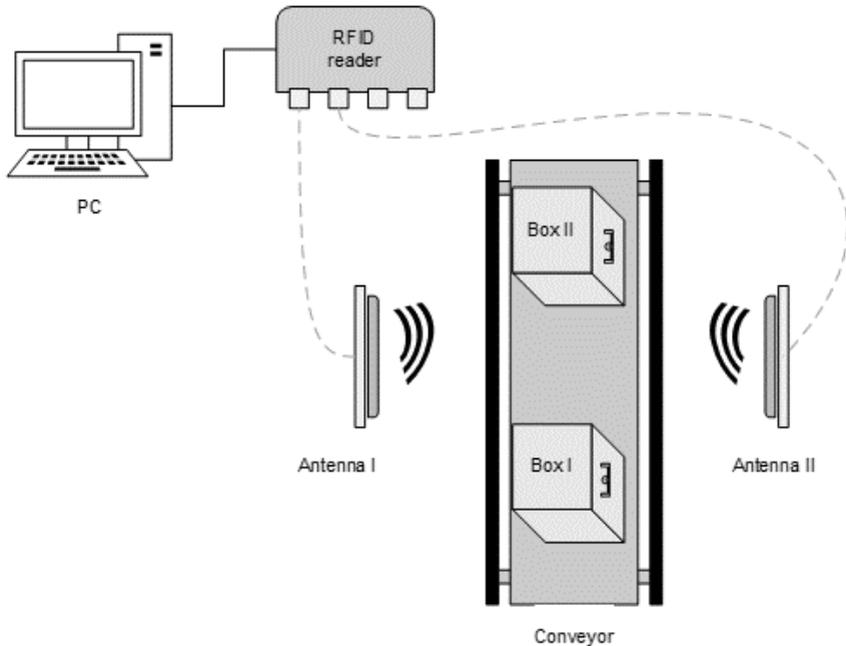


Figure 9: Example of an RFID system

#### Creation of an RSSI curve

After they had seen the past project, the first part they wanted to test was the reaction of the RSSI curve related to the product analyzed and the power level set. Indeed, they decided to follow the experience studied but applied a scaffolding approach. They started with two different power levels (18 dBm and 30 dBm), one type of antenna, and just an empty box, with a single Dogbone R6 Monza, applied horizontally on its side, in order to analyze the trend of the RSSI curve when the radio frequency does not have interference. This trend has to be analyzed according to the function of the RSSI and the reading time.

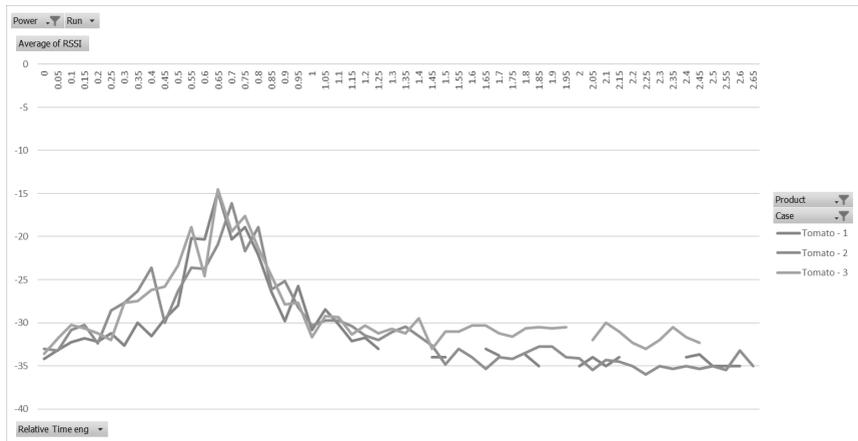


Figure 10: Example of a real RSSI Curve

Successively through these basic tests, they saw that with a low power level (18 dBm) the curve is volatile, while with a higher power level (30 dBm), the RSSI curve became continuous but consisted of a huge amount of unwanted tag readings (those that were present in a laboratory, but were not attached to the products studied, but were registered). After receiving these results, the students decide to extend the power settings to five levels (18, 21, 24, 27, 30 dBm), analyze their trend with far-field and near-field antennas, and analyze the empty boxes and three more products to see how the RSSI curve tendency changed.

As the company where George works specializes in the food industry, the products analyzed are (i) plastic water bottles, (ii) tomato sauce metal cans, and (iii) plastic cooking oil bottles. Moreover, the following products were chosen due to their nature and packaging peculiarities, as they represent (i) an RF absorbing product, (ii) an RF reflecting product, and (iii) an RF friendly product. As the empty box, each box studied was equipped with a single Dogbone R6 Monza tag on the side. In order to receive faster reports from the students, George decided to assign each group of students a different product.

Once all the students had finished their own analyses, George gathered all the results and created a final report by merging them with the previous analysis and comparing them.

Tasks: Creation of RSSI curves

- a) Create an RSSI Curve with the power levels 18, 21, 24, 27, 30 dBm and with the products (i) plastic water bottles, (ii) tomato sauce metal cans, and (iii) plastic cooking oil bottles
- b) Analyze RSSI Curve performance according to different power levels
- c) Analyze RSSI Curve performance according to a different type of products

### *Reading optimization*

After receiving the report, George understood that the RSSI trend shows the reaction of different products but there is a lack of reliability in the RFID system. To measure it, George decided to analyze the Alpha and Beta errors which are the percentage of tags missed in the readings, and the percentage of unwanted tag reads respectfully. As previously, George and his students, started the investigation of former projects and experiences.

By studying this project, George and the students understood that the efficiency of the system lies in the function of different parameters like: (i) type of antenna, (ii) orientation of antennas, and (iii) power level. Similarly to the previous analysis, the students start with a simplified experiment, having three different power level parameters (18, 21, 24 dBm), one type of antenna (Far Field), one orientation (parallel to the conveyor), and one product (metal cans of tomato sauce). To perform the experiment, George and the students placed three boxes of the same product on a conveyor belt. Each lateral side of each box contained two tags of the same type, but a different orientation: one vertically and another one horizontally oriented. The tags amounted to eight tags per box and 24 per three boxes, which are present in the experiment. They wanted to investigate the corresponding errors in relation to each box, by considering the tags on that box as the only desired tags.

After collecting and analyzing the data, the students submit the report to George. However, George finds the results inconclusive and is convinced that testing five different power levels is not enough to determine the best system configuration. Thus, George decides to reduce a step in the power levels to 1 dBm and analyze each power level from 18 dBm to 30 dBm. Moreover, he is eager to know more about possible improvements through antenna modifications. Firstly, he wants to know how changing an angle in the far-field antennas to the disposition of a tag influences the reading results. Secondly, he has heard that specialized near-field antennas may show

better results in the current testing scenario with only ~70cm between both antennas. He chooses to compare the following different antenna setups:

1. Near-field antennas in parallel orientation (NF)
2. Far-field antennas in parallel orientation (FF //)
3. Far-field antennas rotated 45° in motion direction (FF + 45°)
4. Far-field antennas rotated 45° against motion direction (FF - 45°)

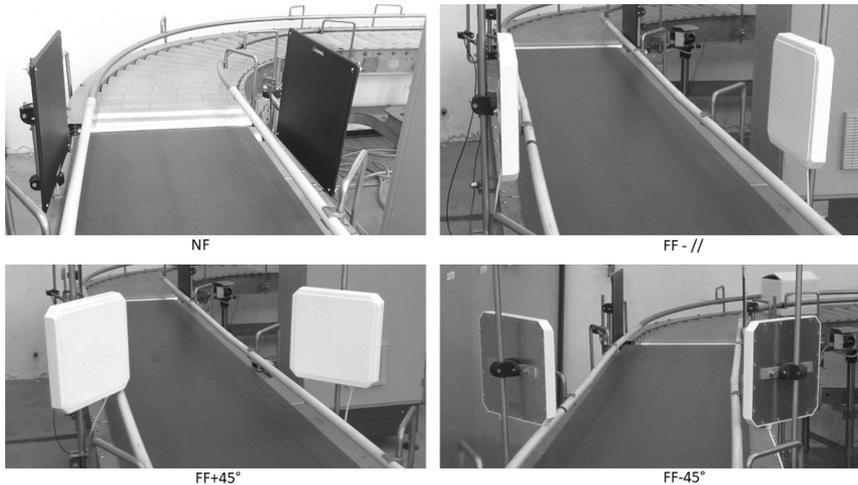


Figure 11: Scenario 2 antenna configurations.

To do so, George assigned testing the different antenna setups to four different students.

Once the experiments were completed, the students created a report with the conclusions on the Alpha and Beta errors' trends according to the different power levels. To compare the results, George gathered all the Alpha and Beta errors from the different configurations, analyzed them again and added them to the management report. In the report, the differences between the different configurations and how the desired and unwanted readings behave accordingly are highlighted.

Tasks: Reading Optimizations

- d) Measure and calculate Alpha and Beta errors in relation to the different boxes, power levels (18 to 30 dBm), different antennas (near and far

- field), different orientations (parallel, 45° in motion and 45° against motion direction) and RSSI
- e) Compare the results achieved with the different antennas' configurations and comment on them
  - f) Select the most effective combination of type of antenna, antenna orientation, and power level

### *Economic evaluation*

On receiving the report, George immediately decided to work on the missing economic considerations himself. In detail, George's aim is that of calculating the most remunerative value of reading power of the RFID gates, based on economic values and estimations. At present, the company produces on average 300,000 cases of products per year.

First, George identified the following (unitary) costs per element of the RFID system installed in the production line:

Element	Cost [€/u]
Tag	€ 0.12
Antenna	€ 300.00
Reader	€1,200.00
Printer	€ 4,000.00

Also, the following boundary conditions are provided for the products:

- Each printer can process 100,000 tags/year,
- Each conveyor line is provided with a reading gate, composed of one reader and two antennas,
- Each conveyor line is expected to process 20,000 cases of products per year,
- Each case of products is provided with one tag.

Additionally, he needs to calculate the economic impact of Alpha and Beta errors. If a desired tag is not read, the corresponding product must undergo manual recovery and processing. This process is estimated to be done by a single worker who will dedicate half a day, two times a week to this procedure. George also evaluated a cost of € 4,500.00 for the reverse logistics, and he assumed an average Alpha error of 2.5%. In contrast, if an unwanted tag is read by the system, the costs generated might be estimated at around 0.50 €/tag, as a weekly control of the RFID database costs at around € 10.00 and fixes 20 tags, on average.

Also, as regards fixed costs, the extra hardware of the new RFID system will cost € 10,000, and the software package to manage it, i.e. the middle-

ware connecting the RFID system to the company ERP, will cost € 40,000. The loan used to fund all the hardware and software investment will be amortized in 5 years.

On the other hand, George works hard with colleagues from the sales, marketing, and IT departments to estimate the profit generated by case-level product tagging. Their calculations showed that tagging allows the company to re-allocate two full-time workers from the inventory sector to other tasks. Moreover, that implementation will reduce the inventory and save € 27,000.00, and € 15,000.00 will come from the reduction of returns and re-working. The marketing department also estimated an increase in sales of € 13,000.00 as a result of higher customer satisfaction.

Having those data, George calculates the most remunerative power level value, considering that the actual volume of the company is 300,000 products/year. George decided to use a conservative approach; thus, he considered the worst scenario for cost reduction and new incoming costs.

**Additional values:** the personnel costs are estimated at € 17.00 per hour, and the working time is 8 a.m.–12 a.m. and 2 p.m.–6 p.m. Furthermore, the company grants seven weeks of holiday per year.

Tasks: Economic evaluations

- Identify variable costs, semi-variable costs, and fixed costs
- Identify the cost driver(s)
- Assign the costs
- Identify the most remunerative combination of antenna types, antenna orientations, and power levels.

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# 3 Interactive Demos



*Michael Klein, Andrej Itrich and Thomas Eppler*

## **Interactive Demonstration showing a Remote Lab using the Fischertechnik learning Factory 4.0**

### Abstract

A fully automated remote lab based on a fischertechnik learning factory to reproduce Industry 4.0 and Internet of Things processes. Participants can control and analyze the lab via the university cloud, independently of time and location.

### Keywords

fischertechnik learning factory 4.0, MQTT, OPC/UA

## **1 Introduction**

The fischertechnik learning factory is a manufacturing plant that consists of fischertechnik elements and is used to simulate a digitalized factory. The simulation reproduces the ordering process, the production process, the delivery process, and the storage process in digitalized process steps.

The factory has several stations such as a vacuum gripper robot, an automated high-bay warehouse for storing nine colored workpieces, a multi-processing station with a simulated kiln and milling machine, a sorting line with color recognition, a delivery and pickup station, and a sensor unit station with an integrated swiveling camera for monitoring the factory.

The individual workpieces are tracked and described by NFC (Near Field Communication). This allows the tracking and visibility of the current status of the workpieces in the manufacturing process.

## 2 The fischertechnik learning factory 4.0

### 2.1 MQTT

The factory is controlled with a Siemens PLC control (industry standard). The entire communication within the factory takes place with MQTT. The messages use the JSON format.

MQTT communication makes it possible for you to write your own software to control the fischertechnik learning factory.

In addition to the web-based dashboard, provided by fischertechnik to control the learning factory, it is also possible to trigger the ordering process via Python scripts. With this tiny client, it is possible to display the current stock of the high-bay as well as the current camera image. The current status of a station can also be requested.

This data is sent to the university's MQTT broker using an MQTT cloner (Python script), which runs on the learning factory's Raspberry Pi, where the data is processed and distributed to different systems via Apache Nifi.

### 2.2 Apache Nifi

Apache Nifi is a data ingestion system with which data routes from a data source, in this case the fischertechnik factory, to a data sink, in this case various database management systems, can be built up graphically without having to be coded. The statuses of the stations and the camera images are stored in Hadoop's distributed file system HDFS. The sensor data is sent to AWS RedShift in the Amazon Cloud. The sensor data are graphically processed using a Python script.

Figure 1 shows an extract of the Apache Nifi ETL structure.

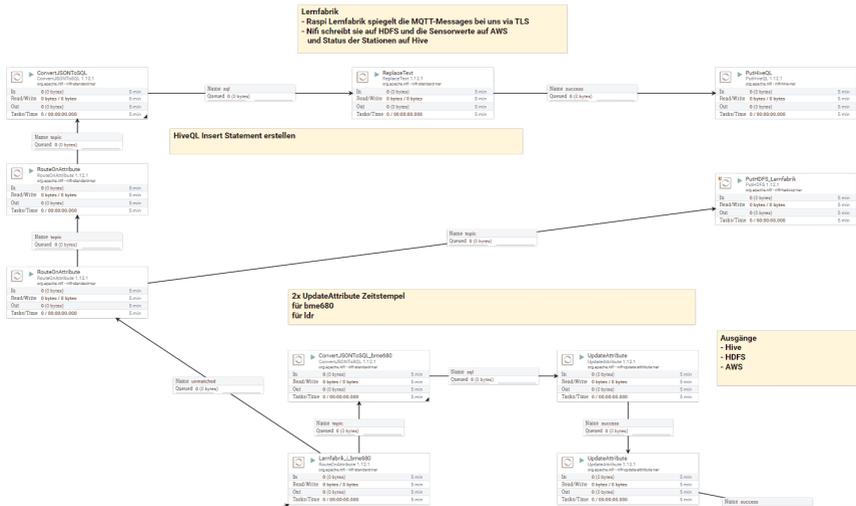


Figure 1: Apache Nifi ETL extract

### 2.3 OPC/UA

In addition, the Siemens PLC control of the fischertechnik Learning Factory has an OPC/UA data interface (Open Platform Communications — Unified Architecture), which is currently the standard for unrestricted platform-independent industrial communication.

With the "OPC-Router" from inray, it is explained step-by-step with example projects how OPC communication between the learning factory and the OPC-Router is realized. Exercises show how the OPC/UA server connection to the learning factory is established with the OPC Router and how sensor-, production-, and order data from the different stations can be read.

Furthermore, the possibility of controlling the learning factory via the OPC Router is described. Ordering processes can be triggered via the OPC Router and the progress of production can be monitored with the integrated camera.

Figure 2 shows the OPC-Router project, which reads various status data from the factory every 10 seconds and stores them in several databases in the university cloud.

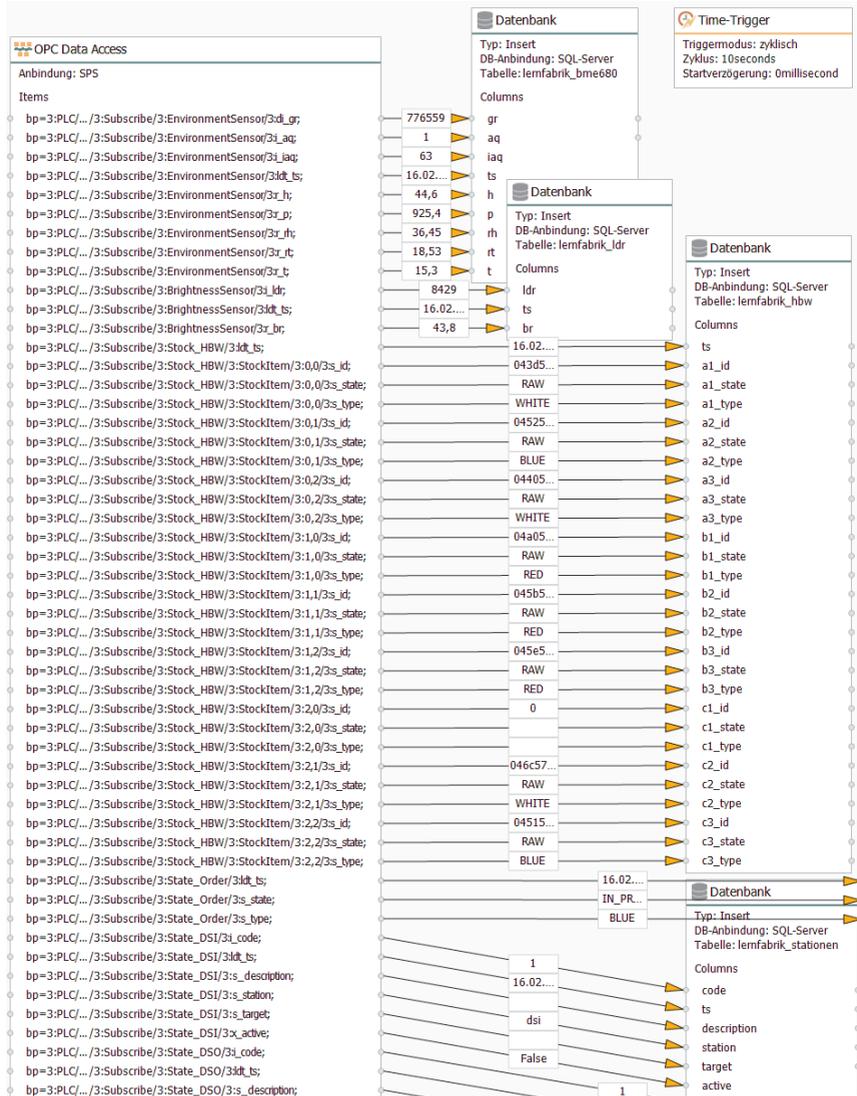


Figure 2: OPC-Router project

### 2.4 Communication structure

The communication structure of the system described above is visualized in the following figure:

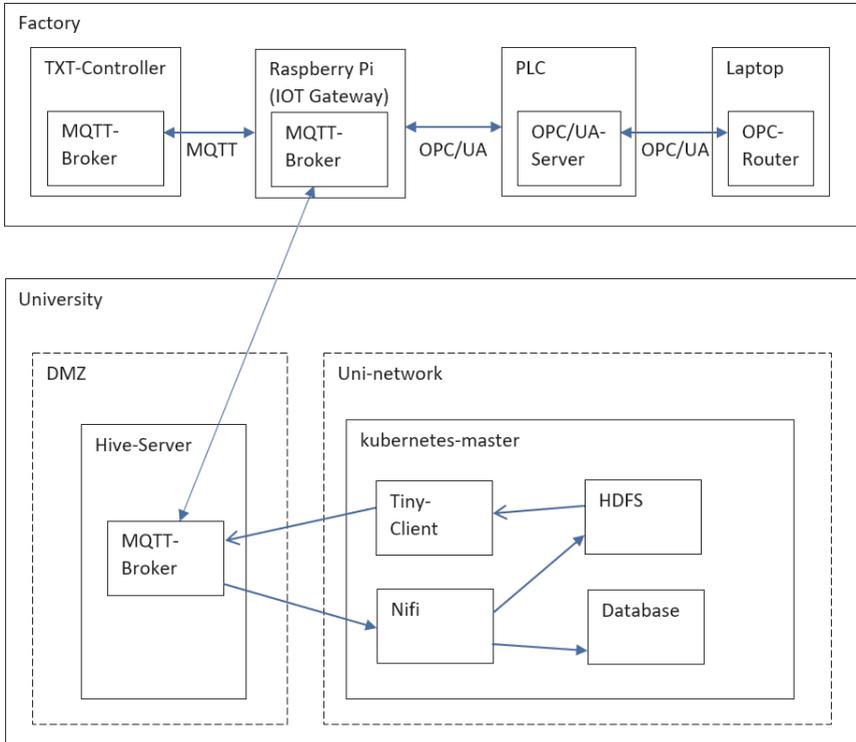


Figure 3: Communication structure

### 2.5 Study materials and exercises

The ordering and storage process is described in detailed study materials. Exercises including solutions for the ordering and storage process, the data ingestion routes, and data evaluation and visualization deepen the understanding of communication with the learning factory.

The participants can access the system regardless of location and time and can carry out the exercises at any time. The fischertechnik system

was converted into a fully automatic and autonomously operating system. However, tests still have to show if the components installed by fischertechnik are fail-safe, and predictive maintenance functions still need to be developed in order to be able to detect the failure of a subsystem at an early stage.

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*Paul Press*<sup>1</sup>

## **A Rationale to Form a Community to Develop Free Online Simulations that improve Access to Higher Education Science and Engineering Courses for Students in Low-Income Countries**

Abstract

A number of inspirational educational leaders, such as Brian Mulligan (2022) of The Atlantic Technological University (ATU), have long since advocated for ways to reduce the cost of online Higher Education courses in order to improve access to students from low-income countries. This paper argues that, while cost may be the major barrier to access, education systems in low-income countries may not provide students with the necessary skills to pass entry requirements to, or succeed in, such courses – particularly in regard to subjects such as Science and Engineering.

The specific focus of this paper is to provide a rationale to create a community of online simulation developers, with the intent of improving the skills of students in their ability to make abstract connections. Abstract connections are necessary for students to make predictions based on hypothetical situations. This, in turn, enables students to succeed in tasks that require understanding consequences, generalizing learning to new situations and relating cause to effect – all essential to success in Engineering and Science courses.

With the ubiquitous nature of smartphone technology, it is the author's belief that effective online simulations can now be developed and distributed relatively efficiently, which could support the development of abstraction within students whose education may be lacking in this area.

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<sup>1</sup> E-Mail: Paul.Press@atu.ie

Keywords

Abstraction Science Engineering

## 1 Introduction

### 1.1 *Scope of this paper*

The Remote Labs initiative at the ATU, Sligo, in Ireland, has been looking into ways of developing content for delivering its practical work in an online setting during the Covid-19 pandemic, and beyond. The basis of this paper is to develop a rationale for scaling up this work, using a global community of developers, with the aim of producing freely available resources to improve access to higher education Engineering and Science courses.

### 1.2 *Background*

Between 2016 and 2019, I worked with a group of international secondary school students on a project in a remote village in Mozambique. This was a long-term ongoing community project. The latest task was to build a Community Centre, where the villagers could gather to discuss their business. For decades, this function had taken place under a large mahogany tree, but the villagers felt that a modern brick-built alternative would be more appropriate for the present-day. In order to document the history of the project, the students hoped to learn about the discussions that had previously taken place under the tree. They asked one simple question the village elders, “If the tree could talk, what would it say?” The response was unanimous, “Don’t be silly, trees can’t talk.”

## 2 Abstraction

### 2.1 *Taking the hypothetical seriously*

Further discussion with the elders suggested that this was more than just a misunderstanding of the question or a problem with translation. What the villagers lacked was the ability to make an abstract link between the tree as an inanimate object, and the tree eavesdropping during village debate, in an anthropomorphized form. They were unable to hypothesize based on this abstraction. Flynn (2013) refers to this as not being able to “take

the hypothetical seriously”. His studies on IQ testing suggest that western education systems have changed significantly during the course of the 20<sup>th</sup> Century to facilitate a more abstract way of thinking. The question of what the tree would say highlighted a disconnect between the rurally-educated villagers, and the internationally-educated students, many of whom shared the same ethnic background as the villagers.

According to Duke University (“The FASD Student & Learning Issues”; 2016), a student who has “difficulty with abstract and conceptual thinking” can exhibit a number of characteristics that may not have caused them a problem prior to the 20<sup>th</sup> Century, but that are detrimental in today’s complex interconnected society. These include not understanding consequences; not being able to generalize learning to new situations; not relating cause to effect; an inability to determine similarities and differences between events; difficulty with money and time, poor social skills; and problems interpreting verbal information.

As Cherry (2010) explains, Piaget, in his theory of the four stages of mental development, found that the ability to abstract and form reasoned hypothetical arguments develops in children aged around 12 and up. However, Blake and Pope (2008) reason, using Vygotsky’s theories, that in order to move cognitive development forward, students need to be in the “Zone of Proximal Development” (ZPD). This requires the modeling of new (increasingly complex) concepts by a “more capable person, such as teacher or peer”. Abstraction, therefore, as a high-order cognitive function, requires both physical development, and exposure. If it is not seen, it is not learned.

Although Flynn (2013) notes the importance of subjects like history and geography in contributing to the political strength of hypothetical debate, he points to advances in science education as being pivotal in developing the ability, in students, to hypothesize based on abstractions. Millar (2004) suggests more specifically that “practical work in teaching and learning of science content is to help students make links between...the domain of objects and observable properties and events on the one hand, and the domain of ideas on the other”. In other words, practical work in science education helps to form a bridge between the concrete and the abstract.

Based on this, it would seem that a well-constructed program of practical science should expose students to a range of links between the concrete and the abstract, thereby modeling the process of abstraction, and supporting student cognitive development in this area.

## 2.2 *Abstraction in Physics*

Just performing practical work itself is not enough, however. It needs to be meaningful practical work. In the domain of Physics, for example, there are often two levels of abstraction.

The first level of abstraction in Physics is the simplification of the real-world problem, and the second is the conversion of that simplified problem into a mathematical model. Take, for example, a soldier pulling a tyre up a hill, or a speed skier racing down a ski slope. As they stand, these scenarios are too complex to investigate practically in a secondary school classroom, so teachers simplify them into an abstract representation – a trolley on an inclined plane (“Investigating motion on a sloping surface”, 2021) where, no doubt, friction, and air resistance are ignored. The simplified physical model can then be analyzed and a mathematical relationship determined that is consistent with Newton’s Laws of Motion – an abstract mathematical model of the abstract trolley on an inclined plane.

To present the abstraction of a trolley on an inclined plane directly to a student assumes that they have some ability to relate what they are seeing to something concrete in the real world. If the student is then presented with an exam question based on a different real-life example, they are expected to first realize that this is simply a manifestation of an abstract trolley on an inclined plane, before they can then take their second abstract leap and apply Newton’s Laws of Motion. The student who can do this successfully under exam conditions is allowed to study the subject further at a higher level (subject to being able to afford the fees). However, without being able to make the first abstract leap, the student will almost certainly fail at the second hurdle. Abstraction in Physics, therefore, is the key to problem-solving, which is a prerequisite for most Higher Education Science and Engineering courses.

## 2.3 *Education without abstraction*

Mozambique is a country still recovering from a brutal 16-year civil war that ended as recently as 1992. One report (“Education in Mozambique”, 2021) showed that less than 7 percent of potentially eligible young Mozambicans complete secondary school, of which there are only 82. Even those few Mozambicans who complete their state secondary education are unlikely to do so with the use of a well-resourced science laboratory.

The problem is not confined to Mozambique, however. In 1964, the Malawi government commissioned UNESCO to develop a post-colonial primary science curriculum (Dzama, 2006). This was introduced in 1966 and

aimed to provide students at the secondary school level who were “endowed with enquiring minds; pupils who were prepared to ask questions and who are not always ready to accept answers”. This was a far cry from the previous British missionary education system to which the country had been subjected for many years, yet it was discarded by the Malawi government in 1972 as the political elite wanted to produce citizens who would obey without asking questions. These “modern methods” in education were abandoned, and the system that was introduced still prevails today.

When teaching in an international school in Thailand in 2014, I worked with a group of students who wanted to reach out to a local, under-resourced, secondary school to offer practical science classes to their students. Once per week, the local students would visit our expansive private campus, where our students would create stimulating and engaging practical activities in our well-resourced science laboratories. Within a month the Thai ministry of education stepped in and canceled the project. The local students were not spending enough time in their classrooms “learning science”. They even had their holiday canceled so that they could make up for the lost time.

These are just a few specific examples, based on my own teaching experiences, but it is likely that there are many more places around the World where the trees can’t speak. Populations where consequences of actions are not being understood, where effect is not being linked to causing, and where similarities and differences between events are not being recognized.

#### *2.4 Smartphone solutions*

It is unlikely that we will change the views of the political elite or provide science teachers and equipment to every remote village school across the globe. However, the answer to the problem might lie in that same village in Mozambique, where each week hundreds of people sit down to watch their local pastor deliver a sermon. With Covid-19 guidelines in place, these sermons are being delivered remotely, and people are watching through social media platforms on their smartphones. GSMA (“The mobile economy”, 2021) expects that by 2025, 31% of Sub-Saharan Africans will have internet-capable phones. That means, if someone doesn’t own one, they will likely know someone who does.

To make the trees speak, we need to produce freely available authentic scientific-practical experiences, grounded in the real world but linked to the abstract, that can be conducted on a smartphone, by anyone, in any language.

There are many laboratory simulations and videos available online (Press, 2021a), but experience suggests that most of those that are freely

available require the student to understand an already abstract view of an experiment. One of the leading developers in this area is the University of Colorado, with the PhET range of simulations. These have revolutionized teaching using simulations within secondary schools and higher education institutions, but even they rarely present a realistic real-world experience. There are an increasing number of Virtual Reality (VR) simulations available, which can provide this context but, even if they are free, they require the use of additional equipment (e.g. VR goggles), which can make them inaccessible to people from low-income countries.

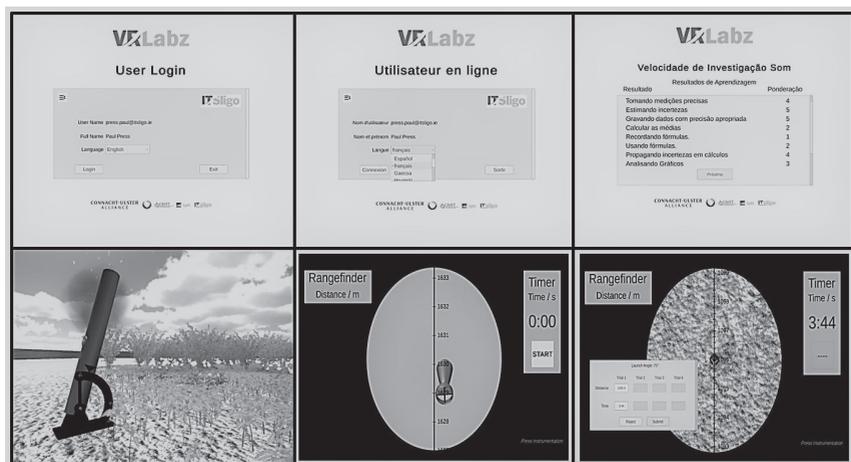


Figure 1: Screenshots from *Speed of Sound* (Press, 2021)

The ATU, Sligo, has been investigating the use of the game engine, Unity, to design and develop a prototype of suitable practical work, starting with an investigation into the Speed of Sound (Press, 2021b). The strengths of this simulation are that it is grounded in a real-world context, web-based, and therefore freely available, provides feedback on performance when completed, and is multilingual. The hope is that mass production of realistic simulations, of this kind, could help students to make links between real-world phenomena and the abstract scientific concepts that underpin them – thus developing their general skills of abstraction.

## 2.5 Further studies

Research is needed into the efficacy of simulations in developing an ability to form abstractions. The simulation above is still in a proof-of-concept stage and requires further development to produce a smartphone-compatible version, as well as context-sensitive support, perhaps using Artificial Intelligence to maintain students within their ZPD. Developing this further would require a community of developers with the necessary skills. However, this simple example demonstrates that simulations of this type can be easily produced, and this may provide a solution to the problem of providing contextualized practical experiences for students to model abstraction, irrespective of their geographical, linguistic, and financial barriers.

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# **XR Twin Lab: an Open-Source Toolbox for XR Remote Access to Experimental Setups in Photonics based on Web Technologies**

## Abstract

Remote labs are a trendsetting way of teaching, communicating, and experiencing science as well as enabling collaborative work. Unfortunately, the implementation of remote access involves cost-intensive development or at least requires a certain technical skill set. To establish remote labs across disciplines, especially outside the field of IT and engineering, the technical access threshold must be low enough to support their self-contained implementation by researchers, assistants, and technical staff. Here, we demonstrate one possibility with the open-source toolbox XR Twin Lab for the research field of Photonics. The XR Twin Lab (XRTL) provides a modular way of building a web-based application to control optical experimental setups with the integration of VR and AR endpoints.

## Keywords

Remote Lab, Web Technologies, Mixed Reality

## **1 Introduction**

There has been increased development of new teaching concepts involving digital technologies, especially shaped by the ongoing COVID pandemic. In the research field of photonics at Friedrich Schiller University, Jena (FSU), this development is being driven forward by three partners: the international and interdisciplinary graduate school Max Planck School of Photonics (MPSP) has set up a digital teaching lab to test and implement cross-site pilot projects in digital teaching (Kaiser, 2021). The DAAD-funded project digiPHOTON aims to open the master's degree course in photonics at the FSU to remote students. One particular task hereby is to make

practical content and laboratory experiments accessible. The photonics makerspace “Lichtwerkstatt”, a BMBF-funded project to establish open innovation processes in the photonics industry (Zakothe, 2019), offers space, tools, and knowledge for community-driven open-source development. One of the many projects (Kretzschmar, 2021) accomplished over the last year in cooperation with the MPSP and digiPHOTON is the remote lab framework XRTwinLab (XRTL), which we would like to present here.

## 2 Implementation

To minimize the technical requirements for users, such as operating systems or runtime environments, XRTL is implemented as a Single Page Application (SPA) in JavaScript and can be executed by any ES6-compatible web browser. The steep learning curve of the script language JavaScript allows non-professional developers like teaching staff, researchers, or students to adapt applications to their use cases. Using the open-source framework React, JavaScript components can be directly mapped to corresponding counterparts in experimental setups. This emphasizes the modularity and adaptability throughout XRTL. The server application is developed accordingly in JavaScript and runs in a node.JS environment to ensure a uniform technology stack, as shown in Figure 1. On the experiment side, lab components are equipped with motorized attachments or sensors, which are connected to ESP32-microcontroller boards, which are capable of Wi-Fi connections. To maximize the benefits of XRTL, the repository is intended to be a growing resource of remotely accessible lab components, such as 3D-printable models, PCB designs, and source codes for using existing interfaces. The communication and synchronization between the client(s) and experiment are event-driven using the Socket.IO communication protocol, which is based on web sockets. To further enable collaborative work and live feedback, the camera and microphone feeds of the users and experiment are integrated with WebRTC, a protocol for real-time communication.

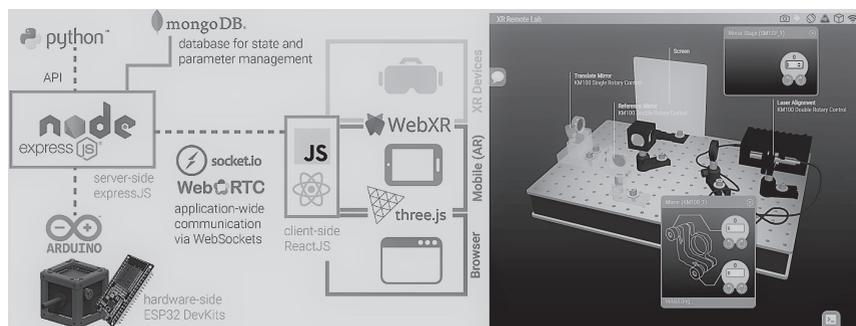


Figure 1: Architecture and Technology Stack with Screenshot of XRTL

We want to design the experience of remote accessing an experiment as closely as possible to real lab work. This supports learning in workflows in a lab and communication in collaborative work processes. Therefore, we focused in particular on the integration of Extended Reality (XR) visualizations and functionalities. With the JavaScript library Three.JS and WebXR, we can show and augment an interactive 3D model of components and setups in a collaborative virtual room.

We finished a functional prototype controlling a Michelson-Interferometer students kit from Thorlabs. In the future, we will test the modular adaptability of our platform regarding its integration into the modular optics toolbox UC2 (Diederich, 2021) and current research experiments from our partners at the FSU and MPSP. We will evaluate the feasibility of XRTL integration under various conditions as well as the user experience of the application itself, especially comparing the browser-only, and augmented and virtual representation.

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*Hans-Georg Reimer, Felix Gers and Steffen Prowe*

## **Is Game-based Learning as a Computer Game a Benefit for Teaching?**

### Abstract

Game-based learning (GBL) has gained increasing attention in different areas of school and university teaching and industrial training. We apply game-based learning to laboratory exercises in microbiology. These are composed of a complex ensemble of interconnected parallel processes. Using a game-based simulation, students should get the opportunity to independent and realistic preparation for the experiments. This asks for special requirements in the graphical user interface of the game-based learning application. It should promote independent learning and render the virtual operations in the game transferable to the real laboratory. To do this, the user interface must provide context-sensitive help, give immediate feedback, and contain an evaluation and reward system. We demonstrate the realization of the user interface of the game-based learning application as a virtual laboratory including an assistant as an avatar. The application has been evaluated quantitatively in a field trial with students in a real laboratory. The analysis of the results shows the added value of the application for the participants. It demonstrates in particular the ease of learning and the usability of the interface, as well as an increase in effectiveness for participants using the game-based application.

### Keywords

Game-Based Learning, Virtual Laboratory, Evaluation

## **1 Introduction**

Game-based elements are introduced into a learning application by means of playful engagement (Subhash 2018, Koivisto et al., 2019 ; Zainuddin 2020). A more active insight into topics is often achieved than with purely theoretical reading activities (Koivisto and Hamari, 2019). We use GBL to prepare laboratory exercises in microbiology. To complete the experimental workload in the given time frame, it is necessary to strategically plan the se-

quence of steps in concurrent subprocesses so that they interlock optimally. In order for students to optimize the process sequence for themselves before the course begins, we provide a GBL application as preparation (Gers and Prowe, 2014). If the result of this preparation is sufficiently good, the experiment takes place as usual in the laboratory under personal supervision. The GBL application is intended to provide the most realistic preparation possible for microbiology laboratory exercises. The realistic representation and animation of working environments are essential to the learning process (Sailer, 2020) and for transferring what has been learned to the real laboratory. We formulate the requirements for the user interface of the GBL application, implement them as a Graphical User Interface (GUI), and evaluate the GUI and the overall effectiveness of the GBL application in a field trial.

## **2 The GBL application**

The GBL application for preparing laboratory exercises contains a simulation of the procedures to be performed in the real laboratory. The GBL application is based on a form of logic that maps the complexity of the laboratory experiment procedures onto a network structure (Gers and Prowe, 2014). This network structure links strands of workflows that must be correctly processed and timed. Students must strategically plan the sequence of steps in concurrent subprocesses so that they interlock optimally. Only in this way can the experimental workload be completed successfully within the specified time frame.

### *2.1 The User Interface*

The graphical user interface of the GBL application, as a realistic representation of the laboratory, is shown in Figure 1. The GUI allows direct manipulation of all displayed components using the computer mouse or other pointing devices. Initially, a virtual shelf contains all the initial products and the tools necessary for the experiment. In addition, in the course of an experiment, the intermediate products created are added. The display and position of each product in the virtual lab are determined by the application. The player can combine products, according to the hidden process logic, using drag & drop. By doing so, they apply a tool if necessary, or use laboratory apparatus, such as a centrifuge. For some steps in the process, such as stirring or shaking, small skill games must also be completed. A

lab assistant avatar accompanies the player throughout the experiment. He supports the player with praising and reprimanding comments as well as practical help, which are spoken and appear simultaneously in a speech bubble.

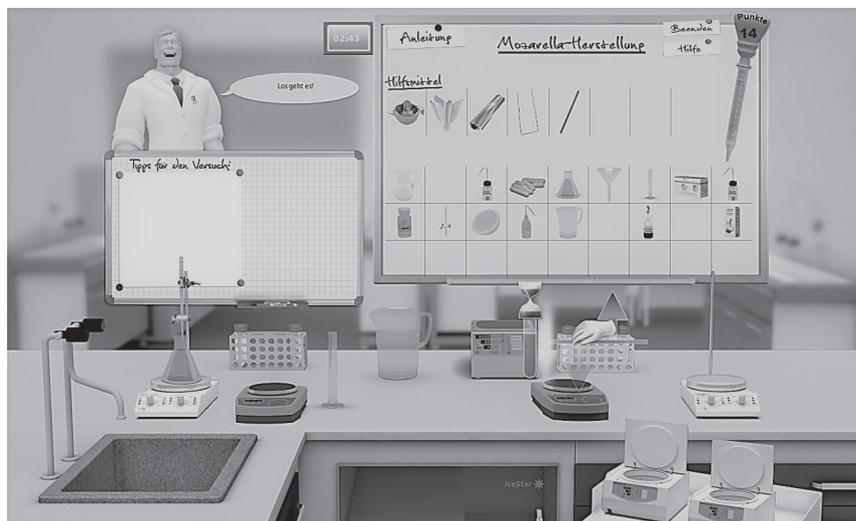


Figure 1: The virtual laboratory (text in German)

### 3 Field Trial

The GBL application was evaluated in a field trial with two study groups (Gers and Prowe, 2014). Both groups completed the experiment simultaneously in the same laboratory. All participants were from the same semester of study and were randomly assigned to the groups. One study group prepared using the GBL application in addition to the printed instructions. They repeated the GBL application until each participant felt well enough prepared before the experiment in the laboratory took place (which was a maximum of five repetitions of the virtual experiment). The instruments used for quantitative evaluation were a questionnaire, observations by the laboratory supervisor, and the results achieved in the GBL application.

### 3.1 Results

The learnability, usability, and design of the GBL application were rated as positive. The students rated the application as very helpful for planning the workflow in the laboratory. If we compare the two test groups, the study group with the GBL preparation made significantly fewer errors and completed the laboratory experiment faster.

## 4 Summary

A GBL application was developed for the preparation of laboratory experiments for students. Its GUI is a realistic representation of a laboratory, in which all steps of a real experiment can be virtually reproduced by direct manipulation. A lab assistant avatar accompanies the user with praise, reprimands, and hints. The learner is supported by context-sensitive help regarding all components and tools used in each particular experiment. The context of the help is not only object-related but also time-related, i.e. it also refers to the current state within the workflow of an experiment. In a field experiment, the GBL application was evaluated positively overall; this is especially true for the learnability, usability, and design of the user interface (GUI). Participants indicated that the GBL application helped them in planning the laboratory experiments. By preparing using GBL, they made fewer mistakes when conducting experiments in the lab.

**Acknowledgments.** This project was funded by the Stifterverband Deutsche Wissenschaft in cooperation with the Joachim Herz Stiftung as part of the initiative "Excellence in Teaching".

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*Jean-Vincent Loddo and Rushed Kanawati*

# **Mariotel: A Virtual Remote Computer Science Lab**

## Abstract

This paper introduces Mariotel: a free-software project for deploying virtual remote computer science labs that are easily accessible from ordinary web browsers. The Mariotel platform was developed during the first generalized lockdown period due to the Covid-19 pandemic situation. The system has been successfully used at USPN since early 2020.

## Index Terms

Online learning, interactive learning, Remote computer science Lab

## **1 Introduction**

This work presents a new web-based virtual remote lab, called Mariotel, which has been developed at USPN as a tool to ensure online distance learning to support online labs during lockdown periods dictated by the pandemic situation due to Covid-19.

Two main features of the platform developed are the following:

- Allowing access to a customized Linux-based virtual machine through simple web browsers.
- providing a simple shared control facility that allows teachers to efficiently help students during the practical lab sessions.

A quick user guide to the platform is described in section

The general architecture of the platform is summarized in section III. Finally, a short usage report is given in section IV.

## **2 Mariotel: Usage Guide**

Two main users' roles are defined in the Mariotel application: the *teacher* role and *student* one. The latter role is automatically assigned to users who receive a *student access link*. The teacher role allows working sessions to be

## Bonjour **kanawati**, bienvenue sur la page de réservation d'une salle Mariotel<sup>i</sup>



The screenshot displays a web form titled "Votre réservation" (Your reservation). It contains four input fields arranged in a 2x2 grid:

- Date et heure** (Date and time): A text box containing "2021-09-24 16:39" and a calendar icon.
- Durée** (Duration): A dropdown menu showing the value "3".
- Nombre d'étudiants** (Number of students): A dropdown menu showing the value "25".
- Email de notification du lien** (Link notification email): A text box containing "kanawati@univ-paris13.fr".

Below the input fields is a dark grey button labeled "Réserver" (Book).

[Déconnexion](#) [Inscrire](#) [Profil](#) [Planning](#)

Fig. 1. Mariotel: Booking interface

booked and, hence, student access links to be generated. Three levels of teacher role are defined:

- Level 0: this allows limited working sessions to be booked. Limitations cover a limited session duration (up to 5 hours in the current implementation) as well a limit on the number of students to be invited (up to 32 students).
- Level 1: in addition to the privileges of level 0, level-1 teachers can also register new teachers (of level 0 or 1). This level also allows long working sessions to be booked (up to 10 hours per session)
- Level 2: this level corresponds to the *super use* of the platform, as it allows involvement in sessions booked by other teachers (of any level). This level also allows large-scale working sessions to be booked, which can also be used for performance testing (up to 320 students per session).

Figure 1 shows the booking interface that allows the main session parameters to be specified: session date, number of students, and the length of the session.

The booking interface also allows different services to be accessed, such as changing the current user profile (updating e-mail addresses, and/or the user password), accessing the booking schedule of the platform, and registering new users (if the current user has teacher level 1 or 2).

Once a teacher has booked a session, reservation information is displayed, including two types of platform access links (see Figure 2).

Réservation de salles Mariotel<sup>1</sup>

Détails de la réservation

ioddo-202010090900-NhfIC8cRK3HoWCLw

**Réservation**

Responsable : **ioddo**, date : 2020-10-09 09:00:00, durée : 4 heures, nombre d'étudiants : 30

**Lien d'accès étudiant**

<https://tel.marionnet.org/session.php?link=ioddo-202010090900-NhfIC8cRK3HoWCLw>  
 Mot de passe VNC/Unix : **WCLw** (4 derniers caractères du lien)  
 Note : après la saisie de votre NOM-DE-FAMILLE, vous serez automatiquement connectés au système GNU/Linux

**Lien d'accès enseignant**

<https://tel.marionnet.org/session.php?teacher=5d91c62d61&link=ioddo-202010090900-NhfIC8cRK3HoWCLw>  
 Mot de passe VNC/Unix : **HoWCLw** (6 derniers caractères du lien)  
 Note : vous serez l'utilisateur Unix **teacher** seulement sur votre poste, vous partagerez l'écran et l'identité Unix **student** sur tous les postes étudiants

Envoyer un email

mailto: students    mailto: teacher

Déconnexion
Inscrire
Profil
Réservation
Planning

Fig. 2. Booking confirmation window with both student and teacher access links

- *Student access link*: this is the link to send to students in order for them to access the platform. This link allows one free virtual machine to be accessed in the context of the booked session. The invited student has to give their name (as a label for the accessed virtual machine) and should provide a predefined password composed of the last four characters of the access URL. In the first implementation of the platform, all students have the same password to access virtual machines activated in the working sessions. Naturally, once a virtual machine is accessed by

## Accès à la salle virtuelle Mariotel

kanawati-202107271555-zJgVloRaK5X8Sr9O

Réservée par kanawati, 24 postes, en cours

Pour la semaine 30, mardi 27-07-2021 de 15:55 à 18:55

## Affectation des stations de travail (2/24)

Étudiant	Station	Étudiant	Station	Étudiant	Station	Étudiant	Station	Étudiant	Station
1 Alain		2		3 Demarlot		4		5	
6		7		8		9		10	
11		12		13		14		15	
16		17		18		19		20	
21		22		23		24		25	

Fig. 3. Mariotel: Teacher's view of the online lab

one student, it cannot be accessed by another. This simple method of authentication relies heavily on a *social protocol* which assumes that students will not forward the student access link to unauthorized persons. While this approach may seem to be a light authentication approach, it has its roots in the simplicity design rule adopted in this project and the fact that the virtual machines accessed contain no personal information and they have a limited life span.

- *Teacher access link*: this link allows the teacher to access the whole booked session. Figure 3 shows the teacher's view of the ongoing working sessions. The teacher can see all the virtual machines included in the session. The name of the student using a machine is displayed next to the machine icon. The teacher can access students' machines with a simple click on the icon. The teacher then shares the control of the machine with the student and can help the student to correct or accomplish the required task.

A simple planning display module is provided, allowing *teachers* to display all scheduled sessions booked by themselves or other teachers (see Figure 4). Naturally, a teacher can edit their own booked sessions: change their different parameters, or even cancel a session.

In order to run a remote practical lab, the teacher has to book a session as well as a video-conferencing session using their favorite conferencing solutions (e.g. Microsoft Teams, Zoom, Discord, etc.). The conferencing tools serve to establish a real-time interaction channel between the students and the teacher. Any participant can share the display of their own

### Planning des salles Mariotel<sup>1</sup>

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Réervations planifiées (6)

Filtres

De kanawati

Cette semaine 38

Inclure résolues

#	Date	Début	Fin	Durée	Étudiants	Responsable	Lien	Ports	État	Action
<b>Semaine 38</b>										
1282	24-09-2021	17:17	20:17	3	25	kanawati	<a href="#">kanawati-202109241717-mp1Y0DwVxyZPzYr</a>	26900		
1275	25-09-2021	10:00	13:00	3	25	sow	<a href="#">sow-202109251000-3R8MGpddQvWw2X1</a>	27000		
1274	25-09-2021	10:01	13:01	3	25	sow	<a href="#">sow-202109251001-r1iy9Mz38vzuCb73</a>	26900		
1277	25-09-2021	10:06	13:06	3	25	sow	<a href="#">sow-202109251006-OnRc1KWLJmzEK782</a>	27100		
1280	25-09-2021	11:00	14:00	3	25	sow	<a href="#">sow-202109251100-1f1b5Z3BM02UQX1a</a>	27200		
<b>Semaine 39</b>										
1273	28-09-2021	17:00	21:00	4	25	sow	<a href="#">sow-202109281700-pu1Kz01VgXJ0L79L</a>	26900		

Déconnexion
Inscrire
Profil
Réserveation

Fig. 4. Teacher’s view of Mariotel planning

(virtual) machine to others. However, only the teacher can access any machine (“workstation” hereafter) included in the session. Observations show that students prefer using classical chatting tools provided by conferencing systems to interact with one another and with the teacher.

### 3 Mariotel: Architecture

The internal behavior of the Mariotel system is based on two fundamental software components, Docker [1] and noVNC [2], which are both, in turn, based on the GNU/Linux platform. In addition, the assembly of the Docker and noVNC technologies into a virtual GNU/Linux distribution system (precisely, the popular Ubuntu 18.04) was realized from a third relevant software component provided by the Accetto project [3].

- 1) *Containers*: Docker allows a group of processes, named “containers”, to run within a single Linux instance, sharing the same host kernel but running local processes in full isolation (local process trees, local network, local user IDs, local mounted file systems, local resource limiting for memory and CPU, etc.). Avoiding kernel replications, Docker containers are extremely *lightweight*, in such a way that a single physical server (or even a virtual machine) can run several containers simultaneously.
- 2) *noVNC*: Our Docker containers are structured, except for the kernel, like an ordinary GNU/Linux distribution system, both for the file system and the initial part of the system process tree. This way the user, i.e. the student, will have the impression of using a real workstation with a graphical desktop environment. The noVNC component is required at this point: we want a comfortable GNU/Linux distribution system, like the popular Ubuntu 18.04, where the standard X11 graphical server would be replaced by noVNC. Actually, by means of a companion tool on the server side (websockify.py) and a second companion tool on the client side (a JavaScript application), this special X11 server will be able to display the graphical elements and control X11 events in an HTML canvas in a tab of any web browser.
- 3) *Accetto*: The third free software component we used is the branch named *ubuntu-vnc-xfce* from the Accetto project. This branch provides a working version of a setup program, called “dockerfile”, able to build an Ubuntu 18.04 image integrating noVNC into a Docker container. Even if the adaptation work

has been substantial, this initial dockerfile has proved to be an essential working base to get an image suitable for our USPN students in a very reasonable time. One of the most important modifications made concerns the installation of the Marionnet software [4], allowing the simulation of TCP/IP networks, thus allowing labs for several courses about computer networks learned at USPN. It is interesting to note the impressive number of nested virtualization layers this implies, and it is satisfying and quite fun to watch as it runs smoothly, demonstrating the robustness of each

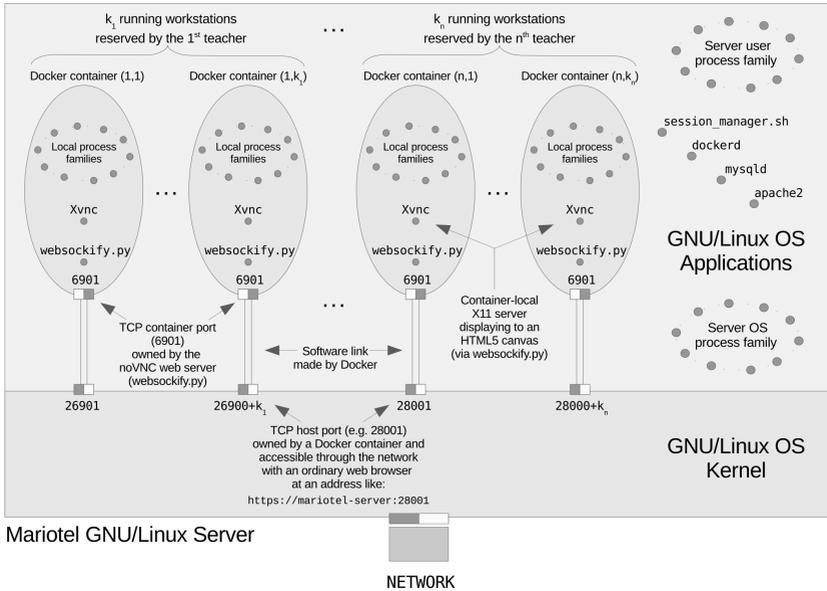


Fig. 5. Mariotel: Server architecture

layer. Actually, the server used is a QEMU [5] virtual machine (equipped with a GNU/Linux Debian 10), supporting Docker containers that run, in their turn, the UML (User Mode Linux [6]) virtual machines launched by Marionnet.

The Mariotel project integrates these first three components, adapting them with two new software components: the booking manager and the session execution manager. Mariotel code is released under a GNU-GPL license, while all other components used are redistributed according to the original free license. The whole project is available from the LIPN git repository.<sup>1</sup>

- 4) *Booking manager*: A web interface allows teachers registered on the platform to book and manage lab sessions. The website has been developed with the PHP framework, using the Bootstrap software library [7]. When a classroom is reserved, the record defining the scheduled session is stored in a MariaDB database [8]. The two HTML links generated for

1 <https://depot.lipn.univ-paris13.fr/marionnet/mariotel/>

the students and teacher are displayed on a page that summarizes the booking (see figure). Through the same page, these links can be transmitted by email to the group of students or to the teacher themselves. At running time, when the session is active and every student is assigned to their workstation, the teacher will access a web page representing the room (see Figure 3) via the link reserved for them and is so able to access all the stations and help the students. There are two important technical points to this part. The first point concerns the choice of a unique range of TCP ports for the set of workstations in a given session, avoiding all possible intersections with other interlacing sessions, even if only for a few minutes. The second point concerns the assignment of stations to students in a quasi-alphabetical order, so that the teacher can easily find the place occupied by a student who needs help.

- 5) *Session manager*: The goal of this component is to manage the lab sessions, i.e. to launch all the workstations booked for the students and to stop them. These two kinds of actions should happen on the two dates of the beginning and end of the project, as foreseen by the teacher during the reservation. To perform this task, the session manager, scheduled as a Unix *cron* task, is launched regularly, every two minutes, on the server to query the booking database and then to activate or stop the sessions involved. Figure 5 gives an outline of the running processes and their dependencies, assuming that  $n$  teachers have each booked a class and are using  $k_1, \dots, k_n$  workstations for their students respectively.

A secondary task of the manager is to protect the active sessions from possible unauthorized users, whom we call “disturbers”. A disturber is someone, identified by their IP address, that has attempted to connect to at least two distinct workstations without being recognized as a possible teacher (because they are not in the database of IP addresses associated with a teacher). Actually, the only ones naturally allowed to connect to several machines in the same session are teachers. So, others are disturbers. When a disturber is detected, an *iptables* command banning the access of the disturber is sent and executed on all workstations of the session in question.

The session manager has been developed with the Bash language, which is sufficient, even very efficient, for this kind of task, which consists, in a caricatural way, only of automating the launching of complex Docker commands, so complex that it would be difficult to launch them manually. With algorithmic problems having been confined to the booking manager, and thus easily solved in PHP, the Bash language is perfectly adapted to this simple mission of building and launching complex Unix shell commands.

## 4 Mariotel: Usage Report

The Mariotel platform was first implemented on a virtual server with 32 cores and 96 GB of Ram memory. The server was put into effect in order to host different programming, system administration, as well as computer network labs scheduled during the first lockdown period due to the Covid-19 pandemic situation in early 2020.

The simple user interface proved to be very effective since both teachers and students are able to use the system without any training. The fact that users are free to use their favorite video conferencing tool in parallel to the Mariotel-based remote practical session was also an important factor in the early adoption of the system. The computation power of the deployed server was enough to support up to 150 simultaneous student connections involved in ten different lab sessions (not all using Marionnet networking virtual lab applications). However, the server proved to be very limited in running labs using greedy CPU-power applications such as GNS3.<sup>2</sup>

On the negative side, the social protocol underlying the platform access scheme was rapidly revealed to be very limited. Some teachers sent students the teacher access link instead of the student access one, allowing students to access any machine in the session in question. This problem can be quickly solved since teachers can cancel a scheduled session and reschedule a new one, which can be ready to run in less than 3 minutes.

More seriously, a few sessions were targeted by some unauthorized disturbers, as described in section III-5. In order to limit these perturbations, simple patches were applied to the system's access module. Access from devices assigned to foreign IP addresses was banned. In addition, a student's IP address is allowed to be connected only once to a given session. These rapidly deployed patches drastically reduced the sessions' perturbations.

Except for these very few perturbations (concerning less than 1% of sessions), the platform was successfully used during the first lockdown period by 32 distinct teachers operating more than 4500 student connections whose working duration exceeded one hour. The platform is still being used for in-person computer science labs since students widely appreciate the shared control features the platform offers to teachers during students' sessions. Another kind of use of the platform consists in scheduling sessions where students can work in an autonomous way in order to review the principles and topics they have studied.

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<sup>2</sup> <https://www.gns3.com/>

## 5 Conclusions

The generalized Covid-rooted lockdown periods have increased the awareness of academic authorities of the absolute necessity of deploying virtual remote labs in higher education institutes. The Mariotel platform we have presented in this paper provides a simple but powerful solution for rapidly deploying GNU/Linux-based computer science VRL. The main advantage of the platform is its ability to export the displays of virtual machines running on a central server in the students' browsers, allowing students to have access to low computation power as well as a low bandwidth network connection to join a practical lab efficiently. The shared control between the teacher, on the one hand, and each student, on the other, is another main feature of this platform. Mariotel was deployed during the first lockdown period in France (Spring 2020) and was extensively used with very few incidents despite the use of a simple social access protocol.

Short-term extensions of the current work include implementing a robust access and authentication process and implementing a persistent virtual machine allowing each student to have her/his own virtual machine that can be accessed at any time and on which they can save both data and modified configurations. This is particularly interesting for system administration-oriented labs.

## Acknowledgment

We would like to thank Xavier Monnin, the IT System administrator at LIPN Computer science laboratory CNRS UMR 7030, for his valuable support in providing the first infrastructure for hosting the Mariotel platform. Thanks goes also to LIPN for allowing us to use the lab IT infrastructure to host the first operational Mariotel version and git repository. We would also like to thank the Technical University Institute of Villetaneuse (IUTV) for its financial support.

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