Fab Lab

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Definition

Fab labs are shared workshops, open to the public and equipped with modern as well as traditional tools and machines. A typical setup may consist of an electronics laboratory, 3D printers, laser cutters, and other computer-controlled machines, as well as classic hand tools and machines for wood-, textile, and metalworking – in line with the motto *make (almost) everything*. The term *fab lab* was coined by Neil Gershenfeld, meaning a "lab for fabrication or simply a fabulous laboratory" (Gershenfeld 2005, 12). *Fab* goes back to the English fabrication, with its etymological origin in the Latin *fabrica*, which in a narrower sense denotes the workshop of an artist working with hard materials (Lewis and Short 2020, 414). *Lab*, short for "laboratory", stems from the Latin *lăbor*, meaning "work" but also "toil, effort, drudgery", which can also be translated as "fruit of labor" (Gershenfeld 2005, 594). The core of its concept is to bring people from different backgrounds – design, engineering, architecture, urban planning, biology, crafts, software development, art, and education – together to create. The common mission is to develop, share, and transform knowledge and to create technologies with practical relevance in everyday life. This turns fab labs into spaces of transdisciplinary learning and working.

On the one hand, some of these facilities present themselves as sites of decentralized and distributed manufacturing or of economically oriented innovation (Kohtala et al. 2020). Concrete goals are often deliberately avoided. The focus is on providing a freely usable infrastructure. Fab labs allow individualized one-offs to be produced, or spare parts that are no longer available on the market (*rapid manufacturing*). The actors in the workshops – also called *makers* – define themselves as part of a grassroots movement that empowers people to deal competently with technology and move from being passive consumers to self-confident producers (Smith et al. 2017). Hepp (2018) challenges this perspective and characterizes makers as a pioneer community that is partly created by media hype and sponsored by corporations. On the other hand, fab labs collaborate with educational institutions (including schools and universities) and provide (in)formal education. Such facilities position themselves as places of learning and portray their activities as *maker education*.

Background

Fab labs became known through an initiative at the Massachusetts Institute of Technology, where in 1998 Gershenfeld offered an experimental course entitled "How to Make (Almost) Anything". The course, designed for a small group of physics and computing students, attracted a broad audience from all backgrounds, including design and architecture. It was the starting point for numerous other activities, including the foundation of the first fab labs as part of an outreach program (Gershenfeld 2005, 12). Similar developments preceded this (Kohtala et al. 2020; Sipos and Franzl 2020; Smith 2014); some of them followed the popular concept from the US. Today, fab labs exist in many large cities around the world (Smith et al. 2017).

Maker education refers to an experience-based and hands-on approach to learning that engages participants in subjects and learning activities at the intersection of computer science, design, art, and engineering, among others (see Brandenburger and Vladova 2020). Mastering subjects in science, technology, engineering, arts, and mathematics (STEAM education) is supposed to prepare students for the challenges of a highly technological and digital society: This is where maker education comes in. It benefits from easy access to digital fabrication and shared software, hardware, and designs, which is seen as democratizing the access to technology and understanding technology. More important than democratizing access, however, are the opportunities maker education creates to empower students and raise consciousness (Blikstein 2013; Halverson and Sheridan 2014).

Fab labs hold a versatile educational potential that has been discussed in various academic studies within and outside the higher education sector (Mostert - van der Sar et al. 2013; Troxler et al. 2014; Rosenbaum and Hartmann 2020). Thus, fab labs can be seen as a key innovation for the tertiary education sector. Due to their open, project-based, and cooperative learning character, fab labs bridge higher education, industry, and society (Pernía-Espinoza et al. 2017). They enable a technology-based environment for knowledge transfer between and beyond academic disciplinary boundaries. This is precisely why they are an ideal opportunity for implementing transdisciplinary learning.

In the higher education context, learning in fab labs has been shown to have a positive impact on team communication, self-efficacy, individual understanding of learning, and overall student outcomes (Andrews and Roberts 2017; Hilton et al. 2018; Tomko et al. 2018). Moreover, studies show that such open learning spaces foster so-called *21st century skills* (skills, abilities, and learning dispositions that have been identified as being required for success in 21st century society and workplaces), including critical thinking and problem-solving skills (Rayna and Striukova 2021). Next to teaching specialized knowledge, it is these skills that are increasingly of interest for new educational concepts, as they prepare students for the future. Overall, students are encouraged to participate and take control and responsibility for their own learning (Martinez and Stager 2013, 81).

Gauntlett's description of "making as connecting" (Gauntlett 2011) offers a possible starting point for such transdisciplinary learning processes: connecting things (materials and ideas), connecting people, and "connecting with our social and physical environments" (Gauntlett 2011, 2). Making is a counterpoint to the "sit back and be told" (Gauntlett 2011, 8) culture inside and outside of school education, it resonates with the idea of learning as a co-creation of knowledge.

For this reason, fab labs that explicitly aim at promoting participation and self-organization are particularly relevant for transdisciplinary learning. They are meeting places and communication spaces, not just providers of manufacturing infrastructure. The focus is on them being open – not limited to access, but encompassing a multi-layered philosophy: participation in governance, in determining the institutional structure and rules, and in the development of the place itself. This refers to the willingness to adapt organization and infrastructure to the needs of the community, the network of people who feel a sense of belonging to each other through a shared practice and place. This includes the existence of formats, sets of rules, or institutional forms of participation through which community members can become active in a process of adaptation and transformation. Fab labs are not only places of learning but also places of transformation that afford to rethink existing structures.

Debate and criticism

Places that emphasize participation are particularly relevant for transdisciplinary learning. Nonetheless, such open educational practices create tensions with established systems and approaches in higher education. Three juxtapositions show the inherent tensions:

(1) *Rigidity versus fluidity*: Self-organization and participant agency in transdisciplinary fab labs go against the planned and streamlined systems of formal education. They have an air of anarchy and chaos, versus the rules and hierarchies in higher education that stifle creativity and innovation. Nagle (2021) identified five specific challenges academic institutions experienced when installing fab labs, challenges which equally hold for non-library fab labs: staffing, shifting culture, policies and procedures, and demonstrating impact. To develop a balance between order and chaos requires extra attention in transdisciplinary education (Mostert - van der Sar and Troxler 2022).

(2) *Science versus arts*: In a fab lab, the focus is not simply on learning to use tools, developing skills, and creating tangible end products. Key experiences for students are iteration, teamwork, accepting failure as part of learning or failure-positivity (Martin 2015), feedback-literacy, and self-efficacy, among others (Rosenbaum and Hartmann 2020). These elements of learning are valuable and also applicable beyond science and engineering disciplines (Halverson and Sheridan 2014; Lande and Jordan 2014). However, a lack of literature on teaching and learning in the arts and social sciences, let alone transdisciplinary education, hinders students from detecting these contexts (for an outstanding example, see Mizeret et al. 2022). Moreover, the way in which groups that differ – for instance, in age or discipline – interact, which often is a core feature in fab labs, has to be reflected more strongly in transdisciplinary educational research.

(3) *Replication versus repurposing*: Fab labs in educational institutions in the Global South enhance quality education through hands-on activities (Ben Rejeb and Roussel 2018) and collaborations with communities (Oladele-Emmanuel et al. 2018). Serving as community labs or innovation centers, they promote citizen science and social innovation (Schonwetter and Van Wiele 2018, 8–23) through research, making, and cultural activities to address local needs. While this approach is embraced in the STEM fields (Buchele and Dafla 2015), funding, infrastructure, and human capital constraints (Herrera and Juárez 2013) are raised as key challenges to implement maker education more broad adaptable, solutions can be found for different contexts, as long as adequate planning and resource mobilization are in place.

While building a communicative, inclusive, and participatory atmosphere is a challenge in general, it is even more so when inclusion needs to address colonial and indigenous cultures and thought systems. Valuable experiences include the fab lab in Wellington, New Zealand (Neale and Hobern 2017) and the integration of digital technology and indigenous culture in Peru (Gonzales Arnao 2016).

Current forms of implementation in higher education

To facilitate transdisciplinary learning in a fab lab, four international principles have been found useful in practice (Troxler and Mostert - van der Sar 2019a).

1. The project *1:1* is for peer instruction (Mazur 1997). Teachers are trained at the lab to actively encourage peer learning by redirecting questions to the group instead of immediately answering themselves. Thus, they can activate the collective knowledge and capacity of the group. This ties in with the idea of the zone of proximal development (Vygotsky 1978, 84–91), where students achieve a level of potential development through problem-solving under the guidance

of more experienced peers. Even when an answer is not readily available in the group, it is part of peer instruction to develop a solution collectively.

2. The initiative *20-60-20* focuses on how people split time between different learning activities – 20 percent for instruction or lecturing, 60 percent for making and experimenting, and 20 percent for reflection with peers. Again, teachers are trained at the lab to design their lessons according to this principle, as they notoriously tend to stretch lecturing to the detriment of the experimenting, where peer instruction can take place (Troxler and Mostert - van der Sar 2019b). Reflection makes room for productive failure (Kapur 2008; Persaud et al. 2022).
3. The idea of *3i* is to foster imitation, iteration, and improvisation (El-Zanfaly 2015), a three-step approach to appropriate technology. Imitation is the basis for learning a particular technology. In iteration, students add changes and modifications, and in improvisation they use the technology for their own ends.
4. The project *4 all* is for lessons at the lab that are open to peripheral participation (Lave and Wenger 2003), i.e. not exclusively to students attending class. Combined with the principle of peer instruction, it can create powerful moments of transdisciplinary learning.

Fab labs have found diverse forms of implementation internationally, as the following examples show. *Vigyan Ashram*, established in 1983, is a center for ancient Indian philosophy in Pabal, India, engaging rural youth in learning rural technologies and entrepreneurship. Since 2002, Vigyan Ashram has been home to a fab lab – the first outside MIT – used by rural youth, often school dropouts. The school awards a diploma in basic rural technology. The pedagogy involves students in "Socially useful productive work" of various domains, focusing on agriculture and fabrication. They also offer services to the community in areas such as biogas, solar energy, food processing, and machine repair. These efforts have transformed the village of Pabal into a hub of innovation, creating opportunities for rural youth to learn and become self-sufficient. The center helps young entrepreneurs start their enterprises, and disseminate technology among rural communities (Kulkarni 2016).

Fab Lab Wgtn is located at a design school in Wellington, New Zealand. It works from a perspective of inclusiveness and of integrating indigenous perspectives into the ecosystem. To do so, Fab Lab Wgtn developed a code of conduct that begins with a *whakatauki*, a proverb written in both te Reo Maori, the first language spoken in Aotearoa New Zealand, and English. The *whakatuki* represents the lab's ethos: "*He waka eke noa* – We are all in this together." It is followed by a statement about honoring indigenous perspectives and acknowledging that diverse approaches enrich the culture of the lab. Innovation begins with inclusion, which leads to the explanation about what is not considered discrimination, such as reasonable communication of boundaries. The code also lists characteristics outside the dominant paradigm, usually subject to discrimination – e.g. ethnicity, age, gender, but also profession and technical ability – which are protected within the Fab Lab Wgtn ecosystem (Neale and Hobern 2017).

Learning by doing at Ashesi University (Ghana): The Introduction to Engineering course at Ashesi University (Beem 2021) teaches students about engineering through a transdisciplinary approach that includes lectures, lab sessions, and real-world projects. The course focuses on technology mastery, critical thinking, problem-solving, leadership, and collaboration. The curriculum is project-based, promoting hands-on learning, and students experience the full product development cycle. Teaching methods include in-person and online lectures, guest presentations, and lab sessions. The course is three credits and evaluates students through class participation, quizzes, and a final project. Beyond the course, students can engage with the community through extracurricular activities and projects led by the Design Lab (Ambole 2020) and projects such as Agbogbloshie Makerspace Platform (Potter et al. 2019).

In conclusion, fab labs can be seen as a seminal step for learning communities where students, teachers, staff, and experts work together in co-creation, adding value for all parties involved within the ecosystem. Technology is used in all areas of life and decisively shapes social development. Fab labs offer a promising hub by linking technology, formal education, and civic and entrepreneurial engagement. At the same time, computer science and engineering components find their way into other subject areas through a technology-oriented learning environment. They allow for cooperative and contemporary learning in an applied and real-world environment characterized by a high degree of exchange, participation, and openness. Institutional and disciplinary boundaries give way to pluralistic project work oriented towards issues affecting society as a whole.

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