The Role of "Core" and "Anchored" Concepts in Knowledge Recall: A Study of Knowledge Organization of Learning Thermal Physics

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ABSTRACT: This study is an investigation of whether learners' knowledge is organized around a "core" concept within a knowledge domain, which is strongly linked to other secondary concepts, called "anchored concepts." In other words, the "core" concept and "anchored" concept are mutually supportive of one another. These two concepts can be linked with other concepts to produce more extended and robust knowledge structures in memory. This study used a flow map method to identify learner's "core" and "anchored" concepts derived from the treatment instruction about thermal physics. The results showed that with the assistance of "core" concept, profitably mediated by the "anchored" concept, learners could recall more extended knowledge, with greater richness and with higher connection than in the absence of this organizing information (Experiment 1). However, the difference between the provision of a group core concept and an individual core concept did not reach any significance level in the recall task two-month later (Experiment 2). When the recall task was carried out six months later, the group "anchored" concept showed the essential assistance to the recall of knowledge (Experiment 3). This study has provided potential insights not only about the functional mechanisms of learners' knowledge construction but also for classification research.

1. Background

Researchers have advocated that a better understanding about knowledge organization can help all students of education (Dahlberg 1993; Tsai and Huang 2002). Several perspectives have been proposed by psychologists and educators who are interested in knowing more about the structures of learners' knowledge and their conceptual organizations (e.g., Anderson and Demetrius 1993; Ausubel, Novak and Hanesian 1978; Crosson, et al. 1999; Novak and Gowin 1984, Riggs 1996). For example, Ausubel, Novak and Hanesian (1978) and Novak (1977) have theorized that information is assimilated through a series of cognitive steps; namely, subsumption, progressive differentiation, and integrative reconciliation, which together construct hierarchical conceptual frameworks. Many of these researchers also assert that the recall of knowledge is almost certainly not a process of encoding and a part-to-part readout as it was heard from a tape recording. Memory is reconstructed from component parts of knowledge, assembled in relation to certain organizing principles derived from the learner's existing experiences and ideational frameworks. Furthermore, knowledge structures may be correlated with neural schema or networks of connected neuronal elements, but probably not in a hierarchical nature (Anderson 1992 and 1997). Moreover, it is evident that the cognitive structure of the learner, expressed as a network of connected ideas in memory, is dynamically related to the individual's orientation toward learning science and how effectively science is learned (McRobbie 1991; Snyder 2000; Tsai 1998a and 2003; West and Pine 1985). This strengthens the need for full and detailed exploration of learners' knowledge structures, because these structures may be related to a variety of learning variables.

1.1 "Core" and "anchored" concepts

No matter which perspective one may take, it is initially plausible to assume that people's knowledge is organized around a "core" concept, or the more central concept, (but not necessarily in hierarchical formats). It is strongly linked to other secondary concepts within a domain of knowledge. (In this paper, the term "concept" or "concepts" are used in a broader sense, referring to ideas, thoughts, knowledge bits, and propositions.) An individual constructing the knowledge structure within a domain may not only depend on one core concept. In order to have a fuller description about a learner's knowledge structure, this study also proposes (assumes) that there is an "anchored" concept, or the less central concept, that also plays an important role in stabilizing the "core" concept and other peripheral concepts. The position of "core" as well as "anchored" concepts in one's memory may be similar to that illustrated in Figure 1. The model, a hypothetical representation of

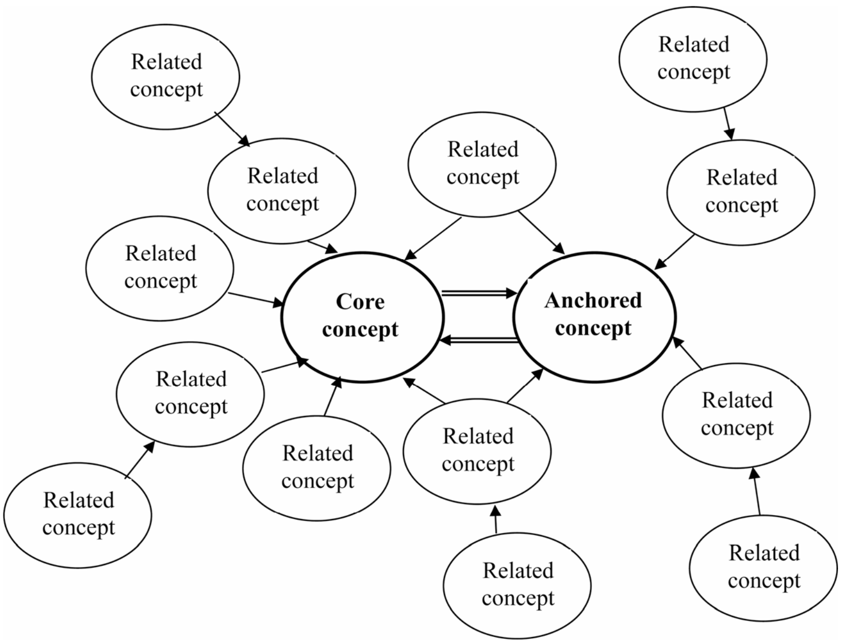

Figure 1. *A model of knowledge structure*

one student's knowledge organization in a domain, shows that the "core" concept is connected with numerous related concepts. The "anchored" concept is also connected with some related concepts, likely playing the role of secondary core concept. The recall of "core" concept, perfectly with the recall of "anchored" concept, can help the student recall all other related concepts in the domain.

As shown in the figure, the "core" concept is connected with most of the relevant concepts in the knowledge domain, while the "anchored" concept is connected with the second most of the related concepts. (It is certainly possible that there may be the third core concept or second anchored concept in a knowledge structure; however, for research and theoretical purposes, this study explores the first two important concepts, which are defined as "core" and "anchored" concepts.) The "core" concept and "anchored" concept are mutually supportive of one another, and then can be linked with other peripheral or related concepts to produce a robust knowledge network in memory. The "core" concept plays a central role in helping the individuals to recall related concepts. The "core" concept, with the assistance of an "anchored" concept, stabilizes knowledge structures. Hence, the "anchored" concept, on one hand, supports the salience and nodal position of the "core" concept. And on the other hand, through linkages to other information in memory, integrates related concepts into the knowledge frameworks. In other words, students who employ a meaningful learning approach should implicitly identify some "core" and "anchored" concepts, which acquire high significance in the domain of knowledge, and then organize their ideas around these "core" and "anchored" concepts. If a student fails to locate "core" and "anchored" concepts that can help to organize information in memory, there is likely less efficiency in accessing the information during recall. According to a new understanding of cognition, students who are not skilled in self reflection during learning and lack well-organized knowledge structures, may deem all new information to be equally important and consider each conception to be unique and individually significant (Tsai 2001a). By this, no cognitive process of differentiating the important or focus concepts (such as the "core" and "anchored" concepts defined in this paper) in the knowledge structure is employed.

Some researchers have asserted that theories and methods about knowledge organization should gain support from epistemological perspectives (Hjorland 2003). The ideas of "core" and "anchored" concepts are also consistent with the epistemological perspectives that the concepts in a field are not of equal importance, and some should be viewed as central concepts (such as core concept) while some should be viewed as peripheral ideas (Duschl 1990; Lakatos 1970). The ideas of "core" and "anchored" also concur with the viewpoint that highlights the importance of classifying knowledge when analyzing its organization (Zins 2004).

1.2 Identification of concepts

Consequently, educators may face new challenges, such as how to identify the "core" and "anchored" concepts in a knowledge domain that students are expected to learn and how to help them effectively utilize these organizing ideas in constructing robust knowledge structures. In order to accomplish the task, researchers have to develop effective ways of representing student knowledge structures and then possibly reveal the "core" and "anchored" concepts through eliciting the structures. Tsai and Huang (2002) have critically reviewed five methods of probing learners' knowledge structures, that is, free word association, controlled word association, tree construction, concept map and flow map. Tsai and Huang (2002) have concluded that the flow map method can provide richer and more detailed information in representing knowledge structures while comparing to the other four methods. Therefore, we used a flow map method (see Anderson and Demetrius 1993; Tsai 2001b) to potentially identify students' "core" and "anchored" concepts in a domain of scientific knowledge; i.e., thermal physics. (This study was conducted to illustrate how to identify "core" and "anchored" concepts in a domain of knowledge, such as the subject of thermal physics or heat and temperature, and then how to make use of these concepts. Therefore, a comprehensive review about research studies exploring students' ideas or conceptual development about thermal physics may not be necessary here. Readers of interest can refer to Arnold and Millar (1994, 1996); Erickson and Tiberghien (1985); Harrison et al.. (1999); Kesidou and Duit (1993); Lewis and Linn (1994).) Furthermore, we examined the role of the identified "core" and "anchored" concepts in subsequent knowledge recall. In sum, through exploring a group of high school students' learning about thermal physics, we attempted to establish the functional details of the relationships among information in memory within a perspective of "core" and "anchored" concepts.

2. Method

2.1 Participants

A total of 120 10th–grade students (65 males and 55 females) from eight classes of a high school in Taipei City, Taiwan, participated in this study. This study was conducted within their "fundamental physical science" course regularly taught at school. The teacher was a female teacher with five years of high school science teaching. The teacher had a Bachelor of Science degree as well as a Master of Science degree in physics. In terms of her academic qualifications and teaching experiences, she was a suitable teacher for this study.

2.2 Procedure

2.2.1 Treatment instruction

The teacher conducted a four-period (50 minutes per period) treatment instruction about thermal physics on the subject of "heat and temperature." The instruction covered the concepts of thermal equilibrium, temperature, thermometers, heat change, specific heat, and the relationship between heat and energy. Among the four periods, the first two periods were lecture-type instruction basically related to thermal equilibrium, temperature, thermometers and heat change. The third period included lab-based activities that utilized different types of thermometers and measured heat change. The final period was lecture-oriented, mainly covering the concepts about the relationships between the heat and energy, and a review of these four periods. This research project was conducted during the appointed periods when heat and temperature were scheduled in the syllabus.

The study, then, was followed by two stages – identification and experimentation. The first stage of the study was to explore and identify the "core" and "anchored" concepts by a knowledge recall task immediately after the instructional unit on heat and temperature – the so-called identification stage. The second stage of the study was three experiments examining the role of "core" and "anchored" concepts in a knowledge recall task two months later (Experiments 1 and 2), and six months later (Experiment 3, with the same participants as in Experiment 2) (see Figure 2).

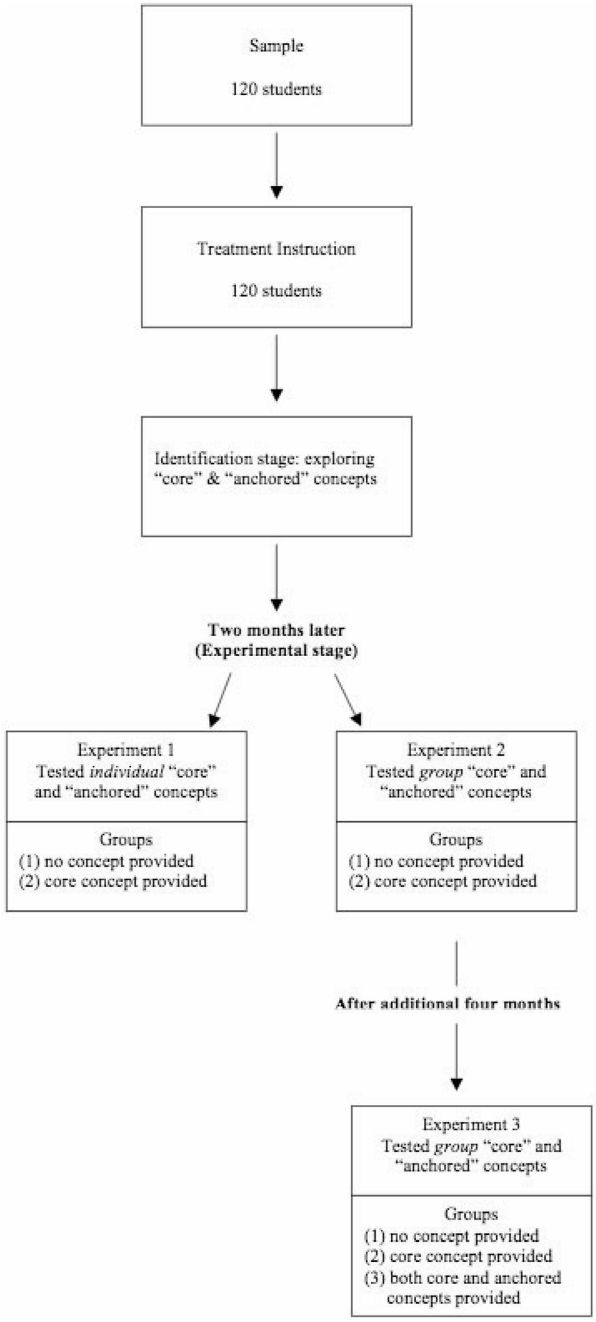

Figure 2. *The research design of the experiments*

2.2.2 Identification stage: Identify "core" and "anchored" concepts by the flow map method

The subjects in this study were interviewed immediately after the four-period treatment instruction about thermal physics, and their interview narratives were analyzed through a flow map method. The basic rationale of using a flow-map method is to capture both the sequential and network features of human narratives in a non-directive way. In particular, it can effectively display the inter-relationships among concepts acquired by each individual student (Anderson and Demetrius 1993; Tsai 2001b; Tsai and Huang 2001). As the existence of "core" and "anchored" concepts is based on the inter-relationships among concepts, using flow map method is viewed as very appropriate. Adequate validity and reliability of using the flow map method have also been revealed by previous studies (Anderson, Randle and Covotsos 2001; Tsai 1998a; Wu and Tsai 2005). The flow map can represent both the serial order and cross-linkage of ideas in narrative. In order to acquire a learner's ideas in narrative, every selected subject was interviewed individually and the process was recorded in tapes. The interview questions are presented in a non-directive way. For example, in this study, when probing a learner's ideas about "heat and temperature," the researcher asked the following interview questions:

- Could you tell me what the major concepts about heat and temperature are?
- Could you tell me more about the concepts you have described?
- Could you tell me more about the relationships among the ideas you have already told me?

By such an interview-recall method, coupled with a meta-listening technique (i.e., asking each subject to listen to an audio replay of the immediately-prior elicited recall and possibly to modify the original ideas, for details, see Tsai, 1998a, 1999, 2001b), every selected student's interview narrative was further analyzed by a flow map method (Anderson and Demetrius 1993; Bischoff and Anderson 2001). The interview recall data were tape-recorded. A flow map is constructed by diagramming the respondent's verbalization of ideas as it unfolds, and it is a convenient way to display the sequential and complex or cross-linkage ideational patterns expressed by the respondent. The flow map is assembled by entering the ideas in sequence as they are uttered by the subject. Figure 3 shows a sample of flow map used in this study. The student in the interview recalled ten ideas, shown in a sequential flow.

In addition to sequential (linear) linkages, the flow map shows some recurrent linkages for revis-

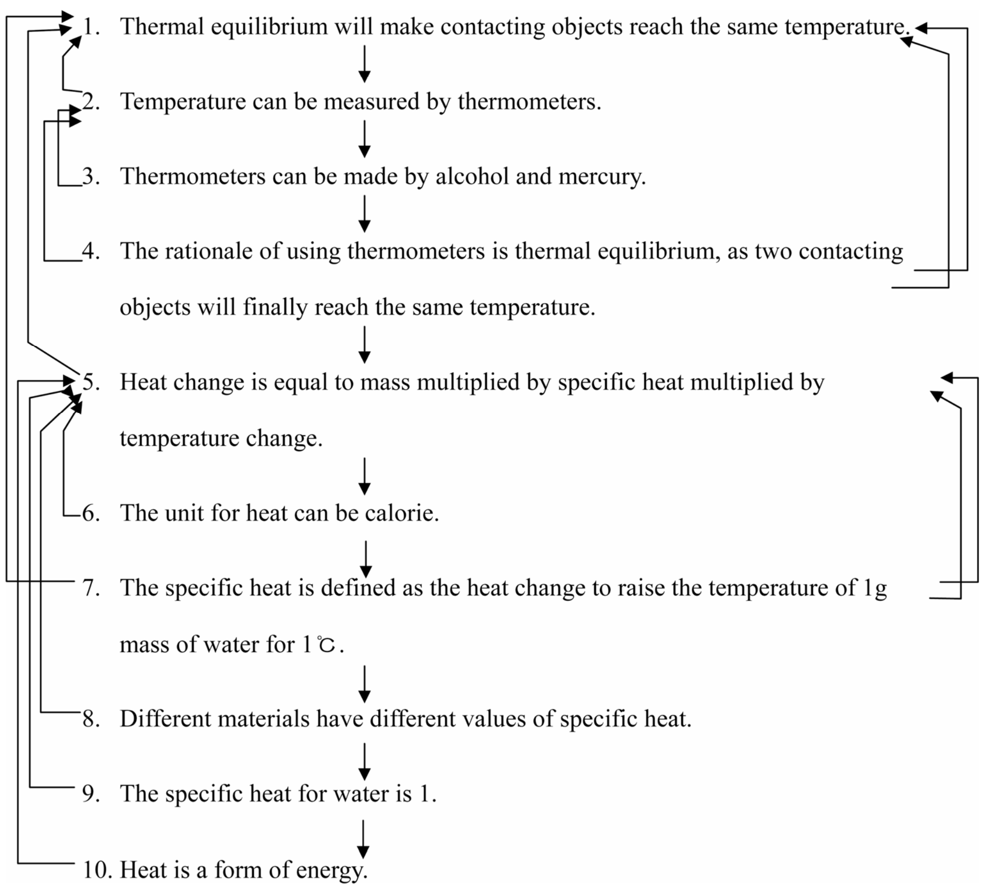

Figure 3. *David's (pseudonym) flow map elicited immediately after the treatment instruction*

ited ideas. For example, statement 4 in Figure 3 (i.e., The rationale of using thermometers is thermal equilibrium, as two contacting objects will finally reach the same temperature) includes three revisited (related) concepts: thermometers, thermal equilibrium and temperature. The researcher, hence, drew three recurrent linkages from statement 4 to the earliest steps the subject stated these ideas, that is, statement 2 (i.e., Temperature can be measured by thermometers – the earliest statement mentioning about thermometers), statement 1 (i.e., Thermal equilibrium will make contacting objects reach the same temperature – the earliest statement about thermal equilibrium), and statement 1 (the earliest statement mentioning temperature). The number of recurrent concepts shows the richness as well as the connection of ideational networks in student knowledge recall. A statement with more recurrent linkages indicates that it is a major concept related to many other ideas in knowledge structures. As a result, this study used this method to identify the "core" and "anchored" concepts in a domain of knowledge acquisition. (For more details and example of narratives please refer to Appendix 1).

As a result, the flow map interview described above was used with every selected student immediately after the treatment instruction about thermal physics. A flow map was constructed for every individual by the researcher based on an analysis of the tape-recorded narrative. The recurrent linkage data derived from this part of analysis were used to identify the "core" and "anchored" concepts in this study. We proposed the following criteria for defining the "core" and "anchored" concepts:

– "Core" concept: the concept connected with the most recurrent linkages
– "Anchored" concept: the concept connected with the second most recurrent linkages.

The recurrent linkages reveal the relevancy and integration among ideas around a focal or core concept. A large number of recurrent linkages connected with a concept indicate that the concept is associated with many other related concepts. Although the definitions above may be technically straightforward, they are consistent with the perspective proposed earlier (section 1.1 and Figure 1) that the core concept is connected with the most relevant concepts in the knowledge domain, while the anchored concept is connected with the second most relevant concepts. In other words, these criteria are proposed because the core concept is an idea that integrates the largest amount of related thoughts in memory, as shown in Figure 1. A similar rationale can be applied to the identification of the anchored concept. Take the student in Figure 3 for example. The core concept for the individual student was the fifth idea shown in the flow map (i.e., Heat change is equal to mass multiplied by specific heat multiplied by temperature change), which gained six recurrent linkages. His anchored concept for the topic of "heat and temperature" was the first idea, "Thermal equilibrium will make contacting objects reach the same temperature," acquiring five recurrent linkages.

2.2.3 *Experimental stage: Data analysis for individual and group concepts, and Experiments 1 and 2*

To explore the role of core and anchored concepts in knowledge reconstruction, the interview data obtained from 120 students were randomly divided for two uses (see Figure 2). The first half of the data was analyzed to explore student's individual core and anchored concepts (by using the aforementioned definitions) and their effects on subsequent knowledge recall. The core and anchored concepts might be varying across individual students. The second half of data was analyzed in order to obtain students' core and anchored concepts as a group, and then evaluated the effects of these concepts on students' knowledge structures probed in a later experiment. The findings derived from the second half of data would shape more practical implications for classroom teaching, as science teachers in actual classrooms, in many cases, would guide students' knowledge growth as a group, and they may not have many opportunities to facilitate each individual student's conceptual development. As a result, the first experiment would use each student's individual core and anchored concepts shown in the identification stage for further exploration. On the other hand, the second experiment used the students' group core and anchored concepts to examine the role of these group concepts. The group core and anchored concepts were searched by reviewing those revealed by individual students and found those most frequently shown by the group of students, based upon the flow map data.

– Core concept: Heat change is equal to mass multiplied by specific heat multiplied by temperature change.

- Anchored concept: Thermal equilibrium will make contacting objects reach the same temperature.

The core concept above gained a total of 178 recurrent linkages among the sixty subjects in the second experiment (that is, an average of 2.97 recurrent linkages toward the core concept per flow map), and 58% of the students' flow maps displayed the most recurrent linkages on this concept. Furthermore, there were a total of 112 recurrent linkages toward the anchored concept above (that is, an average of 1.87 recurrent linkages toward the anchored concept per flow map), and 48% of the students' flow maps had the second most recurrent linkages on this concept.

In order to examine the role of core and anchored concepts, the 120 subjects involved in this study were randomly assigned into Experiment 1 and Experiment 2. They were interviewed again two months after the treatment instruction to elicit recall during an interview and to obtain evidence of their knowledge structures about heat and temperature. The same protocol was used for this interview as was used for the first flow map interview described earlier. However, in each experiment, sixty participating students were divided into the following three groups based on another random assignment.

The students in Group 1 were interviewed with only the interview questions provided earlier and without providing any concept or hint. The students in Group 2 were given the core concept orally by the researcher before the flow map interview to determine how it might help them recall knowledge. The students in Group 3 were orally provided with both the core and anchored concepts derived from the first stage of flow map analysis before this part of the flow map interview (see Figure 2). After being given the conceptual hint, every student in these groups was interviewed in the same way. (The students in the second and third groups were given conceptual hint(s); however, they were well informed that it was not necessary to use the hint(s) while responding to the interview.) For this part of the interview, only the individual core concept identified in the identification stage was given to each student in Group 2 of Experiment 1, and both individual core and anchored concepts to each student in Group 3. Therefore, the guiding clue(s) for helping students' knowledge reconstruction might be different across individuals within the same group. On the other hand, each student in Experiment 2 was provided with the same group core concept (Group 2) or with group core and anchored concepts (Group 3). The research design of this stage is illustrated in Figure 2. Although the students in each experiment were randomly assigned into these three groups, one student in Experiment 1 and two students in Experiment 2 failed to complete this part of the follow-up interview, therefore the number of students in these three groups was 20, 20, 19 for Experiment 1 and 19, 20, 19 respectively for Experiment 2.

A follow-up study of Experiment 2, Experiment 3 was conducted six months after the instruction and identification stage (i.e., four months after Experiment 2). The same participants of Experiment 2 were interviewed again to obtain their knowledge structures about "heat and temperature." The way of collecting and analyzing interview data was exactly the same as that utilized by Experiment 2. Due to some unexpected students absences, the number of students for the three groups was 18, 19 and 18, respectively.

2.3 Analysis

The students' narratives from this second round interview were also analyzed by the flow map method. In order to make adequate comparisons, it should be noted that, in either experiment, the data gathered from the students in the second and third groups should exclude the core (and the anchored) concepts from the flow map analyses. That is, if a student in Group 2 stated the core concept in the flow map interview, the core concept should be excluded. Similarly, if a student in Group 3 stated the core or the anchored concept in the interview, these elicited concepts were removed from final analyses. Obviously, in Experiment 1, the concepts removed were individual core or anchored concepts, while in Experiment 2, the excluded concepts were group core or anchored concepts. That is, the conceptual hints given by the experiments should be excluded from analysis. Figure 4 and Figure 5 show an example. The respondent in Figure 4, a student in Group 3 of Experiment 2, recalled a total of nine ideas about heat and temperature, but his recall about the group core concept (statement 7 in Figure 4) and group anchored concept (statement 5 in Figure 4) should be removed. A revised flow map, which diagrammed the student's ideas based on only the remaining seven ideas, was developed, as shown in Figure 5.

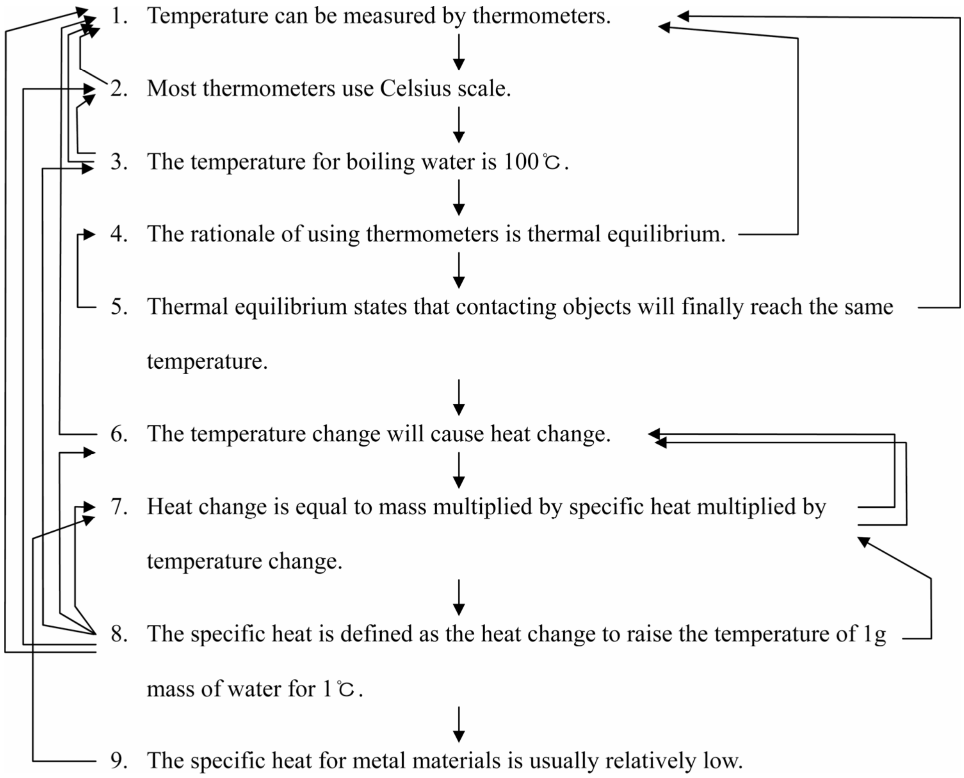

Figure 4. *David's knowledge recall two months after the treatment instruction*

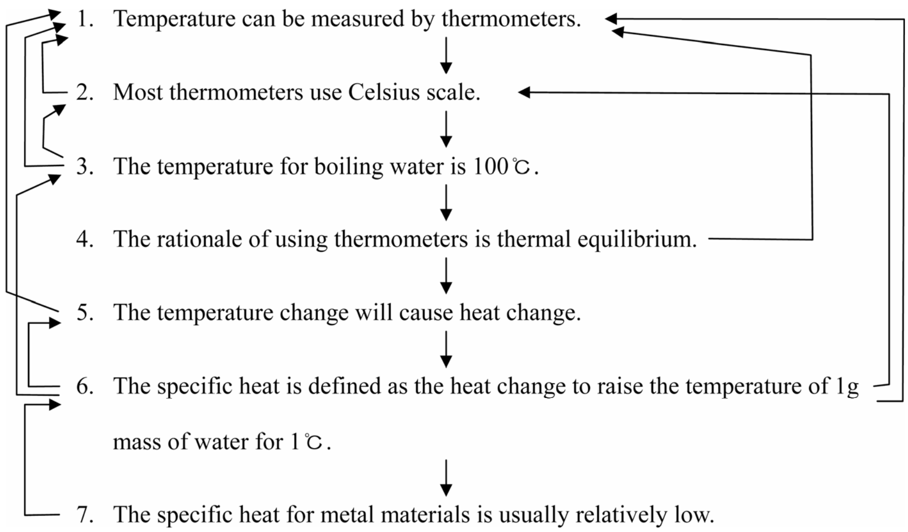

Figure 5. *David's flow map after excluding the core and anchored concepts shown in the interview recall*

By employing the flow-map method, this study had the following major knowledge structure outcome variables resulting from this part of the analysis:

- Size or extent: number of ideas, e.g., 7 in Figure 5
- Richness: number of recurrent or cross linkages, e.g., 10 in Figure 5
- Connection: proportion of recurrent linkages, equal to number of recurrent linkages divided by the number of ideas, e.g., 10/7, 1.43, in Figure 5
- Misconception: number of misconceptions detected in the flow map narrative, a lower score on this indicates a higher precision of ideational networks, e.g., 0 in Figure 5.

These variables were defined similar to those in prior related research utilizing the flow map method (e.g., Tsai 2000 and 2003). A second independent researcher was asked to analyze sixty randomly selected examples of the students' narrative (among 237 narrative records for two experiments of data gathering). The inter-coder agreement for sequential statements was .92 and for cross linkages was .87. The validity of using the flow map has also been evaluated by previous studies (e.g., Bischoff and Anderson 2001; Tsai 1999 and 2001b).

3. Results

3.1 Results of Experiment 1

The first experiment used core and anchored concepts of each individual student explored in the identification stage. The students, two months later, were assigned into three groups to examine the role of these concepts, including no hint (Group 1), individual core concept provided (Group 2), and both the individual core and anchored concepts provided (Group 3). Table 1 shows the results of Experiment 1.

Table 1 showed that students with the assistance of individual core and anchored concepts, or those mediated by only core concept, expressed significantly more ideas than those without any conceptual clue. The core and anchored concept identified earlier by each individual largely facilitated the extent of student knowledge structures. However, in light of the extent of knowledge recall, no statistical difference was found between Group 2 and Group 3. The addition of anchored concepts did not significantly enhance the extent of student reconstruction of knowledge during recall. The analysis of the richness of knowledge structures showed a similar finding. The students, when assisted by individual core concepts or by both of the individual core and anchored concepts, displayed significantly richer knowledge structures (i.e., more recurrent linkages) during recall two-months later than those in the absence of this guiding information.

The results for the feature of "connection," nevertheless, illuminated the particular effect of the individual anchored concept. Students in Group 3, who were provided with both the individual core and anchored concepts for helping knowledge recall, displayed significantly more integrated ideational frameworks than those in Group 1 who were given no clues. However, the difference in this feature between Group 1 and Group 2 (who had only the individual core concept) was not statistically significant. The addition of individual anchored concepts seemed to be helpful to the connection of knowledge structures. This finding suggests that both a relevant core concept and a properly anchored concept effectively construct more integrated knowledge structures in a conceptual domain. The results above also propose the individual core concept, while being profitably mediated by the anchored concept, can facilitate the development of broader, richer and more connected knowledge structures.

Finally, the analysis of student misconceptions shown in this experiment did not reveal any significant difference among group 1 (no clue), group 2

Groups	Extent	Richness	Connection	Misconception
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
(1) no concept provided (n=20)	4.40 (1.50)	3.75 (1.29)	0.88 (0.23)	0.30 (0.57)
(2) core concept provided (n=20)	5.95 (1.70)	5.80 (1.36)	1.01 (0.22)	0.25 (0.55)
(3) Both core and anchored concepts provided (n=19)	6.63 (2.45)	7.21 (1.84)	1.15 (0.26)	0.11 (0.32)
F (ANOVA)	6.97**	25.89***	6.21**	0.81
Scheffë test	(2)>(1) (3)>(1)	(2)>(1) (3)>(1)	(3)>(1)	

**p<0.01, ***p<0.001

Table 1. *Experiment 1 – Student knowledge recall two months after the treatment instruction*

(core concept provided) and group 3 (both core and anchored concepts) (F = 0.81, n.s.). The participating students in this experiment stated very few scientifically incorrect ideas in recall (an average of .22 per flow map, or only 3.9% of their uttered ideas were misconceptions). The effects of core and anchored concepts on student misconceptions are not fully revealed in this study.

3.2 Results of Experiment 2

Experiment 2 used the group core and anchored concepts identified from 60 students in identification stage. These are concepts such as: "Heat change is equal to mass multiplied by specific heat multiplied by temperature change," and "Thermal equilibrium will make contacting objects reach the same temperature," respectively. Table 2 shows the results of Experiment 2: the knowledge recall of students two months after the identification of these group concepts.

Table 2 showed that students who were provided with both group core and anchored concepts (Group 3), or those given only the group core concept (the second), tended to recall significantly more ideas than those without any hint. The clues that were derived from the group core and anchored concept largely enhanced the extent of student reconstruction of knowledge during recall and yielded more substantial evidence of knowledge structures. Similar to the finding in Experiment 1, with respect to the extent of knowledge recalled, there was no difference between Group 2 and Group 3. This suggests that the addition of group anchored concepts may not significantly extend students' conceptual frameworks beyond the effect of providing core concepts alone.

However, the analysis of the flow maps from the perspective of richness showed a clearer trend for the effects of the combination of group core and anchored concepts relative to only providing core concepts. The students who were given both the group core and anchored concepts had significantly more recurrent linkages in the flow map obtained from the interviews than those who were given only the core concept. Moreover, students who were given the hint of a core concept alone still displayed a greater richness (i.e., more recurrent linkages) in their flow maps than those without conceptual hints. This finding suggests that the group core concept may readily facilitate the richness of knowledge frameworks, but even with the existence of the group core concept, the group anchored concept can still largely enrich the reconstruction of information from networks in memory.

The results derived from an analysis of the feature of "connection" showed that students in the second and third groups (who were reminded of group core concept or both group core and anchored concepts before the interview) displayed significantly more integrated knowledge frameworks than did Group 1 (who had no conceptual hint). Similar to the findings revealed in Experiment 1, with respect to misconceptions, there were no significant differences among these groups. The students in this experiment as a whole stated very few scientifically inaccurate ideas in the recall (an average of .23 per flow map, or only 4.2% of their ideas were misconceptions).

Groups	Extent	Richness	Connection	Misconception
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
(1) no concept provided (n=19)	4.32 (1.70)	3.74 (1.66)	0.85 (0.33)	0.32 (0.58)
(2) core concept provided (n=20)	6.05 (1.93)	5.60 (1.98)	0.95 (0.24)	0.20 (0.52)
(3) Both core and anchored concepts provided (n=19)	6.00 (2.05)	7.16 (1.95)	1.24 (0.26)	0.16 (0.37)
F (ANOVA)	5.16**	15.89***	10.39**	0.51
Scheffë test	(2)>(1) (3)>(1)	(3)>(2)>(1)	(2)>(1) (3)>(1)	

**p<0.01, ***p<0.001

Table 2. *Experiment 2 – Student knowledge recall two months after the treatment instruction*

3.3 Comparison of the Experiments 1 and 2

The first experiment explored the role of individual core and anchored concepts, whereas the second experiment examined the knowledge reconstruction aided by group core and anchored concepts. Consequently, it is interesting to compare the results derived from both experiments. Table 3 collected the variables of knowledge structures and compares the differences between the first two experiments by a series of t-tests. As each student in the study was randomly assigned into either of the two experiments, these students' scores between experiments were independent. The use of t-test here is statistically proper.

Based upon the t-value results shown in Table 3, there was no statistical difference on each variable (sorted by the three groups) between these two experiments. These findings suggested that the use of individual core and anchored concepts, on average, did not display any significant difference from that of group core and anchored concepts in helping the reconstruction of knowledge structures.

3.4 Results of Experiment 3

The experiments above showed that group core and anchored concepts (Experiment 2) were very likely as helpful as individual ones (Experiment 1) for the reconstruction of knowledge two months after the instruction and identification stage. It may be potentially interesting to further evaluate the role of group core and anchored concepts for even a relatively longer time to reveal their long-term effects. Hence, a follow-up study, Experiment 3, was conducted six months after the instruction. The results of Experiment 3 are presented in Table 4.

Table 4 showed that students in Group 3, aided by both core and anchored concepts, displayed significantly more extended and connected knowledge structures than those in Group 1 (no clue offered). Nevertheless, the differences between the first two groups in the features of extent and connection were not significant. Hence, the group core concept alone did not produce effects different from no conceptual clue in the perspectives of these two features. These findings highlighted the important role played by the anchored concept in long-term exploration. That is, the usage of core concept should be necessarily coupled with anchored concepts to extend and integrate knowledge structures, particularly long after instruction, such as six months in the Experiment 3.

With respect to the richness, the results indicated that students in Group 3 outperformed those in the first two groups, and those in Group 2 then outperformed those in Group 1. These findings suggested that the core concept alone was helpful to enrich knowledge structures. However, students with the assistance of both group core and anchored concepts tended to construct richer knowledge frameworks

		Experiment 1	Experiment 2	t
		Mean (S.D.)	Mean (S.D.)	
Extent	Group (1)	4.40 (1.50)	4.32 (1.70)	0.16 (n.s.)
	Group (2)	5.95 (1.70)	6.05 (1.93)	-0.17 (n.s.)
	Group (3)	6.63 (2.45)	6.00 (2.05)	0.86 (n.s.)
Richness	Group (1)	3.75 (1.29)	3.74 (1.66)	0.03 (n.s.)
	Group (2)	5.80 (1.36)	5.60 (1.98)	0.37 (n.s.)
	Group (3)	7.21 (1.84)	7.16 (1.95)	0.09 (n.s.)
Connection	Group (1)	0.88 (0.23)	0.85 (0.33)	0.33 (n.s.)
	Group (2)	1.01 (0.22)	0.95 (0.24)	0.88 (n.s.)
	Group (3)	1.15 (0.26)	1.24 (0.26)	-1.15 (n.s.)
Misconception	Group (1)	0.30 (0.57)	0.32 (0.58)	-0.09 (n.s.)
	Group (2)	0.25 (0.55)	0.20 (0.52)	0.30 (n.s.)
	Group (3)	0.11 (0.32)	0.16 (0.37)	-0.47 (n.s.)

n.s.: non-significant

Table 3. *Comparison of the results between Experiments 1 and 2*

Groups	Extent	Richness	Connection	Misconception
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
(1) no concept provided (n=18)	3.67 (1.46)	3.06 (1.43)	0.80 (0.26)	0.39 (0.50)
(2) core concept provided (n=19)	4.63 (1.26)	4.37 (1.46)	0.94 (0.35)	0.21 (0.42)
(3) Both core and anchored concepts provided n=18)	5.42 (2.06)	5.74 (1.63)	1.11 (0.25)	0.21 (0.42)
F (ANOVA)	5.36**	14.56***	5.13**	0.97
Scheffë test	(3)>(1)	(3)>(2)>(1)	(3)>(1)	

**p<0.01, ***p<0.001

Table 4. *Experiment 3 – Student knowledge recall six months after the treatment instruction*

than those with only the core concept. Therefore, the role of the anchored concept became more and more significant after the instruction. Finally, the analysis of misconceptions revealed similar findings to those in both experiments presented previously. That is, there were no significant differences among these groups and students in either group uttered very few scientifically incorrect ideas in the knowledge recall.

4. Discussion and implications

We used the flow map method to identify core and anchored concepts of individual students, and common core and anchored concepts of a group of students in the knowledge domain of thermal physics. The results clearly showed that with the assistance of core and anchored concepts, students could profitably recall more extended knowledge, with greater richness and with higher connection, in the task of knowledge recall two months later, compared with the situation when this organizing information was absent. In addition, a six-month later assessment also indicated the important role played by the core and anchored concepts respectively. In particular, the anchored concept seemed to assist the core concept to help students enhance their knowledge recall in this delay assessment.

4.1 Doubts regarding the number of misconceptions

The students in this study, on average, recalled few misconceptions in the flow map interview in each interview assessment. A plausible interpretation for this may stem from the fact that the students, in the Taiwanese educational context, might have been accustomed to stating only those ideas that they were certain about in the interview, similar to the findings in Tsai (2000, 2003).

4.2 Doubts regarding the sheer number of the given clues

It might be argued that the significant effects on the dimensions of Extent, Richness, and Connection found in the Group 3 in every experiment might be due to the sheer number of the clues given to subjects for recall. It seems that two clues given are better than one for the recalling task, especially in the domain of connecting or trigger-relevant information. Specifically, when the recall task was carried out 6 months after the treatment, the strength of connection of various concepts was enhanced by large numbers of clues. Giving more clues is beneficial in reconnecting the knowledge. If this claim is true, one might expect that more clues would induce better recall.

In order to further clarify the role of anchored concepts, future studies may recruit another group of students. It is proposed that the students should be presented with the anchored concept but without the core concept, or with two other peripheral concepts but without any core concept or anchored concept, possibly to show that the anchored concept alone is significantly less effective as a trigger for recall, and that the sheer number of clues is not the key factor either. The present study is limited by the number of subjects (n=120), so it is not plausible to randomly divide the students into many groups to explore all of these possibilities. These issues are left for further studies.

4.3 *Doubts regarding the structure of knowledge in the brain*

Due to the fact that this study has not provided profound results to the structure of core and anchored concepts, and that this study was not aimed for providing support for any kind of structures of knowledge stored in the brain, it is conservative for us not to approve or commend for the hierarchical organization of knowledge, the semantic construction or the structures of knowledge which have been studied intensively in the field. This study placed more emphases on exploring the practical implications for the identified major concepts on learning and teaching.

4.4 *Doubts regarding the identification of core and anchored concepts*

It is possible that what the identification stage explored were the core and anchored concepts that were given by the lecturer but not from students themselves. Or they might be the prior knowledge that students had learnt earlier. We argue that it is the concept that was used to organize the knowledge that is the focal point of this study, but not the origin of concepts. Furthermore, even if we found that a key concept given to students helped students successfully to acquire knowledge, then we consider this strategy effective and useful for learning. Additionally, one could not eliminate the prior knowledge students had acquired before the test. For this issue, we studied students with similar educational backgrounds and counter-balanced personal differences by the between-subject design of the study. One may also argue that certain interview questions used may lead the students to express certain core and anchored concepts. However, as shown by this study, the students were interviewed by some non-directive questions, which allowed them to freely verbalize their ideas. Therefore, the problem raised by the interview questions may not be critical in this study.

4.5 *The doubts about the importance of recalling in science learning*

Some might question whether the process of learning science is not merely a process of remembering and recalling. Although this seems to be plausible, we argue that the remembering and recalling we tested in this study is rather fundamental in the process of knowledge acquisition. It is the successful recalling that allows further applying and transferring of the knowledge into new scientific concepts. As to the process through which students use the core and anchored concepts in solving real-life scientific problems, it is an issue worth examining in future studies. That is, future studies can be conducted to explore how students use core and anchored concepts in real-life contexts.

4.6 *Findings for practical implications and further study*

Experiment 1 in this study used the core or anchored concepts of each individual student to facilitate knowledge reconstruction, and then examined the effects of these concepts. Experiment 2 used the core and anchored concepts identified from an overall analysis of all of the 60 learners as recall clues. The comparison of these two levels of variation did not show any statistical difference in the recall task after two months. Thus, in terms of research results, the use of overall group core and anchored concepts as clues for helping knowledge recall is viewed as satisfactory. One might question the merit of this approach based on the issue of scientific accuracy and relevance of student-formed concepts, that is the core and anchored concepts as analyzed through a pool of students may not be the same as those of their teachers or experts (such as physicists). As suggested above, locating and refining the core and anchored concepts to more accurately reflect current scientific knowledge can more effectively enhance their role as organizing centers for knowledge recall. Future research is also planned to conduct flow map interviews with a group of science teachers or physicists to reveal their group core and anchored concepts within a particular science content domain (e.g., heat and temperature) and then to compare with those of students.

In addition, the core and anchored concepts identified by the study may be related to the teacher's instructional approach. As the treatment in this study was basically lecture oriented, a study of students' flow maps and then their core and anchored concepts following other types of teaching, such as inquiry teaching, should be added to the future study. Another interesting research question is to explore which students may more likely fail to locate the core and anchored concepts in knowledge recall. It is hypothesized that students who lack meta-cognitive strategies might exclusively focus on encoding all information with equal importance. Consequently, their goal of learning may be often oriented to simply achieving high grades but not necessarily to the development of an integrated understanding of the content (Tsai 1998b and 2001a). More research is necessary to examine this hypothesis.

Finally, this study also provides some potential insights for classification research. The identification of core and anchored concepts is similar to Beghtol's (2003) recent work on what she has called "naïve" classifications. "Naïve" classifications, distinguished from "Professional" classifications by information professionals for information retrieval and communication, include the invention of new classification systems for the purpose of knowledge discovery in various academic disciplines, or of advancing disciplinary knowledge (Beghtol 2003 and 2004). Naïve classifications are particularly concerned with scholarly classifications for smaller areas of knowledge within some major disciplines (Beghtol 2004), such as knowledge related to "heat and temperature" in this study. For either type of classifications, it is important to find out some classifiable elements to discover some classes and subclasses that can be in accordance with the purpose of classification system (Beghtol 2003). The ideas of core and anchored concepts, as proposed in this study, have provided empirical evidence about basic elements of "naïve" classifications. Moreover, the identification of core and anchored concepts is based upon the flow map method, which is derived from student narrative discourse analysis. This perspective also concurs with Beghtol's (1997) views about how to fruitfully analyze information storage and retrieval by using narrative analysis. Further studies can be conducted on the basis of the frameworks as well as findings proposed in the present paper to possibly enrich literatures for the field of classification research.

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Appendix 1: An example of constructing a flow map: the case of David

Interview transcript:

Researcher: Could you tell me what the major concepts about heat and temperature are?

Student (David): Thermal equilibrium will make contacting objects reach the same temperature.

And, the temperature can be measured by thermometers. The thermometers can be made by alcohol and mercury. The rationale of using thermometers is thermal equilibrium, as two contacting objects will finally reach the same temperature. Heat change is equal to mass multiplied by specific heat multiplied by temperature change.

(Then, David stopped for a while).

Researcher: So, could you tell me more about the concepts you have described?

David: The unit for heat can be calorie.

Researcher: Any more?

David: The specific heat is defined as the heat change to raise the temperature of 1g mass of water for 1. Different materials have different values of specific heat.

Researcher: Could you tell me more about the relationships among the ideas you have already told me?

David: The specific heat for water is 1. (David stopped awhile). I think these are all of the concepts I know about heat and temperature.

(Then, the researcher immediately replayed the tape-recording above, and asked David to listen to what he had stated just previously, called as the "meta-listening technique).

Researcher: After listening to your ideas previously stated, do you have something to modify or add about what you learned about heat and temperature?

David: (think a while) Heat is a form of energy. (stop a while) I think these are all of the concepts I know about heat and temperature.

The construction of David's flow map

The researcher used the above tape recording to map David's ideas, as shown in Figure 3. The researcher, first, entered the ideas in sequence as they were uttered by David. David in the interview recalled ten ideas, shown in a sequential flow. In addition to sequential (linear) linkages, the flow map shows some recurrent linkages for re-visited ideas. For example, statement 4 in Figure 3 includes three re-visited (related) concepts: thermometers, thermal equilibrium and temperature. The researcher, hence, drew three recurrent linkages from statement 4 to the earliest steps the subject stated these ideas, that is, statement 2 (about thermometers), statement 1 (about thermal equilibrium), and statement 1 (about temperature).