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科學知識建構：探索「核心」與「定錨」概念所扮演之角色

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科學知識建構：探索「核心」與「定錨」概念所扮演之角色(1/3)

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Abstract

This study proposes that learners' knowledge be organized around a "core" concept that is strongly linked to other secondary concepts within a domain of knowledge. It also suggests that there is an "anchored" concept that stabilizes the "core" concept and other ideas. In other words, the "core" concept and "anchored" concept are mutually supportive of one another, and then can be linked with other concepts to produce more extended and robust knowledge structures in memory. This study further illustrated the use of a flow map method to identify 120 high school students' "core" and "anchored" concepts derived from the treatment instruction about thermal physics. Then, these students were assigned into the following two experiments two months after the instruction. In experiment one, the researchers used each individual student's "core" or "anchored" concepts to facilitate his/her knowledge reconstruction, and then examined the effects of these concepts. In experiment two, the subsequent testing of recall used the group "core" and "anchored" concepts identified from an overall analysis of the learners. The results derived from both experiments showed that with the assistance of "core" concept, profitably mediated by the "anchored" concept, students could recall more extended knowledge, with greater richness and with higher connection than in the absence of this organizing information. However, a comparison of the results of both experiments did not indicate any statistical difference in any feature of the knowledge structures derived from the two-month later recall. A follow-up study conducted six months after the instruction further showed the important role played by the group "anchored" concept. This study may provide some potential insights about the functional mechanisms of learners' knowledge construction.

Introduction

Contemporary cognitive psychologists believe that knowledge is not merely a copy of sensations impressed in memory; rather, it is the product of a complicated and extended sequence of information-processing activities and mediating mechanisms of perception and knowledge construction. During cognition or information processing, our brains sometimes act as mental and emotional filters when acquiring new experiences, or function dynamically as cognitive categorizers framing and molding the sensory input to conform with pre-existing knowledge structures (e.g., LeDoux & Hirst, 1990; Anderson, 1991, 1992, 1997).

As a result, educators are interested in knowing more about the structures of learners' knowledge or their conceptual frameworks. Several perspectives have been proposed. 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. Based upon this theoretical perspective, concept mapping, in the recent two decades, has been proposed and implemented to be a possible way of representing student knowledge structures

(Novak, 1985, 1990; Novak & Gowin, 1984). Recent developments from neuroscience have provided additional perspectives about human information encoding and knowledge construction. Neurocognitive scientists and researchers also have devised ways to represent knowledge frameworks in the brain (e.g., Rolls, 2001; Rantala, 2001). These researchers also assert that the recall of knowledge is almost certainly not a process of encoding and a part-for-part readout as 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. Knowledge structures may be correlated with neural schema or networks of connected neuronal elements, but probably not in a hierarchical nature (Anderson, 1992, 1997). Moreover, there is evidence 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, 2003; West & 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.

No matter which perspective one may take, it is initially plausible to assume that people's knowledge is organized around a "core" concept (but not necessarily in hierarchical formats) that is strongly linked to other secondary concepts[1] within a domain of knowledge. Apparently, 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 that also plays an important role in stabilizing the "core" concept and other ideas. The "anchored" concept may be considered as a secondary core concept. The position of "core" as well as "anchored" concepts in one's memory may be similar to that illustrated in Figure 1.

(Insert Figure 1 about here)

The "core" concept and "anchored" concept are mutually supportive of one another, and then can be linked with other concepts to produce a more robust knowledge network in memory. The "core" concept plays a central role in helping the individual recall related concepts. The "core" concept, with the assistance of an "anchored" concept, further stabilizes knowledge structures. Hence, the "anchored" concept, on the one hand, strengthens the salience and nodal position of the "core" concept, and on the other hand, through linkages to other information in memory, integrates more related concepts into the knowledge frameworks. Consequently, the knowledge structures become more extended and robust. 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. In this perspective, 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.[2]

One may predict that alternatively in the absence of these focal concepts, called "core" and "anchored" concepts in this paper, an individual's knowledge structures (if indeed a structured assemblage of information exists at all under the posited conditions) will become a collection of isolated bits without high integration. Thus, if he or she fails to locate "core" and "anchored" concepts that can help to organize information in memory, there is likely to be less efficiency in accessing it during recall. According to a newer understanding of cognition, students who are not skilled in self reflection during learning, and who lack well organized knowledge structures, may deem all new information to be of equal importance and each conception as unique and individually significant. 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. Hence, this may lead to a strategy of rote memorization and commitment of each part to detailed encoding in memory, but largely as isolated units (Tsai, 2001a).

Consequently, educators may face a new challenge, that is, 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 more robust knowledge structures. In order to respond to this question, 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. A better representation of one's knowledge structure should include its extent, correctness, integration, availability and information processing strategies. From this perspective, Tsai and Huang (2002) have concluded that the flow map method can provide richer and more detailed information in representing knowledge structures, when compared to the other four methods. The use of the flow map method also concurs with recent findings revealed by the field of neuroscience, as those presented previously.[3] Therefore, this study used a flow map method (Anderson & Demetrius, 1993; Tsai, 2001b) to potentially identify students' "core" and "anchored" concepts in a domain of scientific knowledge; i.e., thermal physics.[4] Furthermore, this study 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, this study was an attempt to more clearly establish the functional details of the relationships among information in memory within a perspective of "core" and "anchored" concepts.

Method

Sample

A total of 120 students (65 males and 55 females) from eight 10th–grade 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 the school. The teacher was a female teacher with five years of teaching experience. 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, consisted of two stages. The first stage explored the "core" and "anchored" concepts detected in student knowledge recall immediately after the instructional unit on heat and temperature. The second stage examined the role of "core" and "anchored" concepts in student knowledge recall some months later.

Stage 1: Identify "core" and "anchored" concepts

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 thought in a non-directive way. It can represent both the serial order and cross-linkage of ideas in narrative (Anderson & Demetrius, 1993; Tsai, 1998a; Tsai & Huang, 2001). In order to acquire a learner's ideas in narrative, every selected subject should be interviewed individually to obtain an audiotaped record of his or her thoughts. 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:

1. Could you tell me what are the major concepts about heat and temperature?
2. Could you tell me more about the concepts you have described?
3. 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 his or her *immediately* prior elicited recall and possibly to modify his/her original ideas, for details, see Tsai, 1998a, 1999, 2001b), every selected student's interview narrative was further analyzed by a "flow map" method (Anderson & Demetrius, 1993; Anderson, Randle, & Covotsos, 2001; Bischoff & Anderson, 2001). The interview recall data were tape-recorded. A flow map is constructed by diagramming the respondent's verbalization of thought as it unfolds, and it is a convenient way to display the sequential and complex or cross-linkage thought patterns expressed by the respondent. The flow map is assembled by entering the ideas in sequence as they are uttered by the subject. Figure 2 shows a sample of flow map used in this study. The student in the interview recalled ten ideas, shown in a sequential flow.

(Insert Figure 2 about here)

In addition to sequential (linear) linkages, the flow map shows some recurrent linkages for re-visited ideas. For example, statement 4 in Figure 2 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). 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.

Identifying "core" and "anchored" concepts

As a result, the flow map interview as 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. This study 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

Although these definitions may be technically straightforward, they are consistent with the perspective proposed earlier that the "core" concept is connected with the most of relevant concepts in the knowledge domain, while the "anchored" concept is connected with the second most related concepts. In other words, these criteria are proposed because the "core" concept is an idea that integrates the most amount of related thoughts in memory, as shown in Figure 1. The recurrent linkages provide a good indicator about the relevancy and integration among ideas around a focal or core concept. A similar rationale can be applied to the identification of the "anchored" concept. Take the student in Figure 2 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.

Then, the next stage is to examine the role of "core" and "anchored" concepts in knowledge reconstruction. In this paper, two experiments were designed and the 120 students involved were assigned into either one of the experiments. The first one, including 60 students, explored each individual's "core" and "anchored" concepts (by using the aforementioned definitions) and their effects on subsequent knowledge recall. In this experiment, the "core" and "anchored" concepts might be varying across individual students. The second experiment, also involving 60 students, investigated students' "core" and "anchored" concepts as a group, and then evaluated the effects of these concepts on students' knowledge structures probed in a later stage. The findings derived from the second experiment 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 used each student's "core" and "anchored" concepts shown in the first stage for further exploration. On the other hand, the second experiment used group students' "core" and "anchored" concepts to examine the role of these concepts. The *group* "core" and "anchored" concepts were searched by reviewing those revealed by individual students and found the most frequently shown by the group of students. Based upon the flow map data gathered from the sixty high school students in the second experiment, the following *group* concepts were identified.

"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. For research purposes, this study could only use such a statistical way to identify the *group* “core” and “anchored” concepts to represent these students.

Stage 2: the role of “core” and “anchored” concepts

In order to examine the role of “core” and “anchored” concepts, the 120 subjects involved in this study 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, the sixty participating students were divided into the following three groups based on random assignment.

The students in the first group were interviewed with only the interview questions provided earlier and without providing any concept or hint. The students in the second group were given the “core” concept orally by the researcher before the flow map interview to determine how it may help them recall knowledge. The students in the third group were orally provided with both the “core” and “anchored” concepts derived from the first stage of flow map analysis before this part of flow map interview. After being told the conceptual hint, every student in these groups was interviewed in the same way.[5] For this part of interview, each student in the second group of experiment one was given *individual* “core” concept as identified in the first stage, and *individual* “core” and “anchored” concepts were provided to each student in the third group of experiment one. 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 two was provided with the same *group* “core” concept (the second group) or with *group* “core” and “anchored” concepts (the third group) as summarized from the first stage of investigation. The research deign of this stage is illustrated in Figure 3. Figure 3 showed that the 120 students were involved in either one of the experiments and each experiment included three groups for exploration. Although the students in each experiment were randomly assigned into these three groups, one student in experiment one and two students in experiment two failed to complete this part of follow-up interview, therefore the number of students in these three groups was 20, 20, 19 for experiment one and 19, 20, 19 respectively for experiment two.

(Insert Figure 3 about here)

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”) concept(s) from the flow map analyses.** That is, if a student in the second group stated the “core” concept in the flow map interview, the “core” concept should be excluded. Similarly, if a student in the third group stated the “core” concept and (or) the “anchored” concept in the interview, these elicited concepts (or the concept) should be removed from final analyses. Obviously, in experiment one, the removed concepts were *individual* “core” or/and “anchored” concepts, while in experiment two, the excluded concepts were *group* “core” or/and “anchored” concepts. That is, the conceptual hint(s) given by the experiments should be excluded from analysis. Figure 4 and Figure 5 show an example for this. The respondent in Figure 4, a student in the third group of the experiment two, 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.

(Insert Figure 4 and Figure 5 about here)

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

1. Size or extent: number of ideas, e.g., 7 in Figure 5,
2. Richness: number of recurrent or cross linkages, e.g., 10 in Figure 5,
3. 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.
4. 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, 2003). A second independent researcher was asked to analyze sixty randomly selected examples of the students' narrative (among 237 narrative records for two stages 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 & Anderson, 2001; Tsai, 1999, 2001b). For example, it was found that students with richer and more integrated knowledge frameworks as labeled by the flow map method tended to have higher academic achievement and to organize their knowledge in higher-order cognitive operations, which provides a type of concurrent validity.

Results

Experiment one

The first experiment used each individual student's "core" and "anchored" concepts identified in the first stage for further exploration. The students, two months later, were assigned into three groups, including no hint, (individual) core concept provided, and both the (individual) "core" and "anchored" concepts provided, to examine the role of these concepts. Table 1 shows the results of experiment one.

(Insert Table 1 about here)

Table 1 revealed 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" concept (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 the second group and the third group students. The addition of "anchored" concept may not significantly enhance the extent of student reconstruction of knowledge during recall. The analysis of the richness of knowledge structures showed a similar finding above. The students, when assisted by individual "core" concept or by both of the individual "core" and "anchored" concepts, displayed significantly richer knowledge structures (i.e., more recurrent linkages) during a two-months later recall 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 the third group, who were provided with both the individual "core" and "anchored" concepts for helping the knowledge recall, displayed significantly more integrated ideational frameworks than the first group students (no clue). However, the difference in this feature between the first group and the second group (only offering the individual "core" concept) was not statistically significant. The addition of individual "anchored" concept seemed to be helpful to the connection of knowledge structures. This finding suggests that teachers should help students to develop both a relevant "core" concept and a proper "anchored" concept to effectively construct more integrated knowledge structures toward a conceptual domain. The results above also proposes the individual "core" concept, when 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 stage did not reveal any significant difference among these three groups. 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). A plausible interpretation for this finding is that these students may have tended to only state ideas that they felt very accurate (perhaps, due to the traditional instructional strategies they commonly received). This result was similar to that found in other related studies in Taiwan (e.g., Tsai, 2000, 2001b). As a result, the effects of "core" and "anchored" concepts on student misconceptions may not be fully revealed in this study.

Experiment two

In stage 1, an overall analysis of 60 experiment two students' narratives identified the *group* "core" and "anchored" concepts respectively 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." Table 2 shows the results for experiment two students' knowledge recall two months after the identification of these group concepts.

(Insert Table 2 about here)

Table 2 showed that students who were provided with both group "core" and "anchored" concepts (the third group), 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" concept (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 one, with respect to the extent of knowledge recalled, there was no difference between the second group and the third group students. This suggests that the addition of group "anchored" concept 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 with no conceptual hint. 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. This implies that educators should encourage students to develop not only a relevant “core” concept but also the appropriate “anchored” concepts, if they expect students to develop richer connections among existing ideas.

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 the first group of students (no conceptual hint). Similar to the finding revealed in experiment one, 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).

Comparison between two experiments

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 lists the outcome variables of knowledge structures collected in the second stage by each group and experiment, and then compares the differences between the experiments by a series of t-tests.

(Insert Table 3 about here)

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. This conclusion is highly encouraging for practical purpose, because teachers in actual classrooms may more likely utilize *group* “core” and “anchored” concepts as guiding clues to facilitate student knowledge recall. On the basis of the results of the present study, it is expected to produce statistically similar effects to those of using individual “core” and “anchored” concepts. In general, the usage of group “core” and “anchored” concepts are supposed to save practicing teachers’ instructional time and efforts.

Follow-up study of experiment two

The experiments above found that *group* “core” and “anchored” concepts (experiment two) were very likely as helpful as *individual* ones (experiment one) for the reconstruction of knowledge two months after the instruction. 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 of experiment two was conducted six months after the instruction (i.e., four months after the experiment). The same participating students 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 two. Due to some unexpected absence of the students, the number of students for the three groups was 18, 19 and 18 respectively. The results of this follow-up study are presented in Table 4.

Table 4 showed that students in the third group (aided by both “core” and “anchored” concepts) displayed significantly more extended and connected knowledge structures than those in the first group (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 different effects 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” concept to help students develop extended and integrated knowledge structures, particularly in the case for long time after the instruction, such as six months in this follow-up study.

With respect to the richness, the results indicated that students in the third group outperformed those in the first two groups, and those in the second group still performed statistically better than those in the first group. These findings suggested that the “core” concept alone was helpful to enrich students’ knowledge structures than in absence of this concept. However, students with the assistance of both (group) “core” and “anchored” concepts tended to construct richer knowledge frameworks than those with only the “core” concept. Therefore, the role of “anchored” concept was gradually apparent long time 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.

Discussion and implications

This study used the flow map method to identify individual student’s “core” and “anchored” concepts, or a group of students’ common “core” and “anchored” concepts for the knowledge domain of thermal physics. The results derived from this study 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 than in the absence of this organizing information, when the knowledge recall was documented two months after the treatment instruction. To state more specifically, this study mainly included two experiments. In experiment one, the researchers used every individual student’s “core” or “anchored” concepts to facilitate his/her knowledge reconstruction, and then examined the effects of these concepts. In experiment two, the subsequent testing of recall used the “core” and “anchored” concepts identified from an overall analysis of all of the 60 learners as clues. However, a comparison of the results of both experiments did not indicate any statistical difference in the two-month later knowledge recall. Consequently, in terms of research results, methodological simplicity, and in providing information of direct use to teachers, the use of overall group “core” and “anchored” concepts as clues for helping students’ knowledge recall is viewed as satisfactory.

Moreover, as shown previously, the students in this study revealed adequate agreement about their “core” and “anchored” concepts. For example, 58% students in the second experiment held the same “core” concept identified in the first stage of this study. The findings derived from students' group "core" and "anchored" concepts may shape more insights to real classroom practice, as classroom practice is often more oriented to group instruction. For practical purposes, teachers can subsequently use the identified group "core" and "anchored" concepts as a guide for lesson review. That is, teachers can carefully present the "core" and "anchored" concepts to the students, or encourage them to identify them during focused discussion, and use them to help students better reconstruct what they have acquired more broadly within a subject domain.

Moreover, a follow-up study of utilizing group "core" and "anchored" concepts revealed that with the assistance of group "core" concept, necessarily mediated by group "anchored" concept, the students, six months after the instruction, could construct more extended and integrated knowledge structures. Although the group "core" concept facilitated students' development of richer conceptual frameworks than in absence of this organizing concept, students with the addition of group "anchored" concept still outperformed those with the "core" concept alone for the richness feature of knowledge recall when the investigation was conducted six months after the instruction. The role of "anchored" concept seemed to be progressively evident in light of long-term observations. In sum, based upon the results from both experiments and follow-up study, the "core" and "anchored" concepts, as identified by the flow map method, may enrich student cognitive facility in recalling information and presenting it in a form that reflects better ideational networks.

One may 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 teacher(s) or experts. And, as suggested above, the teacher may need to help students locate and refine the "core" and "anchored" concepts to more accurately reflect current scientific knowledge and to more effectively enhance their role as organizing centers for student knowledge recall. Future research is also planned to conduct flow map interviews with a group of science teachers to reveal their (group) "core" and "anchored" concepts within a particular science content domain (e.g., heat and temperature). If these concepts are different from those of students, researchers can undertake four-group comparisons to assess the role of "core" and "anchored" concepts. These four groups can be as follows:

A. Interview with the hint of the (group) "core" concept as identified from students.
B. Interview with the hint of the (group) "core" concept as identified from teachers.
C. Interview with the hint of both the (group) "core" and "anchored" concepts as identified from students.
D. Interview with the hint of both the (group) "core" and "anchored" concepts as identified from teachers.

The results collected from these four groups can re-examine the effects of "core" and "anchored" concepts in comparison to those revealed by this study. Moreover, the comparisons between group A and group B and those between group C and group D can help educators clarify the effects of students' and teachers' "core" and "anchored" concepts on student knowledge recall.

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.

Certainly, in order to more clearly reveal the role of "core" and "anchored" concepts, some follow-up comparisons with other groups of students may be quite helpful. For instance, a follow-up study in the future may include a group of students who are presented with the "anchored" concept but not the "core" concept, to possibly show that the "anchored" concept alone is significantly less effective as a recall trigger. Also, a group of students who are presented with the third most recurrent linkages to show that is less effective as a recall clue can provide more convincing evidence for the role of "core" and "anchored" defined in this study. Due to the limited sample involved in the present study (n=120), it is not plausible to randomly divide the students into many groups to explore all of these possibilities.

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 metacognitive strategies may exclusively focus on encoding all of 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, 2001a). More research is necessary to examine this hypothesis.

Finally, this study showed evidence that the "core" and "anchored" concepts identified by the flow map method substantially enhanced subsequent knowledge recall. That is, educators can use the flow map as a potential tool to find the "core" and "anchored" concepts in a domain of student learning. These can be evaluated for scientific accuracy and relevance and amended if needed before further instruction. The study presented in this paper explored student learning and knowledge construction in the subject of heat and temperature. It is only an initial attempt and example for this line of research. Science educators can utilize a similar method to probe students' "core" and "anchored" concepts in other science domains, such as motion, light, chemical reactions, and evolution.

In conclusion, this study described an initial attempt to identify a group of high school students' "core" and "anchored" concepts in the domain of thermal physics, and the impacts of these potential organizing ideas on subsequent knowledge recall. Hopefully, this research may encourage others to extend this kind of exploration and further examine the research findings described in this study as a means of better understanding the functional mechanisms of how learners construct knowledge and organize it during recall within task-specific contexts.

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Table 1: Experiment one student knowledge recall two months after the treatment instruction

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
Scheffe test	(2)>(1) (3)>(1)	(2)>(1) (3)>(1)	(3)>(1)	

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

Table 2: Experiment two student knowledge recall two months after the treatment instruction

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
Scheffe test	(2)>(1) (3)>(1)	(3)>(2)>(1)	(2)>(1) (3)>(1)	

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

Table 3: Comparison of the results between both experiments

		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 4: Student knowledge recall six months after the treatment instruction: Follow-up study of experiment two

Groups	Extent	Richness	Connection	Misconception
	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)	Mean (S.D.)
no concept provided (n=18)	3.67 (1.46)	3.06 (1.43)	0.80 (0.26)	0.39 (0.50)
core concept provided (n=19)	4.63 (1.26)	4.37 (1.46)	0.94 (0.35)	0.21 (0.42)
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
Scheffe test	(3)>(1)	(3)>(2)>(1)	(3)>(1)	

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

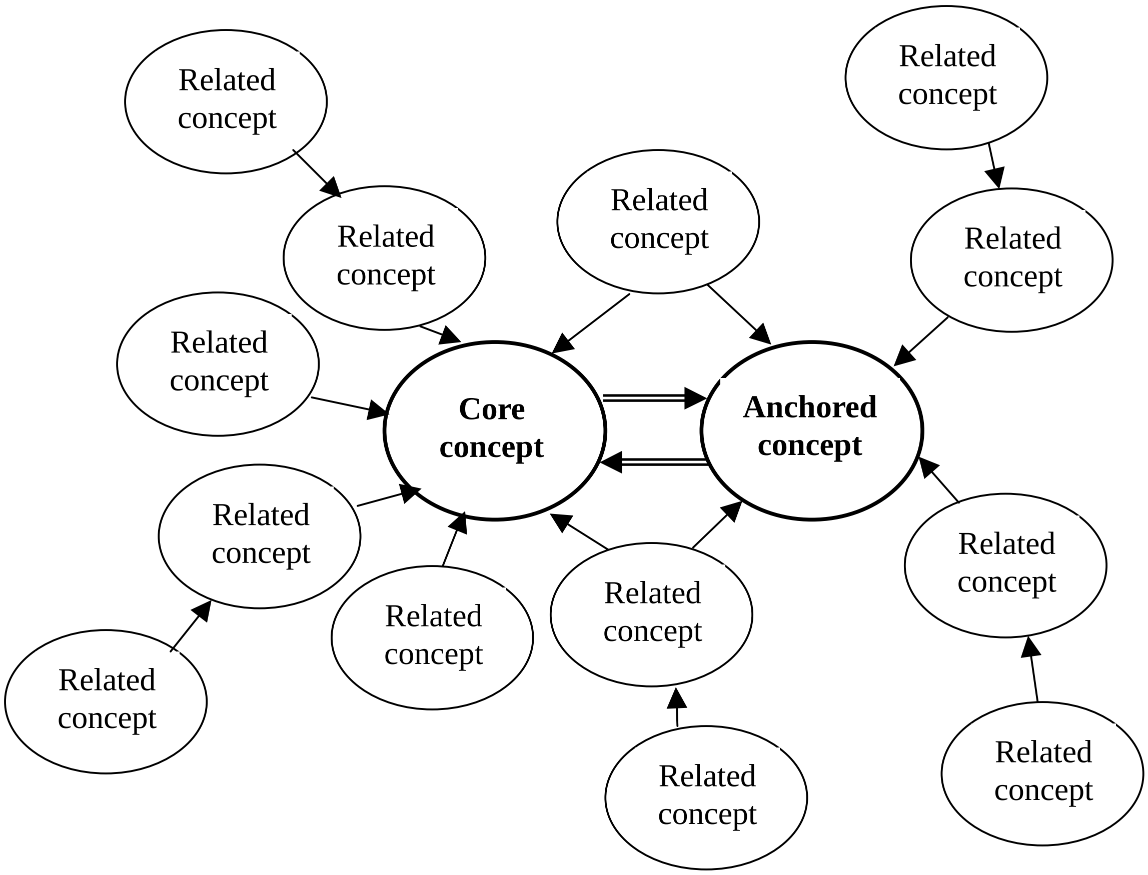

Figure 1: A model of knowledge structure

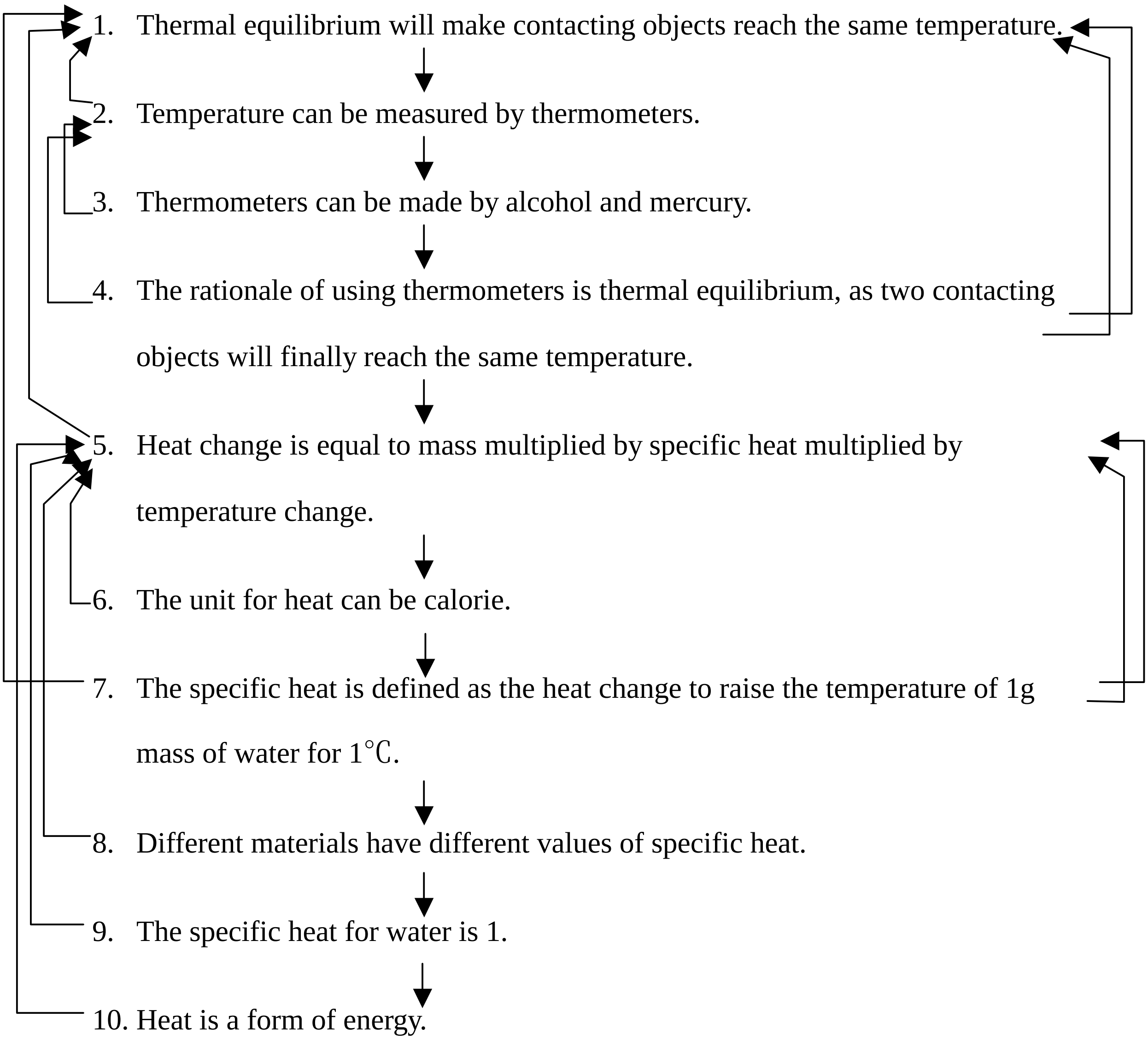

Figure 2: A student's (David, pseudonym) flow map elicited immediately after the treatment instruction

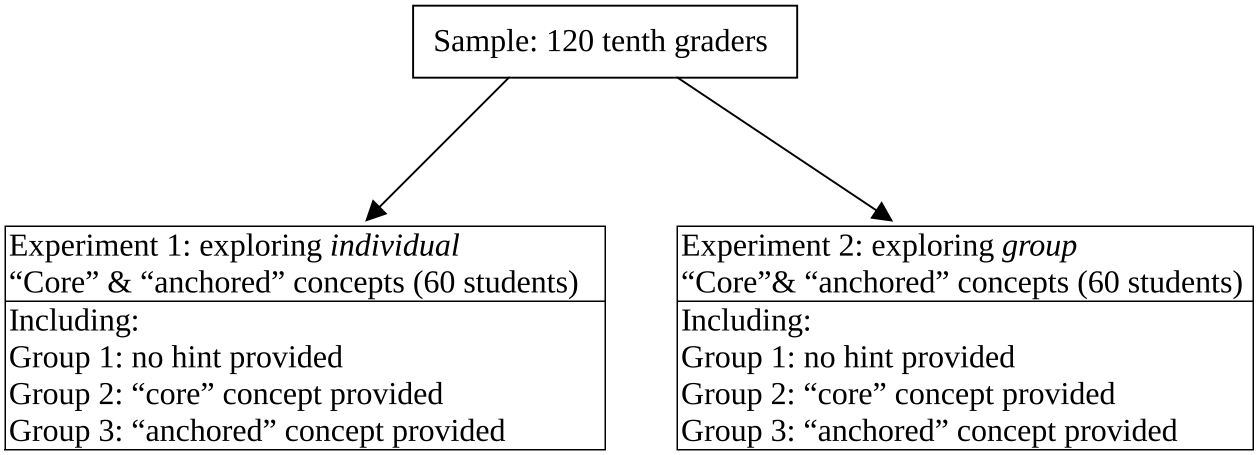

Figure 3: The research design of two experiments

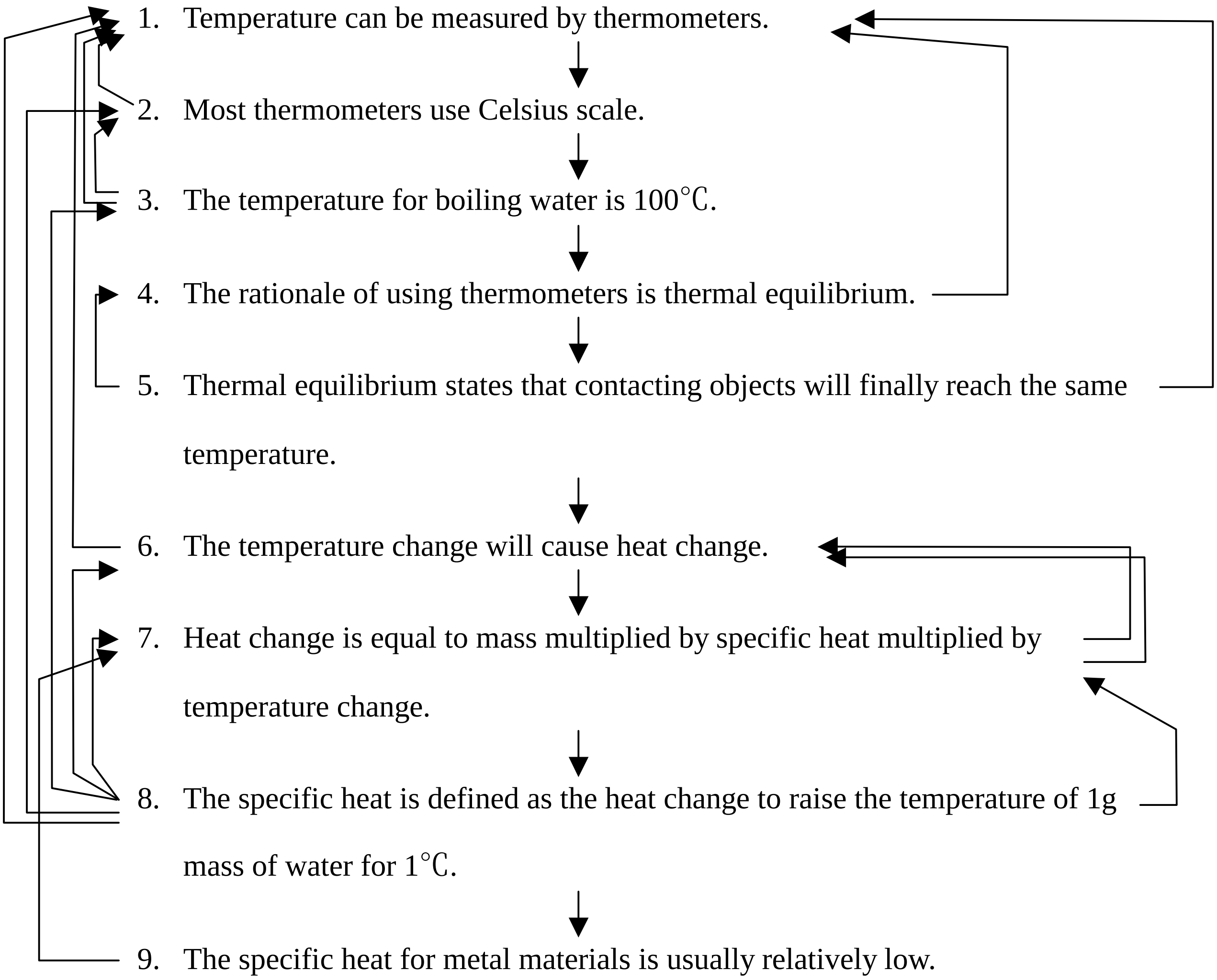

Figure 4: David's knowledge recall two months after the treatment instruction

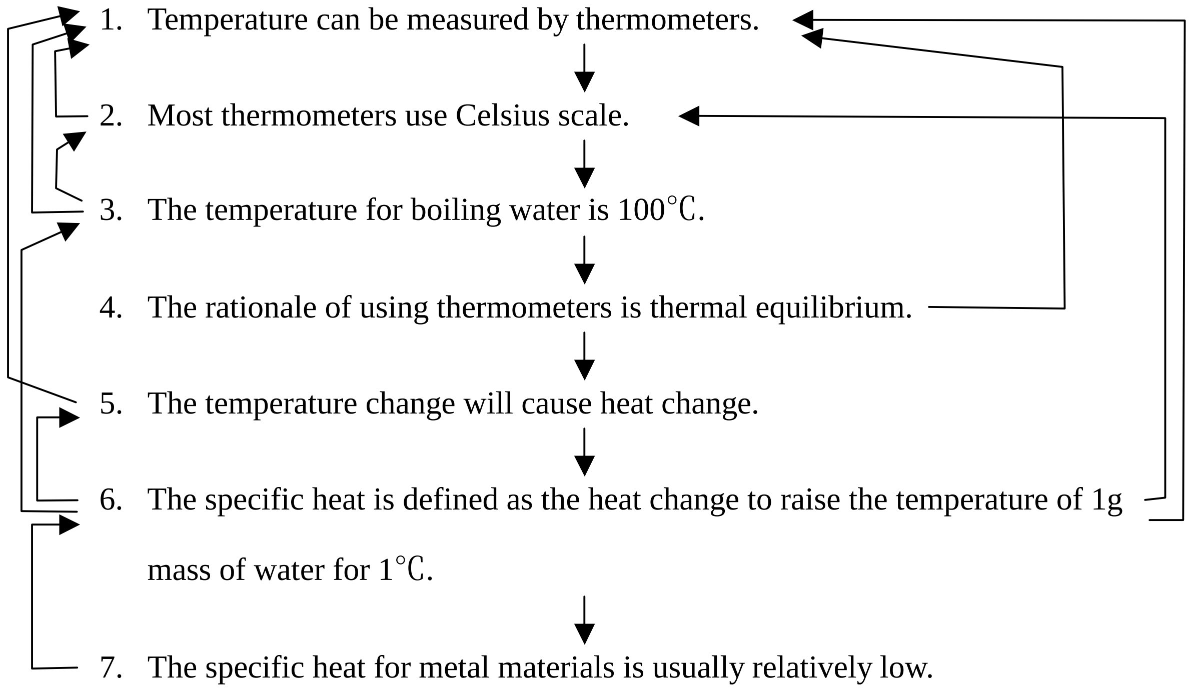

Figure 5: David’s flow map after excluding the core and anchored concepts shown in the interview recall (as David was assigned to the third group which provided both the core and anchored concepts prior to the regular flow map interview)

Notes

[1] In this paper, the term "concept" or "concepts" are used in a broader sense, referring to ideas, thoughts, knowledge bits, and propositions.

[2] 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.

[3] For details, please refer to Tsai and Huang (2002) and Anderson and Demetrius (1993).

[4] 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 & Millar (1994, 1996); Erickson & Tiberghien (1985); Harrison *et al.*, (1999); Kesidou & Duit (1993); Lewis & Linn (1994).

[5] The students in the second and third groups were given conceptual hint(s); however, they were well informed that they did not have to use the hint(s) when responding to the interview.