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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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Abstract

This study proposes that learners' knowledge is 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 illustrates the use of a flow map method to potentially identify sixty high school students' "core" and "anchored" concepts in learning about thermal physics. Research data reveal that with the assistance of "core" concept, profitably with "anchored" concept, these students, two months after the instruction of thermal physics, can recall more extended knowledge, with greater richness and with higher connection than in the absence of this organizing information. 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 as shown more recently functioning 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).

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 development from neuroscience has 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, 1998; West & Pine, 1985). This strengthens a full and detailed exploration of learners' knowledge structures as they 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[i] within a domain of knowledge. Apparently, an individual constructs 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 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 the most of relevant concepts in the knowledge domain, while the “anchored” concept is connected with the second most related concepts.[ii]

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 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.[iii] 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.[iv] 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 sixty students (33 males and 27 females) from four 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 two 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, 1998; 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, 1998, 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 with most recurrent linkages

“Anchored” concept: the concept with 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. Based upon the flow map data gathered from the sixty high school students, the following concepts were identified.

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

“Anchored” concept: Thermal equilibrium will help contacting objects reach the same temperature.

The “core” concept above gained 178 recurrent linkages by the sixty subjects in total (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. On the other hand, 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. These findings, however, indicated that the "core" and "anchored" concepts might be varying across individual students. For research purposes, this study could only use such a statistical way to identify the "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 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, the sixty students were divided into the following three groups based on random assignment.

The students in the first group were interviewed without providing any concept or hint (with only the interview questions provided earlier). 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 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.[v] Although the students in the original sample were randomly assigned into these three groups, two students failed to complete this part of follow-up interview, therefore the number of students in these three groups was 19, 20 and 19 respectively.

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 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. Figure 3 and Figure 4 show an example for this. The respondent in Figure 3, a student in the third group, recalled a total of nine ideas about heat and temperature, but his recall about the "core" concept (statement 7 in Figure 3) and "anchored" concept (statement 5 in Figure 3) should be removed. A revised flow map, which diagramed the student's ideas based on only the remaining seven ideas, was developed, as shown in Figure 4.

(Insert Figure 3 and Figure 4 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 4,
2. Richness: number of recurrent or cross linkages, e.g., 10 in Figure 4,
3. Connection: proportion of recurrent linkages, equal to number of recurrent linkages divided by (number of ideas plus number of recurrent linkages), e.g., 10/(7+10), 0.59, in Figure 4.
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 4.

These variables were defined exactly the same as those in prior related research utilizing the flow map method (e.g., Tsai, 2000, in press). A second independent researcher was asked to analyze thirty randomly selected examples of the students' narrative (among 118 narrative records for two stages of data gathering). The inter-coder agreement for sequential statements was .91 and for cross linkages was .88. 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 validation.

Results

In stage 1, this study identified the “core” and “anchored” concepts respectively as “Heat change is equal to mass multiplied by specific heat multiplied by temperature change” and “Thermal equilibrium will help contacting objects reach the same temperature.” The data in stage 2 were gathered two months after identifying students’ “core” and “anchored” concepts. Table 1 shows the results for student knowledge recall in the second stage.

(Insert Table 1 about here)

Table 1 shows that students who were provided with both “core” and “anchored” concepts, or those given only the “core” concepts, tended to recall significantly more ideas than those without any hint. The clues that were derived from the “core” concept (and “anchored” concept) largely enhanced the extent of student reconstruction of knowledge during recall and yielded more substantial evidence of knowledge structures. Nevertheless, with respect to the extent of knowledge recalled, there was no difference between group 2 students and group 3 students. This suggests that the addition of "anchored" concept may not significantly extend students' knowledge reconstruction and extent of 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 “core” and “anchored” concepts relative to only providing “core” concepts. The students who were given both “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. Once again, as found in the foregoing paragraph, 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 “core” concept may facilitate the richness of knowledge frameworks, but even with the existence of the “core” concept, the “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” further illuminates the effect of the “anchored” concept.

Students in the third group (who were reminded of both “core” and “anchored” concepts before the interview) showed significantly more integrated knowledge frameworks than the first group of students (no conceptual hint), but the difference in this feature between the first group and the second group (only the “core” concept provided) was not statistically significant. This, again, suggests that the “core” concept, when appropriately coupled with the “anchored” concept, can help students develop broader, richer and more connected knowledge structures.

With respect to misconceptions, there were no significant differences among these groups. However, the students 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). A plausible interpretation for this finding is that these students may have tended to only state ideas that they felt were very accurate (perhaps, due to the traditional instructional strategies they commonly received). This finding was similar to that revealed 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.

It may be also helpful to re-examine the original data gathered from the second stage (that is, those **prior to** the exclusion of "core" and/or "anchored" concept(s)) to explore how often the clue concepts appeared in the flow map narrative, although during the interview, students were informed that they did not necessarily use the clue concepts in the interview replies. Table 2 shows this part of analysis.

(Insert Table 2 about here)

Table 2 revealed that the group 3 students used most the "core" and "anchored" concepts in the flow map interview (again, though they were eliminated for the analysis in Table 1), compared to other group students. Seventeen among the nineteen group 3 students (89.5%) recalled the "core" concept, and fourteen group 3 students (73.7%) uttered the "anchored" concept in the second stage of interview. Only about an half of group 1 students (52.6%) recalled the "core" concept and few of them (21.1%) uttered the "anchored" concept. As expected, many students (a total of fifteen) in group 2 (75%) recalled the "core" concept, but not so high proportion of students as that in the group 3 who could present their ideas through using the "anchored" concept (40% versus 73.7% for group 2 and group 3). The different percentage of the occurrence of these concepts by these groups (chi-square = 14.01, $p<0.001$ for the core concept, and chi-square = 56.92, $p<0.001$ for the anchored concept) can be evidence that the identified "core" and "anchored" concepts were being used to actively reconstruct knowledge during recall not merely a stimulus or general clue to help the process.

Discussion and educational implications

This study clearly showed that with the assistance of “core” and “anchored” concepts, students can profitably recall more extended knowledge, with greater richness and with higher connection than in the absence of this organizing information. The results in Table 1 among these three groups may also suggest the following. The "core" concept was found to have main impacts on the extent and richness of knowledge recall but possibly not on its connection, as the difference in the feature of connection between group 2 and group 1 was not significant. On the other hand, the "anchored" concept may have effects on the richness and connection of knowledge structure but not on its extent, since group 3 students and group 2 students did not show a difference with respect to extent of knowledge recalled. In sum, 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.

As described above, this study also showed strong 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 relevancy 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 way to probe students' "core" and "anchored" concepts in other science domains, such as motion, light, chemical reactions, and evolution.

For practical purposes, teachers can subsequently use the identified “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 effectively reconstruct what they have acquired more broadly within a subject domain.

One may question the merit of this approach based on the issue of scientific accuracy and relevancy 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 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 "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 conduct four-group comparisons to assess the role of "core" and "anchored" concepts. These four groups can be as follows:

1. Interview with the hint of the "core" concept as identified from students.
2. Interview with the hint of the "core" concept as identified from teachers.
3. Interview with the hint of both the "core" and "anchored" concepts as identified from students.
4. Interview with the hint of both the "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 1 and group 2 and those between group 3 and 4 can help educators clarify the effects of students' and teachers' "core" and "anchored" concepts on student knowledge recall.

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 is often oriented to achieving high grades but not necessarily to the development of an integrated understanding of the content. More research is necessary to examine this hypothesis. 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: Student knowledge recall two months after the treatment instruction

Conditions	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)	0.44 (0.13)	0.32 (0.58)
(2) core concept provided (n=20)	6.05 (1.93)	5.60 (1.98)	0.48 (0.06)	0.20 (0.52)
(3) Both core and anchored concepts provided (n=19)	6.00 (2.05)	7.16 (1.95)	0.55 (0.05)	0.16 (0.37)
F (ANOVA)	5.16**	15.89***	7.79**	0.51
Scheffe test	(2)>(1) (3)>(1)	(3)>(2)>(1)	(3)>(1)	

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

Table 2: The occurrence of "core" and "anchored" concepts among three groups in the second stage interview

	The occurrence of core concept (n, %)	The occurrence of anchored concept (n, %)
Group 1 (no concept provided, n=19)	10[a] (52.6%)	4 (21.1%)
Group 2 (core concept provided, n=20)	15 (75%)	8 (40%)
Group 3 (Both core and anchored concepts provided, n=19)	17 (89.5%)	14 (73.7%)
Chi-square[b]	14.01***	56.92***

*** p<.001

a: this indicates that ten among the 19 students recalled the core concept in the second stage of flow map interview

b: The (percentage) Chi-square test was conducted on the groups versus the percentage of occurrence and non-occurrence.

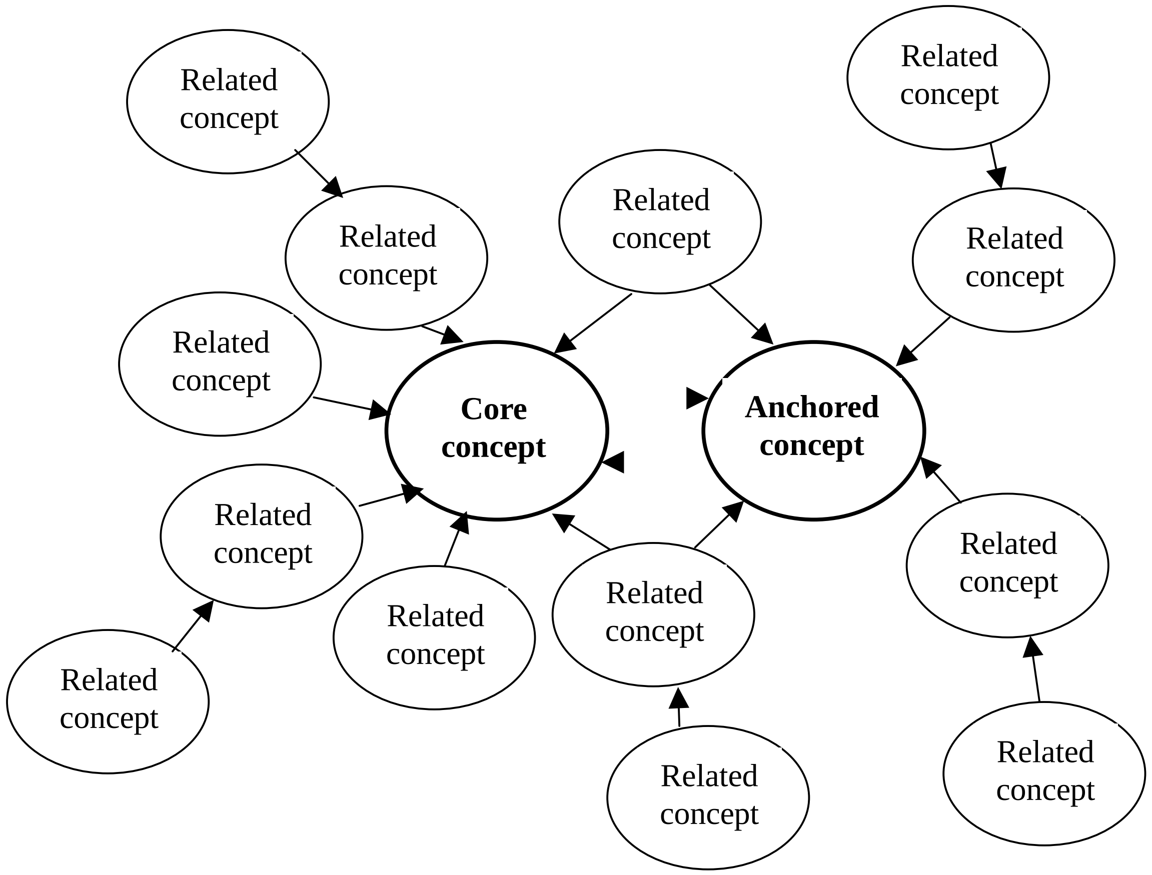

Figure 1: A model of knowledge structure

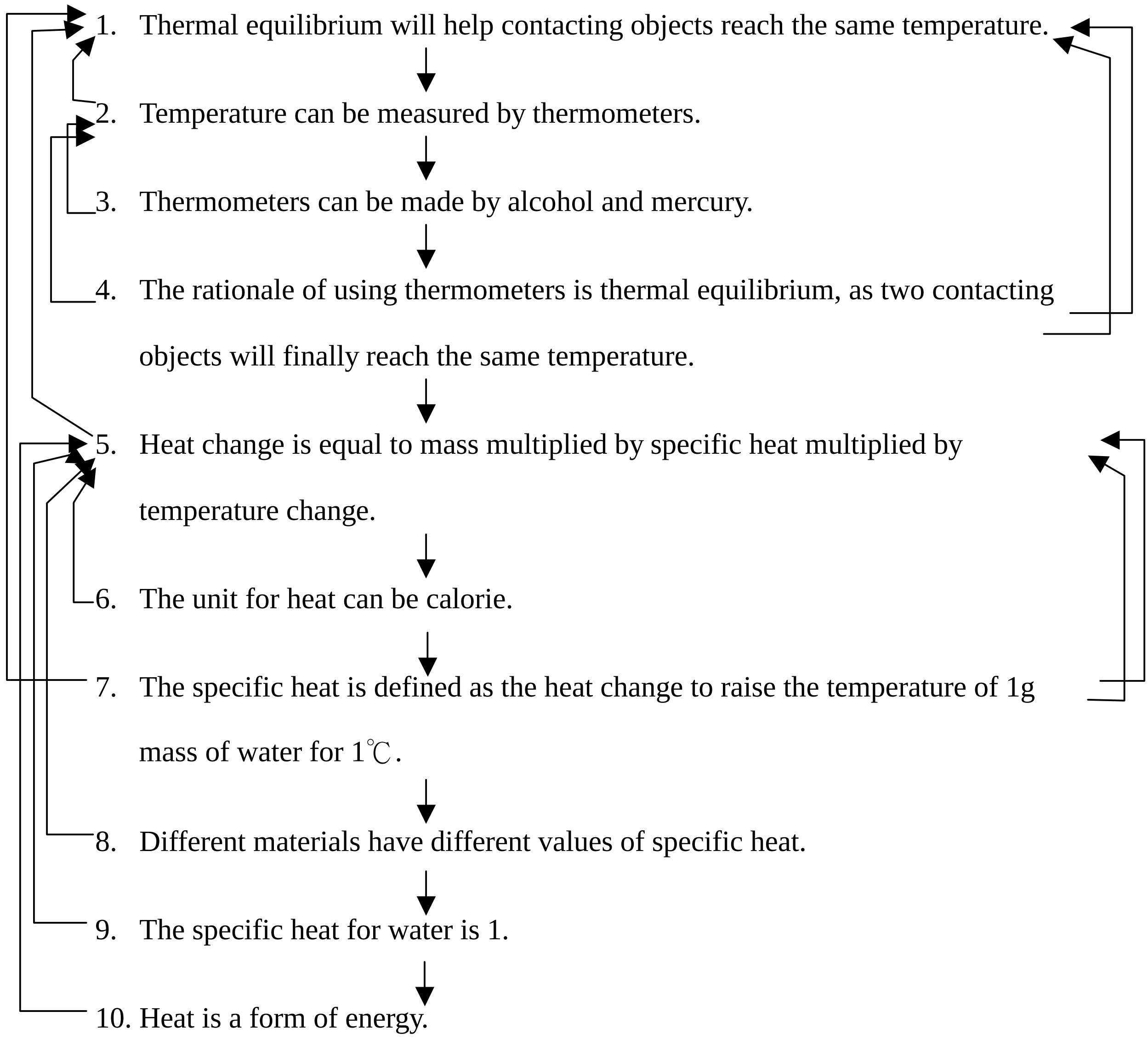

Figure 2: A student's (David, pseudonym) flow map elicited immediately after the treatment instruction

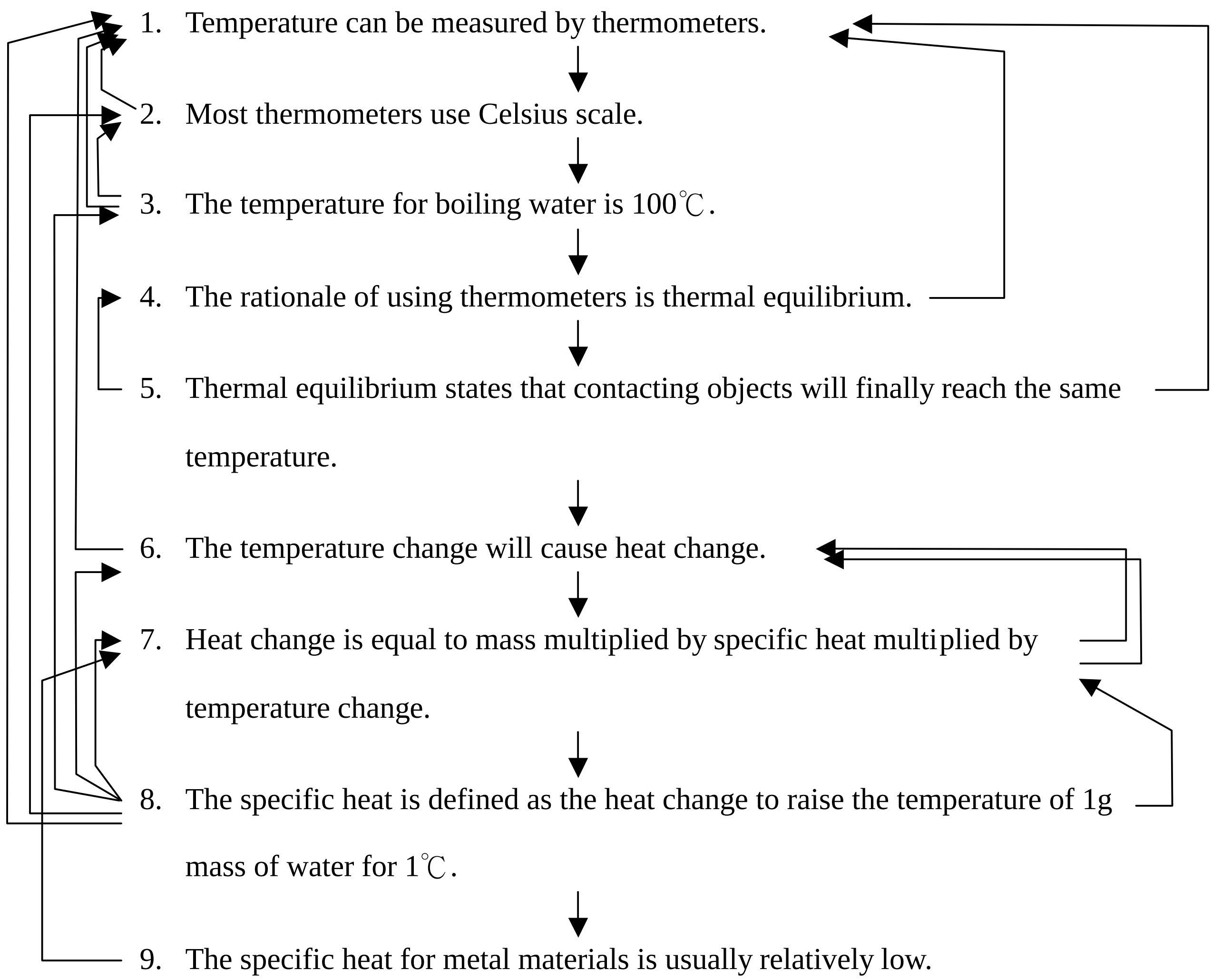

Figure 3: David's knowledge recall two months after the treatment instruction

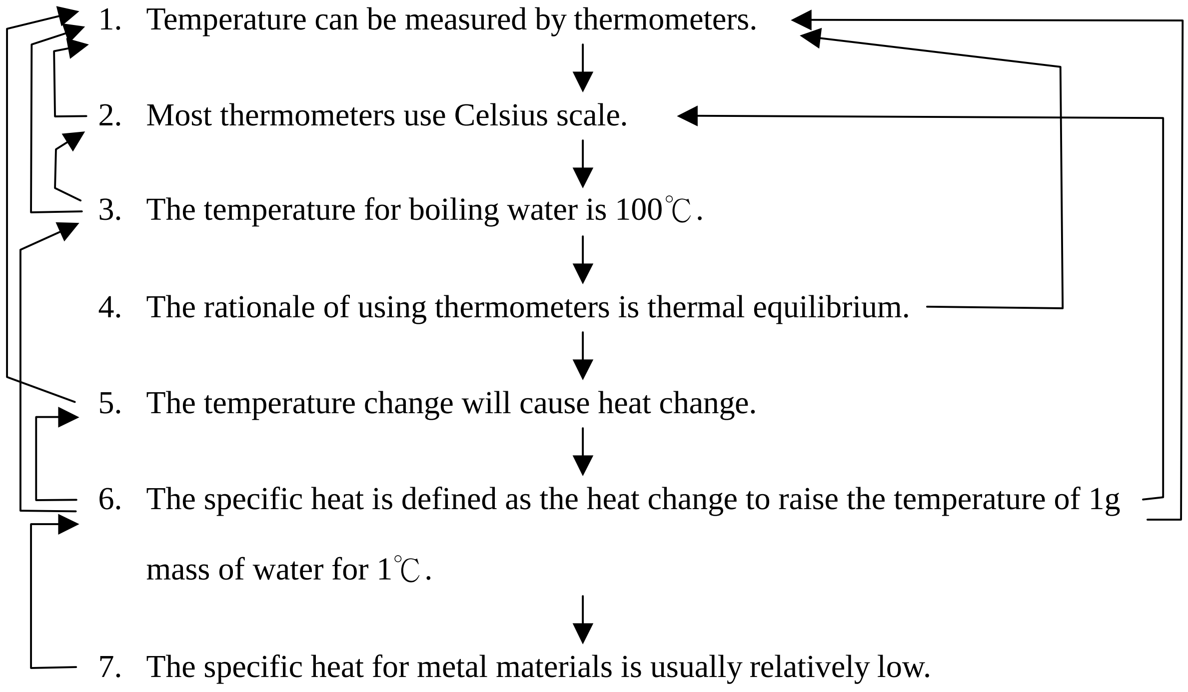

Figure 4: David's flow map after excluding the core and anchored concepts shown in the interview recall (as David was assigned to the third group which provided both the core and anchored concepts prior to the regular flow map interview)

Notes

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

[ii] 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.

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

[iv] 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).

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