Spiral teaching sequence and concept maps for facilitating conceptual reasoning of acceleration

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Contents

Abstract

This study involved a spiral teaching sequence on acceleration using four instructional strategies, namely: 1) preview of the core concepts, 2) a concept map, 3) conceptual questions, and 4) review of the solutions with a focus on the effective derivation routes and the prevalent difficulties that the students encountered. The participants were 402 grade 12 high school students. The results of this study reveal that the spiral teaching sequence, which introduced multiple stages of practicing and instructional explanation, was effective in terms of improving the students’ conceptual reasoning of acceleration. The review of the solutions was perceived by the participants as the most effective teaching strategy, followed by the concept map. We also found that conceptual questions involving a single concept were mostly easier to solve than those involving multiple concepts.

Keywords: spiral teaching sequence, concept map, acceleration

Introduction

Students' initial knowledge may influence their learning of physics concepts (Reiner et al., 2000), but teachers can teach and guide students to change their initial knowledge into expert subject knowledge (Leach & Scott, 1995). The concept of "acceleration" is fundamental to Newtonian Mechanics; however, the literature has reported numerous difficulties that students may encounter in understanding the meaning of "acceleration" (e.g., Rosenblatt & Heckler, 2011). With respect to students' difficulties grasping the details of scientific conceptions, the adoption of conceptual maps and a spiral teaching sequence is perceived as promising instructional scaffolding (Langbeheim et al., 2013, Lindstrøm & Sharma, 2009).

With the goal of helping students to learn the concepts of "acceleration," including instantaneous acceleration and average acceleration, this study adopted a spiral teaching sequence and a conceptual map to help students understand the meanings and various routes of reasoning the different terminologies of acceleration. The spiral teaching sequence consisted of four instructional strategies, i.e., 1) preview of the core concepts of acceleration, 2) depiction of a concept map, 3) practice of conceptual questions, and 4) instructional review of the solutions utilizing the concept map. The purposes of this study were to 1) evaluate the learning outcomes of the teaching intervention, 2) examine the pedagogical effect of the four instructional strategies, and 3) compare the difficulties of the concepts of acceleration regarding the complexity of derivation routes.

Learning difficulties related to Acceleration

Acceleration may be regarded as a basic concept in mechanics, but it is excessively abstract because the phenomena of acceleration may not always seem sensible (Singh, 2009). The source of the difficulties students face in learning the concept of acceleration may be misguided by their everyday life experience (Rosenblatt & Heckler, 2011). For example, they may feel that when an object is at rest, there is no force exerted on it (Sequeira & Leite, 1991), and may think that an object's natural state is to remain resting; therefore, for an object to move, it needs some force to keep acting on it. And the heavier an object that is falling, the greater the acceleration

(Bayraktar, 2009); or, they may think that when an object moves, it has a force parallel to its velocity (Martin-Blas et al., 2010).

On the other hand, from the perspective of social constructivism, the language, symbols, models, and rules of science are constructed by the scientific community, and learning science is a process of exchanging knowledge between the individual and the scientific community (Driver, 1994). The difficulty that many students encounter when learning physics is due to the confusion caused by the difference in the meaning of the language as it is used in physics and in daily life (Williams, 1999; Taibu, Rudge, & Schuster, 2015). Moreover, if students misunderstand a scientific concept, they may choose the inferencing method based on their beliefs (Gardner, 1984). For example, they may treat constant speed circular motion as constant velocity rectilinear motion, and ignore centripetal force because they tend to believe that constant speed means the state of equilibrium (Reif & Allen, 1992). Besides, students may consider the role of "acceleration" as always "speeding up," ignoring the effect of "slowing down" (Champagne, Gunstone, & Klopfer, 1983).

Formulas can illustrate the meanings of the physics concepts and the quantitative relations among related terminologies (Hewitt, 2001). However, physics formulas may not be able to express the causality and limitations of the associated conceptions. For example, students often ignore the fact that Newton's Second Law ($\Sigma\vec{F} = m\vec{a}$) is limited to being observed from an inertial reference frame (Lehavi & Galili, 2009). On the other hand, the community of scientists will choose to apply appropriate scientific knowledge in different situations (Leach & Scott, 2002); for example, students mistakenly think that when an object is in circular motion, its acceleration will always orient towards the center (Shaffer & McDermott, 2005), as they ignore the fact that, under the vertical circular motion, acceleration is actually a combination of tangential and centripetal components ($\vec{a} = \vec{a}_t + \vec{a}_c$) (Reif & Allen, 1992). Therefore, the difficulty of conceptual reasoning does not always come from misconceptions; it may come from a lack of understanding of the scientific discourse or the failure to identify the key features of the context of the questions.

Concept maps and cognitive load theory

In order to help students to construct a robust scientific conceptual framework, drawing concept maps is highly recommended in the literature (Lindstrøm & Sharma, 2009; Marée et al., 2013). It is suggested that teachers should explicitly draw concept maps for their students, which can help their conceptual comprehension and enhance their learning interest (Roth & Roychoudhury, 1993). Concept maps consisting of both terminology and formulas may offer comprehensive teaching scaffolding to help students understand and clarify the concepts and their related formulas (Chang, 2011).

Concept map design adheres to Sweller's (1988) cognitive load theory (Lindstrøm & Sharma, 2009). Because working memory is limited, using an effective representation and teaching process design can reduce extraneous cognitive load and increase germane cognitive load, thus improving students' learning effect (Paas & van Merrienboer, 1993). Because visual and verbal working memories are independent, using visual and aural learning modes to design teaching is preferable to relying on a single mode (Paivio, 1991). Visual representations can also strengthen the retention of the meaning of the written text (Peeck, 1993), improve problem solving ability, and promote the integration of new knowledge. However, there is a prerequisite that students have to have the ability to integrate multiple representations (Sweller et al., 1998).

Instructional Design

Bruner (1978) suggests that scientific concepts, such as acceleration, should be introduced as completely and early as possible to students, who should be allowed repeated practice in order to develop and redevelop their understanding as they become more intellectually mature and can grasp its substance. Bruner argues that the repeated exposure of the student to the specific topic may enhance a deep and more intuitive understanding of the concepts. The essence of a "spiral curriculum" is that the basic concepts are first introduced briefly, then the core concepts are reintroduced with increasing sophistication. The adoption of a spiral curriculum has been found to benefit students' conceptual evolution, both in terms of their conceptual comprehension and epistemological framing (Langbeheim et al., 2013). Besides, a spiral instructional sequence allows students to repeatedly revisit the ideas in different contexts in order to distinguish the differences among related scientific concepts, such as acceleration and velocity, force and impulse (Arons, 1991; Rosenblatt & Heckler, 2011).

Based on the formative assessment theory, Beatty et al. (2006) argued that conceptual questions can help students to explore, organize, integrate, and extend their conceptual understanding. Conceptual questions usually surpass calculating questions in terms of promoting understanding of concepts, allowing the students to better learn to probe the concepts. They are different from the summary assessment questions in traditional courses (Beatty et al., 2008). Contextualized questions will evoke students' dissatisfaction, leading to a change in their concepts (Scott, Asoko, & Leach, 2007). The literature has found a close link between the level of learning motivation and the learners' commitment to learning strategies, such as organization or rehearsal, which have been found to significantly influence their academic performance (e.g., Selçuk, 2010). If students are confident in their incorrect conceptions of physics, formative assessment is required to improve their cognitive and metacognitive learning strategies (Sağlam, 2010).

Methodology

The students participating in this study included three teams from two schools, where each team's students were divided into three groups. There was a total of 402 senior high school students (Grade 12; age 17-18 years), where team A was made up of three classes from one school, while Teams B and C came from another school, as shown in Table 1. All of the students were in the science stream and had completed studying the senior high acceleration content. Different physics teachers taught each class.

Table 1. Number of students per team for the three groups

	Team A (PR*=95%)	**Team B(PR*=88%)**	**Team C(PR*=88%)**
Group 1	42	31	29
Group 2	43	26	26
Group 3	148	27	30

*PR (percentile ratio) is based on the high school entrance examination scores

This study's teaching intervention design included a series of instructional guidance and formative assessment activities, echoing the notion presented in the literature (Langbeheim et al., 2013; Sağlam, 2010). The first and second groups' instructional procedure adopted a spiral design, which let the students repeatedly review the acceleration concepts. Each group's instructional procedure and content differed. The instructional design procedure is listed in Table 2 below. On the left of Table 2, the order and time of introducing the teaching materials to the students are listed, while on the right, the teaching materials introduced to each group are indicated with a "•" showing which particular forms of teaching scaffolding each group received.

Table 2. The teaching scaffolding for each of the three groups

Teaching scaffolding	**Duration**	**Group 1**	**Group 2**	**Group 3**
Preview	5 min	•*	•	
Concept map		•		

Test I	15 min	•	•	•
Review	10 min	•	•	
Test II	15 min	•	•	•

*The symbol "•" indicates the adopted teaching scaffolding of each group

With a focus on reasoning the concept of acceleration, the intervention teaching implemented in this study included four kinds of instructional tools/strategies: 1) preview of the acceleration concepts, 2) a concept map, 3) conceptual questions, and 4) review of the solutions with a focus on the appropriate derivation routes and the prevalent difficulties that the students encountered. They are explained as follows.

1) Preview: Introducing the preview of the acceleration concepts helps the students to recall the previously taught acceleration knowledge, and lets them better understand the scientific language. The preview for Group 1 in this study introduced the five formulas of acceleration and integrated the deduction of the five routes in the concept map. On the other hand, Group 2's preview only listed and explained the five formula routes, but did not introduce the concept map.

Acceleration derivation is introduced as follows:

- Average acceleration can be derived by the change in velocity, $\vec{a} = \frac{\Delta \vec{\upsilon}}{\Delta t}$;
- The change of velocity can include magnitude and direction; acceleration can be divided into tangential (a_t) and normal (a_c) components; $\vec{a} = \vec{a}_t + \vec{a}_c$, where $a_c = \frac{\upsilon^2}{r}$;
- The cause of acceleration is total force. According to Newton's Second Law ($\Sigma \vec{F} = m\vec{a}$), instantaneous acceleration can be derived from the instant total force, or vice versa.
- Newton's Law ($\Sigma \vec{F} = m\vec{a}$) is valid only when observers are limited to the inertial frames of reference. The concept of velocity is relative, but acceleration is absolute.
- For an object moving with constant acceleration in one dimension, we can express acceleration (a), displacement (S) and time (t) as $S = \frac{1}{2}at^2$.

2) A concept map: The concept map presents the ways of reasoning related to the concept of acceleration from the two topics of kinematics and Newton's laws (shown in Figure 1), combined into one formula diagram made up of five routes. When deducing concepts of acceleration, sometimes multiple routes need to be combined, and connection between kinematics and Newton's Laws may be required. The aim of the content design was to address the weakness of the traditional teaching materials

in which the introduction to acceleration often appears to be fragmentary and unrelated, and which also fails to explicitly elucidate the application limitations of each derivation.

For some rather simple questions, a single route, i.e., Routes 1~5 respectively, is enough to solve the problem (Figure 1). However, connections of multiple routes may be essential to successfully solve some complicated questions. Possible links of multiple routes to solve questions regarding acceleration are depicted in Figure 2. For example, Route 6 shows that students need to first select the inertial frame (avoiding observing at an accelerating frame) to observe the variation of velocity (Route 6a), and then determine the magnitude and direction of acceleration (Route 6b); Route 7 starts from drawing a free-force-diagram, determining the total force (Route 7a), then evaluating the tangential and radial components of acceleration respectively (Route 7b); Route 8 first derives acceleration from the object's displacement (Route 8a), then determines the total force from the acceleration (Route 8b). Questions which require multiple routes to derive the solution are normally more challenging to students than those requiring a single route. Explicitly drawing concept maps as scaffolding to help students deal with the complicated task is suggested by the literature (Chang, 2011; Lindstrøm & Sharma, 2009).

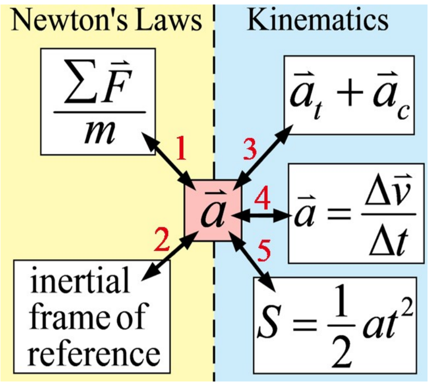

Figure 1. The concept map depicts single routes of reasoning acceleration

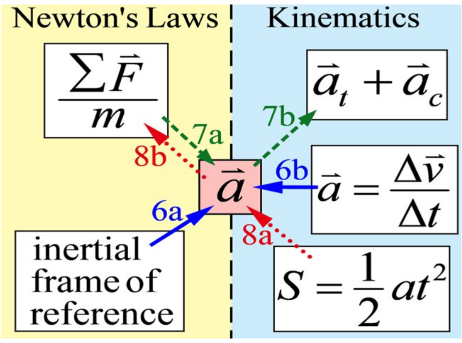

Figure 2. The concept map depicts multiple routes of reasoning acceleration

3) Conceptual questions: The design of the two tests of conceptual questions on acceleration emphasized concept clarification, and reduced the amount of complicated calculation. Moreover, in line with previous research, the level of difficulty of the test content suited the background of the students and was designed to highlight the acceleration difficulties identified in the literature, corresponding to the design idea of the acceleration concept map. After the students completed Test I, the teacher analyzed the deduction of questions in the concept map and integrated the review of the solutions. This was followed by Test II, to see the results. This adheres to the notion of formative assessment (Beatty et al., 2006; Sağlam, 2010). The format of the conceptual questions was single-answer multiple-choice.

4) Review: The review of the solutions involved discussion of the appropriate derivation routes and the prevalent difficulties the students encountered for each question. These explanations not only involved correct reasoning and solutions, but also included discussion of the commonly seen mistakes made by previous students who had taken the test, and the possible reasons for these mistakes. Each question’s choices were designed with reference to students’ acceleration difficulties identified in the literature. Moreover, the explanations could also link to the concept map in order to clarify the acceleration concepts and the multiple routes integrated into the concept map to carry out inferencing, reflecting the assertion of using concept maps to reduce cognitive load (Lindstrøm & Sharma, 2009).

After the completion of the course, 55 students from Group 1 and Group 2 of Team C completed the questionnaire. The survey design included three parts to allow for multi-dimensional points of view and in-depth understanding. The first part consisted of eight close-ended items using a 5-point Likert scale for the qualitative classification of the students’ level of satisfaction including cognition, affect, and metacognition. The Cronbach's α exceeded .85, indicating the reliability of the questionnaire. The second part required the students to list in order the four kinds of teaching scaffolding from the most to the least effective, while the third part consisted of open-ended questions; the students were invited to write down what they had learned as well as their teaching design suggestions, and to point out the strengths and weaknesses of the course. Finally, according to the previous quantitative and qualitative analyses, two students and one teacher were interviewed, with a focus on those questions requiring further investigation.

Both qualitative and quantitative analyses were performed, where the quantitative analysis was performed on the results of the conceptual questions and the first and second parts of the questionnaires, whereas the qualitative analysis included the third part of the questionnaire and the interviews. The data analysis was performed as follows: Regarding students’ performance on the conceptual questions, in order to account for the differences in students’ pre-instruction physics abilities between groups, students' performance on the conceptual questions was modified using their scores on the physics midterm examination at school. In particular, one group was selected as the benchmark group, and the average midterm score of each group was divided by the average midterm score of this benchmark group in order to obtain a correction factor for each group. Students' average scores on the conceptual questions were then multiplied by the corresponding correction factor in each group before any between-group comparison was made. Then, the correct ratio (%) of the conceptual questions was used to analyze the effect of the teaching intervention on each group in order to more deeply probe the influence of the teaching intervention. Using effect size can represent the degree of effect of an experiment (Savinainen & Scott, 2002). The formula for Cohen's d effect size is the difference between the average value of the two groups divided by the two groups' combined standard deviation, where the higher the value, the greater the result of the experiment (Cohen, 1988).

Following this, the concept questions were divided into kinematics and Newton's Law questions for comparative analysis. Comparative analysis was also applied to divide the concept questions into those which required integration of one or two concepts.

Results of Research

Student performance on the conceptual questions

Table 3. The correct ratio of Test Ⅰ and Test Ⅱ for the three groups of each team

	Group 1				**Group 2**				**Group 3**			
	A	B	C	avg	A	B	C	avg	A	B	C	avg
Test Ⅰ	42%	37%	38%	39%	41%	41%	24%	35%	42%	30%	24%	32%
Test Ⅰ	47%	47%	39%	44%	58%	54%	39%	50%	41%	32%	22%	32%

In Table 3, the average correct ratios of Group 3 (without any form of instructional intervention) for Test and Test were found to be very close, indicating that the degree of difficulty of Tests and was similar. In contrast, improvement from Test to Test was observed for both Group 1 and Group 2, which implies the benefit of reviewing the solutions and principles of Test . Meanwhile, the improvement from Test to Test of Group 2 appeared to be larger than that of Group 1 for all teams, which suggests that providing the concept map may have been unhelpful, or even redundant.

In order to evaluate the extent of the students’ improvement due to receiving the different types of scaffolding, such as preview and review, we adopted the effect size tool. The results are listed in Table 4.

Table 4. Effect size between Test Ⅰ and Test Ⅱ

	Team A	**Team B**	**Team C**
Group 1	0.21*	0.59**	0.05
Group 2	0.78**	0.76**	0.93***
Group 3	-0.02	0.16	-0.13

d>0.2 small*， >0.5 medium**， >0.8 large effect***

Table 4 shows the effect size of the improvement between Test and Test for each group in all teams. The effect size for Group 1 and Group 2 ranges from 0.21 (small effect) to 0.93 (large effect) except for Group 1 of Team C. However, with no preview or review, Group 3 of the three teams had no effect between Test and Test . Therefore, providing spiral instructional guidance was found to be essential to facilitating improvement in learning acceleration.

Table 5. The effect sizes of different teams in Test Ⅰ

	Team A	**Team B**	**Team C**
Groups 1→3	0.01	0.41*	0.77**
Groups 2→3	-0.02	0.7**	-0.02

*small effect， **medium effect

When evaluating the outcomes of providing a preview, we compared how students in Groups 1 and 2 performed on Test compared to Group 3, which received no preview. Table 5 shows that in Team B, students who received the preview (Groups 1 & 2) outperformed those who did not (Group 3). However, no difference on Test was found among the three groups in Team A. The students of Team A (PR=95%) had a strong academic background. Therefore, preview of the acceleration concepts may not have been beneficial for these students.

The situation of Team C appears to be complicated. With the teaching strategy of the preview, Group 1 appeared to outperform Group 3, whereas Group 2 did not show any advantage from the preview. The discrepancy between Group 1 and Group 2 may be due to the students’ attitudes toward the task. According to the teacher's response, in

Team C, Group 1 may have been more motivated to take part in the activity than Group 2; this motivation difference may have led to the discrepant performance in Test □. In sum, we found that three out of the six groups did not benefit from the teaching strategy of the preview. Possible reasons may be that (1) it was unnecessary due to the students' strong background (i.e., Team A) or (2) the students were indifferent due to their low motivation (i.e., Group 2 of Team C). Therefore, the expected outcomes of the preview may not have been achieved if the students were not willing to learn or if they did not perceive the instructional guidance as necessary.

Since the only difference in the instructional design provided for Group 1 and Group 2 was the concept map before Test I, comparison of the two groups' performance in Test I was undertaken in order to examine the benefit of the concept map. Table 5 shows that the benefits of the concept map appeared only for Team C, because the effect size of Groups 1→3 is greater than that for Groups 2→3, and they are significantly effective. However, the scaffolding of the concept map seemed not to be beneficial for Teams A and B.

According to the concept map (Figure 1), reasoning the questions of acceleration may involve the five possible routes. We classified the required routes corresponding to the concept map for each question, and the correct ratios (%) of questions in Tests and involving a single route and those involving multiple routes are shown in Table 6.

Table 6. Correct percentages for single-route and multiple-route questions

Reasoning routes	**Group 1**		**Group 2**		**Group 3**		
	Test Ⅰ	Test Ⅱ	Test Ⅰ	Test Ⅱ	Test Ⅰ	Test Ⅱ	average
Single route	43%	51%	38%	57%	39%	42%	45%
Multiple routes	34%	48%	39%	55%	33%	35%	41%

Comparing the three groups' performance on the two tests, five out of the six data showed that those problems requiring multiple routes were more difficult than those involving a single route. Since problems requiring multiple routes are more complex than those requiring a single route, it is possible that this complexity increases the difficulty. In addition, for students, the questions of multiple routes appearing to be more difficult may be not only due to the complexity, but also to their awareness of and ability to connect different concepts from different topics.

Students' evaluation of the teaching design

The students of groups 1 & 2 of team C filled in a questionnaire survey, and the results of the closed questions are shown in Table 7. Among the five levels of agreement, the percentages of highly agree and those of agree were summed to give the agree percentage; meanwhile the disagree percentage is the sum of the disagree and highly disagree percentages, as shown in Table 7.

Table 7. The Students' evaluation of the outcome of the intervention teaching

	Satisfied with achievement	**Enhanced learning interest**	**Stimulated thinking**	**Understood solving skills**	**Promoted confidence**	**Enhanced conceptual comprehension**	**Can apply in the future**	**Informative**
Agree	71%(3)	43%	64%	55%	29%	75%(1)	72% (2)	59%
Disagree	0%	4%	2%	2%	20%	2%	0%	4%

Table 7 shows that the two groups' evaluation of the learning unit appears to be fairly consistent. The top three that received the highest agreement among the eight items were exactly the same for the two groups, namely 1) enhanced conceptual comprehension, 2) can apply to problem solving in the future, and 3) satisfied with learning achievement. Meanwhile, the aspect of promoted confidence in learning physics was found to receive the least agreement in both groups, implying that promoting confidence may not be an easy task to fulfill with such a short-term learning experience.

Taken together, the results of the open form questionnaire survey also showed the students' appraisal that the intervention left a deep impression on them. Many students noted that the question design stimulated their thinking and enhanced their conceptual comprehension. However, a few students expressed their feeling of frustration when participating in the learning. For example, "Although the questions appear to be simple, they can easily identify our misunderstanding and prevalent pitfalls." "The questions are very different from what we have usually practiced. They are very interesting and provoke thinking. I feel [they are] informative." "Physics is truly tough; the ideas are just like what the aliens invented."

The last quotation actually reflects the key notion of social constructivism, highlighting the essential role of providing instructional scaffolding for students to comprehend physics conceptions, which are initiated and gradually formulated by the scientific community (Driver, 1994).

In addition, the questionnaire survey asked the students to rate the most beneficial among the four instructional scaffoldings, that is, the preview, concept map, conceptual questions, and review, the results of which are listed in Table 8.

Table 8. The selection of the most beneficial instructional strategies

	Preview	Concept map	Conceptual test questions	Review
Most beneficial	17%(3)	23%(2)	17%(3)	43%(1)

More than 40% of the students rated the review of the tests as the most effective scaffolding. One merit of the review was that it provided not only the correct solutions, but also the prevalent pitfalls that the students may have encountered. Even the way of understanding a given problem (e.g., by identifying the key features) and the way to reason through the problem (e.g., by performing a component analysis) were explicitly and thoroughly elaborated in the review. The concept map was only ranked as the second most effective scaffolding. Since concept maps are not commonly adopted in physics classes in Taiwan, the scaffolding may require more guidance from the instructor in order to fulfill its expected benefits.

In short, the analysis of the qualitative data showed that the teaching interventions which were effective for student learning acceleration and the students' preferences for intervention scaffoldings were not exactly the same.

Discussion

In this study, the performances of the experimental groups (Groups 1 & 2) in Test I and Test II were found to be better than those of the control group (Group 3). Meanwhile, the performance of Groups 1 and 2 in Test II surpassed that of Test I (see Table 3). The results indicate the learning outcomes obtained by the spiral teaching intervention. The students’ self-report opinions also pointed out that the conceptual question testing and the spiral teaching intervention of explaining and addressing prevalent difficulties was helpful for constructing concepts, reflecting the assertion of formative assessment (Beatty et al., 2006). Besides, the improvement in the experimental groups’ performance from Test I to Test II was obvious, which may reflect the pedagogical demand of providing a sophisticated review of the solutions of Test I and pointing out prevalent pitfalls.

However, from a comparison of Test I (in Table 5) of the experimental groups and the control group, it was found that for those students with a strong knowledge background (Team A) or with low motivation (Group 2 of Team C), providing them with a concept map seemed not to be beneficial, since they may either have confidence in their own background of the topic or be unwilling to learn. The influential factors of metacognition and motivation on learning outcomes is consistent with the literature (e.g., Amadieu et al., 2009; Selçuk, 2010; Sağlam, 2010).

With respect to the complexity of the questions, those involving one route are easier to solve than those involving two. If the basic concepts are appropriately applied, many problems can be easily solved. Physics requires both analysis and synthesis abilities (Tobias & Hake, 1988). For the analysis, we found that conceptual questions which involved one concept were mostly easier to solve than those involving two (see Table 6). The students' ability to understand and apply the formulas, as well as the amount of cognitive load created for the students, all influenced the outcomes. As shown in Table 6, the correct ratio of almost all groups for Test I and Test II showed improvement, showing the demand of sophisticated review and spiral teaching sequence in order to help clarify the concepts.

From the students' questionnaire survey, the teaching intervention results are discussed as follows: (1) detailed review of the solutions provided the most obvious help to the students, as shown in Table 4. The students felt interested in the conceptual questions, which differed from those they usually see in school, thus stimulating their thinking; (2) however, preview of the concepts regarding acceleration was of limited help to the students (see Table 5); and (3) the concept map also failed to provide the anticipated teaching effect (based on Table 5). It is possible that the students were not familiar with the pedagogical tool of the concept map.

Several suggestions are provided based on the students' responses. When introducing the novel tool of concept maps, teachers need to provide more guidance in order to allow the students to comprehend the meanings and purposes. This is consistent with the arguments put forward by Novak (1998) and Roth and Roychoudhury (1993). In their questionnaire responses, the students said that they could understand the concept map, but they still could not use it to solve the problems. This also shows the importance of the spirally repeated practice to help the students gradually comprehend and be able to use concept maps, echoing the plea of Langbeheim et al. (2013). Most of the students may remember the acceleration formulas very well, but they encounter difficulty adopting them effectively to solve problems. Moreover, based on cognitive load theory, the initiation of the concept map intended to reduce the students' cognitive load and to help them integrate and link the associated concepts (Lindstrøm & Sharma, 2009). However, if a concept map is a novel representation for the students, they may not be able to understand its meaning or utilize it as a reasoning tool (Seufert, 2003).

It is also possible to raise the cognitive load, leading to a decrease in student acceptance and satisfaction (Hwang, Kuo, Chen, & Ho, 2014). Using representations to reduce cognitive load may not always be effective for students (Sweller et al., 1998).

Conclusion

In sum, this study has revealed the serious difficulty that the students encountered when conceptually reasoning acceleration. In order to help students gradually grasp the abstract and counterintuitive scientific conceptions, instructional scaffolding of concept maps and a spiral teaching sequence was found to be beneficial. However, among the four instructional strategies, the pedagogical benefits of "preview the core concepts" were not appreciated by some of the participants. Therefore, raising the students' awareness of their conceptual difficulties and promoting their motivation to learn are essential before implementing any teaching interventions.

Several suggestions are made regarding the teaching design. (1) At the beginning of the teaching intervention, a brief concept test can be administered before the strategy of "previewing the core concepts," as it may promote the participants' awareness of the conceptual pitfalls and stimulate their learning motivation. (2) Right after introducing any physics principles or defining formulas, providing conceptual questions for students to practice is crucial in order to allow them to grasp the meanings and usages of the introduced physics concepts; (3) When initiating a novel instructional tool, such as a concept map, the meaning and value of the new tool need to be highlighted; and (4) The spiral teaching sequence, which introduced multiple stages of testing and explanation, received positive appraisal from many students, and was also shown to be beneficial by the objective tests. Therefore, in order to comprehend the insights of physics conceptions and to gradually gain acquaintance with effectively using the concepts, multiple tests (learning practice) and reviews (instructional guidance) are required.

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