Students' performance awareness, motivational orientations and learning strategies in a problem-based electromagnetism course

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Contents

Abstract

This study aims to explore problem-based learning (PBL) in conjunction with students' confidence in the basic ideas of electromagnetism and their motivational orientations and learning strategies. The 78 first-year geology and geophysics students followed a three-week PBL instruction in electromagnetism. The students' confidence was assessed through a diagnostic test on electromagnetism. The Motivated Strategies for Learning Questionnaire (MSLQ) was used to identify students' motivational orientations and learning strategies. The results indicate that many students were confident in incorrect answers, and had inadequate use of cognitive and metacognitive learning strategies. Providing students with some formative assessments during the PBL process could help them to better judge their understanding, which, in turn, would result in better student calibration (i.e., students would be more confident in their correct answers, and less confident in their incorrect answers) in electromagnetism. Helping the first-year PBL students to obtain effective cognitive and metacognitive learning strategies early in the academic year could improve their understanding of physics concepts.

Keywords: Problem-based learning, student confidence, electromagnetism teaching, motivational orientations, learning strategies

Introduction

Research in science education has revealed that students in science courses have many alternative ideas of the basic ideas of science (Driver, Guesne, & Tiberghien, 1985; Driver, Squires, Rushworth, & Wood-Robinson, 1994). While we can find many research reports on students' understanding of the basic mechanics ideas in physics, research on students' ideas in electromagnetism is scarce (Duit, 2009). In one of these studies based upon 214 college students (ages 19-20), Maloney (1985) found that many students believed that magnetic poles were charged, with the north pole being positively charged. He reported that classroom instruction had little effect on changing these ideas. Maloney, O'Kuma, Hieggelke and Van Heuvelen (2001) report that some introductory physics students in colleges and universities use the electric effects of electrical charges when they reason about the magnetic effects of currents; they think that the wire with the larger current exerts a larger force on the other wire in the context of two long, straight current-carrying wires parallel to each other. They found that some students believed that stationary charges experienced a force in a magnetic field, and many had learning difficulties on the topic of electromagnetic induction. Albe, Venturini and Lascours (2001) found that the 64 physical science undergraduates in their study had difficulties understanding the characteristics of a magnetic field, and that the magnetic flux formula was not applied correctly in simple cases. Galili (1995) found that many high school students thought that Newton's third law was not applicable to electromagnetism. Bagno and Eylon (1997) report that misconceptions in one physics topic, such as understanding of speed and velocity in mechanics, may cause difficulties in students' understanding of electromagnetism. They claim that the statements like "induced current is such as to oppose the change of magnetic flux that produced it" might be misinterpreted as the induced current is in the opposite direction of the magnetic field that produced the change of magnetic flux. Loftus (1996) suggests that students' explanations of electromagnetic induction demonstrations with an electromagnet may be explained by a common structure; including an agent such as an electromagnet, an object such as ring, bulb or water, and one-way routes between them such as force, charge, heat or light (Andersson, 1986). Saglam and Millar (2006) found that many junior and senior level high school students had misunderstandings and inconsistencies that suggested they did not have a coherent framework of ideas about electromagnetism. Common student errors consisted of "confusing electric and magnetic field effects, seeing field lines as indicating a 'flow,' using cause-effect reasoning in situations where it does not apply and dealing with effects associated with the rate of change of a variable" (p. 543). In general, the literature suggests that students have a poor understanding of the basic ideas of electromagnetism. It appears that students need effective instructional designs to grasp the basic ideas of electromagnetism.

Problem-based learning (PBL) is one of the student-centred instructional approaches used for effective instruction in science education (Chin & Chia, 2004a; Chin & Chia, 2004b; Chin & Chia, 2006; Lee & Bae, 2008; Senocak, Taskesenligil, & Sozbilir, 2007; Soderberg & Price, 2003; Tarhan, Ayar-Kayali, Urek, & Acar, 2008). The approach assumes that knowledge is actively constructed by learners in a small collaborative group. Barrows and Tamblyn (1980) explain that "problem-based learning is the learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process!" (p. 1). The problems presented in PBL scenarios do not have a single correct solution, i.e., they are ill-structured. The students first summarise the information given in the scenario and state the problem. Then, they generate some hypotheses regarding possible solutions. Next, they identify the learning issues which are the knowledge deficiencies that should be researched during their self-directed learning. After the self-directed learning process, the students apply their new knowledge to the problem and evaluate the hypotheses they generated. Lastly, the students reflect on the knowledge gained. The role of the teacher (i.e., the tutor) is to help students learn the cognitive skills needed for problem-solving and collaboration (Evensen & Hmelo, 2000; Hmelo-Silver, 2004). Although there are examples of studies using the PBL approach in biology and chemistry education, the use of the approach in physics education is not very common. Therefore, there is a need to explore the effectiveness of the PBL approach in teaching physics concepts. Problem solving skills necessary for the resolution of ill-structured problems in the PBL approach include cognitive, metacognitive and motivational strategies. Therefore, successful problem solving involves some domain-specific knowledge, the control and monitor of cognitive processes and students' feelings and interest in the problem (Mayer, 1998). It appears that students' problem-solving skills need to be considered in interpreting the outcomes of the PBL approach (For example, see Anderson & Nashon, 2007, for the effect of physics students' metacognition on the development of their conceptual understanding of kinematics).

Although there are many research methods such as concept mapping, interviews about instances and events, interviews about concepts and drawings developed to elicit these alternative ways of reasoning (White & Gunstone, 1992), written diagnostic questions have been the main way of collecting data from a large sample in a relatively short amount of time. A diagnostic question is a question that analyses an individual's performance in order to locate its strengths or weaknesses in the subject tested. Many written diagnostic tests such as the Force Concept Inventory (Hestenes, Wells, & Swackhamer, 1992) and the Conceptual Survey of Electricity and Magnetism (Maloney, et al., 2001) include multiple-choice questions with five options. However, some researchers point to the value of collecting data regarding students' confidence on diagnostic questions to gain more information about students' cognition (Bowen & Roth, 1999; Caleon & Subramaniam, 2010; Hasan, Bagayoko, & Kelley, 1999; Odom & Barrow, 2007; Planinic, Boone, Krsnik, & Beilfuss, 2006; Potgieter, Malatje, Gaigher, & Venter, 2009). For example, students who are confident of an incorrect answer are more likely to hold onto their incorrect conception even if they are provided with some evidence indicating that their thinking is not scientifically correct (Reif & Allen, 1992).

The literature reviewed suggests that there is a need for research into students' understanding of electromagnetism in the PBL context. Therefore, this study aims to explore PBL students' understanding of the basic ideas of electromagnetism. The research questions that guided the investigation are: (1) how confident are PBL students in their knowledge of the fundamental ideas of electromagnetism?; (2) what are the motivational orientations and learning strategies used by the PBL method on physics students?; (3) is PBL in students' performance on the topic of electromagnetism related to their motivational orientations and learning strategies?

Method

Sample

The sample of this study consisted of 78 first-year geology and geophysics students in the Faculty of Engineering in a large state university in western Turkey. Of these students, 20 were female and 58 were male (with a mean age of 20.9 with a standard deviation of 1.3). It was the only Faculty of Engineering that adopted a PBL curriculum in Turkey, and the geology and geophysics departments played an important role in the administration of the curriculum. The curriculum integrated the chemistry, mathematics and physics topics in two or three-week scenarios. The three-week scenario dealing with electromagnetism was the last one in the spring term. Therefore, the students were familiar with the instructional model. We can expect these students to be well-adapted to the needs of PBL. During the administration of the diagnostic electromagnetism test, the students were asked a question, rated on a ten-point scale, if they believed PBL was an effective approach to teach mechanics, electricity, magnetism, etc. The students selected a ten if the statement was very true to them and one if the statement was not at all true to them. The mean rating for the question was 5.6 with a standard deviation of 2.6. After at least one-year of PBL instruction, it seems that many students believed that PBL was not a very effective way of teaching physics topics.

The PBL scenario

The scenario used the Indiana University Cyclotron Facility as a context to teach the topics of electromagnetism including the magnetic field, due to a long straight current-carrying wire, magnetic force on electric charges, long straight current-carrying wires in a uniform magnetic field and electromagnetic induction. The facility is a multidisciplinary laboratory performing research and development in the areas of accelerator physics, nuclear physics, materials science and the medical applications of accelerators. One of the services provided by the facility is proton therapy, which uses a beam of protons to irradiate diseased tissue, most often in the treatment of cancer. It is a precise form of radiation treatment that minimizes damage to healthy tissue and surrounding organs (Midwest Proton Radiotherapy Institute, n.d.). The scenario, in which I was one of the co-authors, first gives some background information about the facility and states that for some reason the cyclotron stopped providing the proton beam necessary for the treatment. The students were required to state the problem, summarise the information given in the scenario, develop a hypothesis regarding the cause of the problem, and identify the learning issues to test their hypothesis. At the end of the scenario the students had an opportunity to solve some qualitative and quantitative problems in order to reinforce the electromagnetism ideas they learned in the scenario. Then, they were asked to create a concept map to improve the integration of these electromagnetism ideas with each other. The three-week scenario was supported by some direct instruction in electromagnetism after each PBL tutorial. During the administration of the diagnostic electromagnetism test, the students were asked questions, based on a ten-point scale, relating to whether they believed the scenario was effective in teaching electromagnetism. The mean rating for the question was 6.4 with a standard deviation of 2.3, suggesting that it was seen as a somewhat effective scenario by many students. The tutors in the PBL tutorials were experienced in the PBL approach and their area of study was either geology or geophysics. Therefore, they had limited knowledge of the basic ideas of electromagnetism.

Research instruments

The study included two research instruments, one for diagnosing students' understanding of electromagnetism and another for assessing students' motivational orientations and their use of different learning strategies for physics. The diagnostic magnetism test consisted of 16 five-option, multiple-choice questions drawn from the Conceptual Survey of Electricity and Magnetism (Maloney, et al., 2001), and Diagnostic Test of Students' Ideas in Electromagnetism (Saglam & Millar, 2004). Of these 16 questions, two were about magnetic field due to current-carrying wire (Questions 2 and 10 in Table I), six were about magnetic force on electric charge (Questions 1, 5, 6, 7, 8 and 16 in Table I), three were about magnetic force on current-carrying wire (Questions 4, 14 and 15 in Table I), and five were about electromagnetic induction (Questions 3, 9, 11, 12 and 13 in Table I). The questions were translated into Turkish by the author of this article who had a satisfactory level of English. The questions were piloted with some civil engineering students, and necessary changes were made to improve clarity. The instrument collected information about the extent to which students believed that the PBL approach and the scenario used in the study were effective in teaching electromagnetism, as well as some demographic information. To prevent students from guessing and to reveal the misconceptions held by students, the students were given 100 points to divide between the answers for each question. If they were sure that one answer was correct, they gave it 100 points. If they could not decide between the answers, they were allowed to divide 100 points between the answers as they wished. If they had no idea about the question, they were told to divide the points equally between all the answers. In this study the information obtained from students' use of the 100 points in each question was used to investigate students' confidence in the basic ideas of electromagnetism.

The instrument used to assess students' motivational orientations and their use of different learning strategies for physics was the Motivated Strategies for Learning Questionnaire (MSLQ) (Pintrich, Smith, Garcia, & McKeachie, 1991). The instrument is a self-reported, Likert-scaled instrument developed for college students. The motivation scales include three main components: (1) value components (intrinsic and extrinsic goal orientation, and task value); (2) expectancy components (control beliefs about learning, and self-efficacy): and (3) affective components (test anxiety). The learning strategies scales also consist of three components: (1) cognitive strategies components (rehearsal, elaboration, organization, and critical thinking); (2) metacognitive strategies components (planning, monitoring, and regulating strategies); and (3) resource management strategies components (managing time and study environment, effort management, peer learning, and help-seeking). Pintrich, Smith, Garcia and McKeachie (1993) report that the scale reliabilities of the MSLQ are robust, and it has a good factor structure. Buyukozturk, Akgun, Ozkahveci and Demirel (2004) adapted the MSLQ to Turkish. They report that "the Turkish version of the MSLQ can be utilized in experimental research to examine effects of various methods and applications, considering motivation and learning strategies. It can be also used in assessing to what extent students have motivation and use learning strategies at various educational institutions" (p. 235). The students were reminded that they should consider the physics content of the PBL scenario used in the study when they were responding to the MSLQ items.

Results and Discussion

The results of the study will be presented in five sections. The first section is about overall performance of the sample in the diagnostic test. The next section deals with the students' confidence in the electromagnetism questions. The third section considers the motivational orientations of the PBL students. The fourth section is about the learning strategies used by the PBL students. The final section is concerned with the relationships between the PBL students' performance in electromagnetism and their motivational orientations and learning strategies.

Overall performance in the diagnostic test of electromagnetism

The scores for each electromagnetism item were correlated with the relevant total scores to identify the items that were providing unexpected contribution to the total scores. All items except one correlated positively with the total scores at least at the 5% level. So, in general, the items were expectedly contributing to the achievement scores. However, question 1, which was about the force on a stationary charge in a uniform magnetic field, did not correlate statistically significantly with the total scores. On this question, many students confused electric effects on a stationary charge with magnetic effects, and they were confident of their incorrect answers (see Table I). The mean achievement score was 5.5 out of 16 with a standard deviation of 3.0, suggesting that the students found the test quite difficult. The internal reliability of the test was investigated by calculating the KR-20 reliability coefficient. In the calculation, a student who gave at least 50 points to the correct answer got the question right. The test had a KR-20 value of 0.67, suggesting that the test items were reliable measures of the understanding of electromagnetism.

***Table I**. Students' confidence in the basic ideas of electromagnetism.*

	Confidence									
	Confident right		Non confident right		I do not know		Non confident wrong		Confident wrong	
Question	***f***	**%**	***f***	**%**	***f***	**%**	***f***	**%**	***f***	**%**
1	*7*	9.0	*12*	15.4	*7*	9.0	*26*	33.3	*26*	33.3
2	*33*	42.3	*6*	7.7	*2*	2.6	*10*	12.8	*27*	34.6
3	*9*	11.5	*6*	7.7	*8*	10.3	*13*	16.7	*42*	53.8
4	*11*	14.1	*11*	14.1	*3*	3.8	*17*	21.8	*36*	46.2
5	*29*	37.2	*8*	10.3	*7*	9.0	*13*	16.7	*21*	26.9
6	*23*	29.5	*10*	12.8	*6*	7.7	*20*	25.6	*19*	24.4
7	*33*	42.3	*12*	15.4	*9*	11.5	*2*	2.6	*22*	28.2
8	*10*	12.8	*18*	23.1	*10*	12.8	*12*	15.4	*28*	35.9
9	*12*	15.4	*25*	32.1	*5*	6.4	*10*	12.8	*26*	33.3
10	*33*	42.3	*12*	15.4	*5*	6.4	*3*	3.8	*25*	32.1
11	*14*	17.9	*17*	21.8	*8*	10.3	*6*	7.7	*33*	42.3
12	*17*	21.8	*20*	25.6	*8*	10.3	*5*	6.4	*28*	35.9
13	*3*	3.8	*14*	17.9	*9*	11.5	*15*	19.2	*37*	47.4
14	*40*	51.3	*10*	12.8	*10*	12.8	*5*	6.4	*13*	16.7
15	*28*	35.9	*15*	19.2	*7*	9.0	*2*	2.6	*26*	33.3
16	*9*	11.5	*18*	23.1	*13*	16.7	*9*	11.5	*29*	37.2
Total	*311*		*214*		*117*		*168*		*438*	

Note: f is for frequency, and %, for percentage.

PBL students' confidence

Table I presents students' confidence in each electromagnetism question. In the table, a non-confident response occurred when students were not confident in their answer, and so divided 100 points between at least two options. The 'non-confident right' category is for non-confident responses which include the correct answer to the questions. Likewise, the 'non-confident wrong' category is for non-confident responses, which do not include the correct answer to the questions. A student was categorized as a confident right when s/he gave 100 points to a correct answer, and categorized as a confident wrong when s/he gave 100 points to an incorrect answer.

A noticeable finding from Table I is that about half of the non-confident responses (17.1% of all responses) were non-confident right, indicating that many students were in a transition state, and the correct and incorrect electromagnetism ideas existed in their minds together. The correct answers were given at least 50 points in about half of the non-confident right responses. Therefore, the students who provided a non-confident right response may benefit more from a conceptual change intervention than the students who did not use the correct idea when reasoning since they are more likely to question their knowledge when they are confronted with conflicting evidence. The fact that 60.0% of the responses were confident in their answer suggests that the students in the sample were inclined to be confident in their answers to the electromagnetism questions. However, 35.1% of the responses were confident wrong (i.e., overconfidence), suggesting that many students did not know that the answers they provided were incorrect. We can expect these students to hold onto their incorrect ideas even if they are faced with conflicting evidence. These students also are not likely to question their existing knowledge/beliefs about the basic ideas of electromagnetism.

The motivational orientations of the PBL students

Descriptive statistics of the motivation scales of the MSLQ is presented in Table II. The Cronbach's alpha internal reliability coefficients of the scales are similar to the ones obtained by Buyukozturk, et al., (2004). The values of the coefficients suggest that the scales are reliable measures of the PBL students' motivational orientations for physics. The first three scales in Table II are the value components of the motivation scales. The means of these scales are about one point above the mid-point of four, suggesting that the students had high interest in physics after being taught with the PBL approach for a year. However, we would expect the geology and geophysics students to be more interested in physics since they will need considerable physics knowledge to better understand the topics in geology and geophysics.

Table II. *Descriptive statistics of the motivation scales of the MSLQ (n= 78).*

Sub-scale	Number of items	Mean	Standard deviation	Cronbach's Alpha
Intrinsic goal orientation	4	5.15	1.04	0.66
Extrinsic goal orientation	4	5.11	1.31	0.67
Task value	6	4.99	1.04	0.77
Control of learning beliefs	4	5.15	1.03	0.53
Self-efficacy for learning and performance	8	4.93	1.15	0.87
Test anxiety	5	3.85	1.37	0.74

The second component of the motivation scales, the expectancy component, consists of the sub-scales of "control of learning beliefs" and "self-efficacy for learning and performance." The mean values of these scales indicate that the students believed that their efforts to learn physics by the PBL approach could produce positive outcomes, that they would perform well in physics, and that they were able to accomplish a physics task. On the other hand, in the affective component, many students felt anxious when taking physics tests. This may be related to the assessment and evaluation methods adopted by the Faculty of Engineering. The students were assessed through multiple-choice and open-ended questions and they had to score at least 60 out of 100 to provide a good contribution to their final grades. Giving more credit to the assessment and evaluation of the PBL processes rather than students' physics knowledge might take some of the pressure from the students, and they would feel less anxious about their performance in physics.

The learning strategies of the PBL students

Descriptive statistics of the learning strategies scales of the MSLQ is presented in Table III. The Cronbach's alpha internal reliability coefficients of the scales are similar to the ones obtained by Buyukozturk, et al., (2004). It seems that the scales are reliable measures of the PBL students' use of different learning strategies for physics.

***Table III**. Descriptive statistics of the learning strategies scales of the MSLQ (n= 78).*

Sub-scale	Number of items	Mean	Standard deviation	Cronbach's Alpha
Rehearsal	4	4.78	1.19	0.63
Elaboration	6	5.03	0.99	0.78
Organisation	4	5.06	1.13	0.69
Critical thinking	5	4.69	1.21	0.83
Metacognitive self-regulation	12	4.74	0.89	0.78
Time and study environment	8	4.50	1.05	0.76
Effort regulation	4	4.18	1.24	0.62
Peer learning	3	3.82	1.33	0.65
Help seeking	4	4.46	1.25	0.51

The cognitive and metacognitive strategies component of the learning strategies includes the sub-scales of rehearsal, elaboration, organisation, critical thinking, and metacognitive self-regulation. The mean values of these scales suggest that many students will experience difficulties in constructing internal connection between physics ideas to be learned, applying their prior knowledge to new situations in order to solve problems, reach decisions, and having control of their cognition. One would expect the PBL students to use cognitive and metacognitive strategies more frequently since the PBL approach requires students to read many physics materials to be successful in the course. It is quite possible that the students' inadequate use of cognitive and metacognitive strategies contributed to their poor understanding of the basic concepts of electromagnetism as indicated by the mean electromagnetism score of 5.5 (out of 16) with a standard deviation of 3.0. As a student-centred approach, the PBL approach requests students to use their resources, such as students in their PBL group, effectively. However, as suggested by the sub-scales of time and study environment, effort regulation, peer learning, and help seeking, the PBL students in the sample were not very good at using the resources available to them. This also may be a factor contributing to poor conceptual understanding of the PBL students in electromagnetism.

The relationships between the PBL students' performance in electromagnetism and their motivational orientations and learning strategies

The PBL students' performance in electromagnetism was correlated with their scores in motivational orientations and learning strategies scales to investigate if there is a relationship between these variables. There was a weak association (0.252) between the students' performance in electromagnetism and the scores of the self-efficacy for learning and performance scale at the 5% level. Surprisingly, the other variables such as intrinsic goal orientation and critical thinking did not have a significant statistical correlate with the students' achievement scores. The fact that the students found the diagnostic test difficult may be one of the reasons why many motivation and learning strategies scales did not correlate with the students' achievement scores.

Conclusion and Implications

This study investigated university students' confidence in the basic ideas of electromagnetism, their motivation orientations and learning strategies in problem-based instruction. In general, the students preferred to be confident in their answers to the electromagnetism questions. However, many students were confident in an incorrect answer. The questions included in the electromagnetism test have a diagnostic nature. That is, the distractors are students' common incorrect answers in the basic ideas of electromagnetism. The fact that many students were confident in these distractors means that it would be very unlikely that these students would feel a need to re-examine their understanding of the basic ideas of electromagnetism. Therefore, they would continue to have their incorrect ideas about electromagnetism as if they were the correct ones. These students would find it very difficult to accept the scientific ideas of electromagnetism when they are faced with the evidence that does not support their incorrect knowledge/beliefs. On the other hand, it would be very easy for the students who accepted the scientific ideas of electromagnetism after they were faced with counter-evidence to turn back to their incorrect ideas when they reason about them (Reif & Allen, 1992). Perhaps, these students need instructional strategies that provide them with convincing evidence that supports the construction of the scientific ideas of electromagnetism more firmly than the PBL approach. This study found that the PBL approach was not very effective in teaching the basic ideas of electromagnetism, although many students thought otherwise. I believe the approach would be more effective if the tutors in the PBL tutorials had a strong physics background since this might facilitate students' identification of learning issues. Including some formative assessments during the process could help the students to better judge the status of their understanding, which, in turn, would result in better student calibration in electromagnetism (i.e., students would be more confident in their correct answers and less confident in their incorrect answers). The PBL approach puts a great deal of emphasis on students' motivational orientations and learning strategies for students to be successful in the course they are attending. However, the students in the sample had inadequate use of cognitive and metacognitive learning strategies. One would rightly predict that these inadequacies had negative effects on the PBL students' understanding of the basic ideas of electromagnetism. For many of these students, it was the first time that they were asked to be self-directed learners in a course. I believe helping the first-year PBL students to obtain these strategies early in the academic year would have improved their understanding of physics concepts. During the PBL tutorial discussed in this article, the students were expected to learn some pre-determined knowledge to be successful in electromagnetism, and their achievement was assessed through multiple-choice and open-ended questions. I believe that, in addition to multiple-choice and open-ended questions, we need to use different types of assessment techniques to assess the PBL students' performance in electromagnetism. As Barrows & Tamblyn (1980) noted, "problem-based learning requires different types of examination tools that evaluate the student's ability to work with problems and apply learned information to their understanding or resolution" (p. 14).

The findings of this study support the conclusion arrived by Perrenet, Bouhuijs and Smits (2000) that "PBL has certain limitations, which make it less suitable as an overall strategy for engineering education" (p. 345; emphasis added). Therefore, it would be better to include a mixture of instructional strategies such as traditional "chalk and talk" teaching and project-based learning in the engineering curriculum (Mills & Treagust, 2003). As pointed out by Yang, Chang and Hsu (2008), comprehensive lectures and teacher demonstrations with thorough explanation of the process and the results to students are parts of the constructivist instruction, and I believe they have an important place in engineering education, especially in the science courses in the first year of the programme. This study found that tutors' backgrounds in science may be a factor influencing students' success in PBL instruction. Therefore, research on PBL may investigate the effect of the science backgrounds of tutors on student performance in science courses. Future research may also look at the effect of interventions aiming at improving students' motivational orientations and learning strategies on student success in PBL courses. The findings imply that students' confidence in their science knowledge is an important part of their understanding, and the future research in students' understanding of various science topics should pay more attention on this aspect of understanding in science. The theoretical implication of the importance of students' confidence in their science knowledge for the PBL approach is that its design should be improved to incorporate components focusing on student calibration. For example, formative assessments may prove useful in improving student calibration in PBL interventions.

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