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Assessment of Students' Cognitive Conflicts and Anxiety

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Abstract: Cognitive conflict is well recognized as an important factor in conceptual change and is widely used in developing constructivism-based curricula. However, cognitive conflicts can also contribute to student anxiety during learning, which, when not properly addressed, can have negative impacts on students' motivation and achievement. Therefore, instructors need to be aware of the impacts of introducing cognitive conflicts in their instruction. We need a practical instrument that can help identify the existence and features of cognitive conflicts introduced by the instruction and the resulting anxiety. Based on the literature on studies of cognitive conflicts and student anxiety, we developed a quantitative instrument, the *In-class Conflict and Anxiety Recognition Evaluation* (iCARE), and used it to monitor the status of students' cognitive conflicts and anxiety in *Physics by Inquiry* (PBI) classes. In this paper, we introduce this instrument and present the types of information that can be obtained. Research and pedagogical values of this instrument are also discussed.

Key words: cognitive conflict, anxiety, iCARE, Physics by Inquiry

I. Introduction

The study of conceptual change in students has been a major area of research in science education for more than three decades (Duit, 2003). Even though there are continuing debates about the positive and negative effects of cognitive conflict on science learning, many constructivists in science education have argued that cognitive conflict is an important factor in conceptual change (Posner *et al.,* 1982; Strike & Posner, 1992; Dreyfus *et al.,* 1990; Chan *et al.,* 1997; Chinn & Brewer, 1998; Kwon *et al.,* 2000a; Kwon *et al.,* 2000b; Limón, 2001; Lee *et al.,* 2003; Kang *et al.,* 2004; Kim & Kwon, 2004; Kim *et al.,* 2006; Hong *et al,* 2007).

Lee *et al.* (2003) developed a cognitive conflict process model to explain cognitive conflict in terms of four constructs: recognition of an anomalous situation, interest, anxiety, and cognitive reappraisal of the conflict situation. They found that anxiety has both positive and negative effects on student learning. Others have studied feelings of anxiety during academic situations and have consistently reported a negative correlation between virtually every aspect of school achievement and a wide range of anxiety measures (Hembree, 1988; Hong & Karstensson, 2002; Cassady & Johnson, 2002).

During learning, cognitive conflicts among ideas are inevitable (Johnson & Johnson, 1979). These conflicts are especially evident in courses such as *Physics by Inquiry* (PBI) (McDermott *et al.,* 1996), which are designed to help students construct knowledge from seeing and resolving conflicts among peer students, among students and instructors, and between a student's present understandings and new information. When conflicts occur, methods for effective management of such conflicts are crucial to learning. Cognitive conflicts can lead to constructive or to destructive outcomes, depending on how such conflicts are managed (Kim *et al.,* 2006; Kim & Bao, 2005; Johnson & Johnson, 1995; Kim, 2002; Cho *et al.,* 2004; Kim *et al.,* 2005).

However, there has been no readily available method with which one can identify whether students may have encountered cognitive conflicts during their learning and the impacts (such as anxiety) of such conflicts. Therefore, inspired by Lee's study (Lee *et al.,* 2003), we developed a survey instrument, the *In-class Conflict and Anxiety Recognition Evaluation* (iCARE), which can be implemented in classrooms to measure the status of students' cognitive conflicts and their levels of anxiety due to the conflicts. The

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design of this instrument targets two issues: (1) the components of the instruction and curriculum that trigger cognitive conflicts, and (2) students' feelings and reactions in responding to cognitive conflicts. In this paper, we discuss the development of this instrument and the implementation of the tool in the PBI course on electric circuits.

II. The Design of the Instrument

There have been many studies in the literature about cognitive conflict and conceptual change and about affective aspects of instruction such as anxiety (Limón, 2001; Lee *et al.,* 2003; Kim & Bao, 2005; Cho *et al.,* 2004; Kim *et al.,* 2005; Shin *et al.,* 2005). The design of iCARE is based on these studies. This instrument contains four parts: (a) situations that trigger cognitive conflicts, (b) students' feelings of cognitive conflicts, (c) an estimate of anxiety, and (d) student reactions and behaviors in responding to conflict situations. Note that in the existing literature, similar issues were studied and described with different sets of terminology such as "types of conflict" (Cho *et al.,* 2004; Kim *et al.,* 2005; Shin *et al.,* 2005) and "components (or constructors) of cognitive conflict" (Lee *et al.,* 2003). The iCARE survey instrument is included in the appendix. All future developments and documentation can be found at cafe.naver.com/CCLG.

The first part of iCARE is designed to identify specific components and situations in instruction that induce cognitive conflicts in students. During the teaching and learning in a class session, a student can encounter conflicts due to differences (1) between a student's expectations and observations of a demonstration or an experiment, (2) between a student's expectations and observations of different experiments, (3) between a student's understanding and those of peer students, and (4) between a student's understanding and the information delivered by the instructor.

The identification of these different situations is important because they provide some details about the settings of the instruction that may have contributed to students experiencing cognitive conflicts. In addition, studies have shown that different situations can have different effects on conceptual change and cognitive development (Hashweh, 1986; Druyan, 2001; Piaget, 1950). All these are important issues that have to be considered carefully in curriculum development and in teaching.

The second part of iCARE is designed to identify the feelings that students experience during a cognitive conflict. Based on the Cognitive Conflict Level Test (CCLT) developed by Lee *et al.* (2003), we chose to probe three types of feelings that are considered typical during a cognitive conflict process (Dreyfus *et al.,* 1990). These are (A) "The differences surprised me." (B) "The differences increased my interest in the topic." (C) "The differences made me want to pay more attention to the topic and spend more time working on it."

The third part of iCARE provides an estimate of the level of anxiety during the cognitive conflicts. In the literature, researchers have suggested two components to anxiety: a cognitive component, and an emotional component (Liebert & Morris, 1967). The cognitive component of anxiety is believed to be more directly related to learning and task performance (Hembree, 1988). Therefore, iCARE includes three items of cognitive components that are selected and modified from the Cognitive Conflict Level Test (Lee *et al.,* 2003). These items are: (A) "The result of this experiment confused me." (B) "Since I can't resolve the differences, I am uncomfortable." (C) "I am upset because I cannot understand the reason for the result." Students are asked to evaluate each item using a 5-point Likert scale (1= "not at all true", 5= "very true"). Then, a total score of the three items is calculated. If the total score is less than 9, the student is considered to have a low level of anxiety, if the score is 9 or above, the student is considered to have a high level of anxiety (Lee *et al.,* 2003; Kwon *et al.,* 2000a; Kwon *et al.,* 2000b). Based on this calculated score, students are guided to complete one of the two groups of items in part four of the evaluation. It is worth mentioning that these items were developed through systematic research, which showed a content validity coefficient of .93 and a reliability coefficient between .69 and .86 (Lee *et al.,* 2003).

The fourth part of iCARE identifies students' reactions and behaviors in responding to conflict

Table 1
Students' reactions and behaviors in responding to cognitive conflicts

Anxiety Level	Types	Items on iCARE
Low	Multiple predictions	"Before the experiment, I predicted multiple possible outcomes. From the experiment, I have seen one of my predictions proved. So I am satisfied with the experiment result even without detailed explanations."
	Attempts to revise current theory	"I was confident that by reevaluating my previous beliefs, I would be able to find an explanation without others' help."
	Dependence on others' ideas	"I accepted what instructors or my classmates had said. I didn't spend much effort to find an explanation on my own."
	Use of past personal experience	"I made my predictions for this experiment by thinking about my past experience. I also tried to make sense of what I saw in the experiment based on my understanding through that experience."
High	Confidence in preconceptions	"Before the experiment, I was highly confident in my previous understanding of the subject. However, my understanding seems to be inconsistent with the outcome of the experiment."
	Insistence on need for additional variables	"After I saw the outcome of the experiment, I tried to explain it by considering things that I might have ignored as I was making the predictions."
	Lack of self-confidence	"I believe that there must be good reasons that can explain the experiment well. But right now I don't think I have learned enough physics to build a good explanation yet."
	Inability to resolve conflict with past experience	"In this experiment, the results are inconsistent with what I expected based on my experience and I haven't been able to resolve the problem yet."

situations. Students choose to answer one of two groups of items according to their anxiety scores. These items were selected based on previous studies on students' anxiety-related behaviors in cognitive conflict (Kim & Bao, 2005; Kim, 2002; Cho *et al.,* 2004; Kim *et al.,* 2005; Shin *et al,* 2005). In order to identify additional types of anxiety- related behaviors, the fourth part has an open-ended item for students to report cases that are not included. All eight items are summarized in Table 1, along with the types of behaviors that researchers used to categorize the items in the literature.

Ⅲ. Validity and Reliability

The content validity of iCARE was assessed by seven experts. They used a 5-stage Likert scale to judge the validity of each item for each part. Content validity coefficients among experts ranged from 0.71 to 0.83, and the mean value was 0.77. Validity based on response processes is focused on an analysis of responses to specific tasks, and whether these responses are consistent with what is intended to be measured (McMillan & Schumacher, 2001). In order to identify evidence based on response processes, we conducted 13 interviews, which provide a measure of consistencies between students' responses to iCARE and what is intended to be measured.

The interview subjects were solicited with a cash payment incentive from a pool of students who were taking the PBI course at the Ohio State University. Students were interviewed immediately after they finished their learning of a class section. In the interviews, students were asked to take the iCARE aloud in one pass. Then students were asked to go through their responses again to explain why the answers were selected. In analysis, students' explanations were compared with their answers to the iCARE and rated with a score from 1 to 5 for the consistency between the answers and the explanations. See Table 2 for the rating scheme. Examples of actual interview transcripts and analysis are provided on the documentation website for interested readers.

From the interview, we also measured the time that a student takes to finish iCARE in one pass. We

Table 2
The evaluation rubric for consistency

Score	Categories	Criteria for scoring
1	No explanation	The student replied "I don't know" or gave irrelevant explanation.
2	Vague explanation	The student attempted to explain but gave unclear explanations (little details) about what had happened in class that made him/her pick the answers. The student also had little confidence about the explanation.
3	Partial explanation	The students' statements contain some but fuzzy details to what had happened in class that might have caused the conflicts. The student had moderate confidence about the explanation.
4	Sound explanation	The student's explanation contains explicit details about experiment results or other group members' opinions that might have caused cognitive conflicts. The student had moderately strong confidence about the explanation.
5	Very sound explanation	The student's explanation contains rich details about experiment results or other group members' opinions that caused cognitive conflicts. The student had strong confidence about the explanation.

found that the average time that the students use to finish iCARE in one pass was 8 minutes and 53 seconds. The standard error of the average time was 46 seconds. Note that this is the first time the students take iCARE. According to our experience with about 120 students in three classes, the average time the students took to finish iCARE dropped significantly to the level of 5 minutes from the second or third times they did it in class. This result suggests that it is realistic time-wise to implement iCARE in real education practice.

To check the inter-rater reliability and to determine whether the coding scheme is reliable student interview results are analyzed and rated independently by two researchers. The average scores from the two researchers were used as the final score. The inter-rater reliability between the two researchers was established at 92% agreement with a Pearson correlation between two raters at $r = .81$ ($p < .01$).

According to Cohen (1960), inter-rater reliability parallels the concept of equivalence with test. A coefficient of reliability was calculated using Cohen's Kappa formula. Kappa takes into account chance agreement and is designed for categorical data. Kappa values of 1.00 constitute perfect agreement, whereas values above .50 are considered good to agreement (Fleiss, 1971; Landis & Koch, 1977). The raters were the first author and a doctoral student in physics education. This analysis yielded a Kappa coefficient of .58, which is in the region of good agreement. From the interview results, the average consistency score of the 13 students was calculated as 4.86 out of 5.0 with a standard error of 0.12. This result suggests that iCARE has validity with respect to students' response processes.

The test-retest reliability of iCARE was evaluated by calculating the consistency between measurement results of the same PBI class from two consecutive years: one in winter quarter of the first year (N=31) and the other in winter quarter of the second year (N=19). The measurement results from Section 1 to Section 5 were used in the comparison, since the instruction of these five sections covered the same content areas in similar time period. The instruction of later sections of the two classes took significantly different paths in terms of coverage of content areas and time used in teaching.

As an example, we compare the quantitative scores of levels of anxiety reported by students. Fig. 1 gives

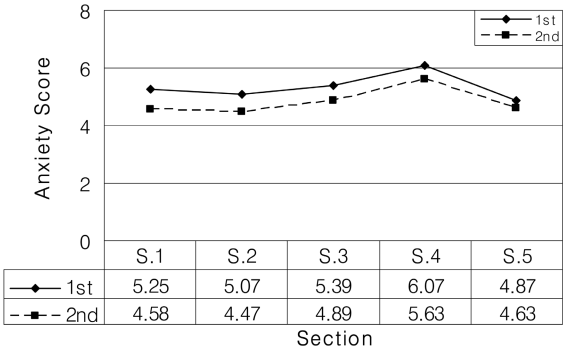


Fig. 1 *Correlation between the 1st year PBI class and the 2nd year class regarding anxiety score.*

the average anxiety scores of the two classes on the first five sections, which shows a similar change pattern. The Pearson correlation between the average anxiety scores of the two classes is very positive $r = .94$ ($p < .05$), which is often considered as good reliability (Ravid, 2000).

In summary, we have conducted two years of qualitative and quantitative research to develop, test, and refine iCARE. The results provide an initial evaluation of the validity and reliability of the instrument. However, establishing the validity and the reliability of an instrument is always an ongoing process that cannot be treated in a once-and-for-all sense (American Psychological Association, 2000). We see the results discussed here as a starting point for further research on validating and refining iCARE.

IV. Application of iCARE in Research

In the following sections of the paper, we present in detail a study that applies iCARE in real education settings – one quarter of a PBI course at the Ohio State University. This 10-week course covers topics on electric circuits. On average, students study through one section per week. Thirty-one students were enrolled in this class.

The PBI course is a group-learning environment that implements an elicit-confront-resolve method of learning. Therefore, there are many situations designed to trigger cognitive conflict among students. Accompanying the inquiry method is a system of formative assessment and feedback through checkpoints, questions of the day, pretests, homework, exams, and journal entries. iCARE was given to students as a post-evaluation to each section (except for Section 9, which was not evaluated due to scheduling problems). We asked students to complete the evaluation in class immediately after they finished work on the section. Having students complete the evaluation right after each section is intended to improve the quality of the data; however, the evaluation is still a "self-reporting" method and is subject to the drawbacks of this type of method. Table 3 lists the sections in which we used iCARE as the post-evaluation.

Table 3
Sections of the PBI class

Section	Topic
1	Single-bulb circuits
2	A model for electric current
3	Extending the model for electric current
4	Series and parallel networks
5	Kirchhoff's first rule
6	Equivalent resistance
7	Multiple batteries
8	Kirchhoff's second rule
10	Ohm's law

V. Results and Discussion

The results discussed in this section are based on data collected with iCARE and other evaluations. Because all the data is in multiple-choice format, the error bars on the results presented can be estimated by the standard error of a binomial distribution. Our sample size is about 30 in most cases, which gives a value of less than 5% as the standard error of a measured mean. In the following discussion, the error bar is not included for simplicity in the presentation. It is also noted that the results presented in this paper are not made to support any claims about student learning performance, but rather are for the purpose of exemplifying the types of information that can be obtained by using iCARE.

1. Situations triggering cognitive conflicts

From iCARE, we found that more than 90% of the students reported at least one conflict in each section. A detailed summary of students reporting numbers of conflicts in various sections is given in Table 4. We can see that for most sections about one-third of the students experience zero to two conflicts while the remaining students experience more than three conflicts.

Detailed analysis of the measurement results also show that the situations leading to cognitive conflicts are different for different students and over different content topics. The design of iCARE allows us to probe four categories of situations coded as CE, CC, CG, and CT. CE represents the type of conflicts induced by differences between students' conceptions and observations in an experiment. CC represents the type of conflicts induced by differences between a

Table 4
Number of reported cognitive conflicts in different sections

Section	Number of Exercises/Experiments	Number of Students vs. Reported Occurrences of Conflicts in a Section*						N**
		0	1	2	3	4	5	
1	14	3	4	4	1	19	0	31
2	7	1	5	4	2	20	0	32
3	10	2	5	4	0	13	8	32
4	14	2	5	1	2	1	18	29
5	9	2	5	1	1	0	14	23
6	5	2	5	1	4	1	11	24
7	16	2	5	3	0	0	13	23
8	18	1	7	1	0	0	12	21
10	14	1	8	1	0	1	19	30
Total	107	16	49	20	10	55	91	245

* 0 means no conflicts; 5 is the maximum number of conflicts that a student can report on iCARE.
** N is the number of students who completed iCARE for the given section.

student's different conceptions. CG represents the type of conflicts induced by differences between a student and his/her group members. CT represents the type of conflicts induced by differences between a student and the teacher.

Fig. 2 shows the relative proportion of the different situations causing cognitive conflicts against the total number of cognitive conflicts reported in each section. We can see that in most sections the CE type caused about half of the conflicts. Notice that the CE type of conflict is often the focus of many researchers (Hashweh, 1986; Piaget, 1950; Hewson & Hewson, 1984) and represents a commonly used method in curriculum development. An interesting result is that among the four categories of conflicts, the CT type is much less frequent than others. All these suggest that the design of the PBI curriculum does a good job in inducing students' cognitive conflicts without much instructor involvement.

2. Students' feelings in conflict situations

When cognitive conflicts are encountered, students may experience different feelings. iCARE includes three items to probe such feelings: "surprised", "interested", and "trying to pay more attention to the topic." The results are shown in Fig. 3, which gives the relative proportions of reported "feelings" normalized with the total number of cases reported in each section. The design of iCARE allows students to report more than one type of feeling; however, our

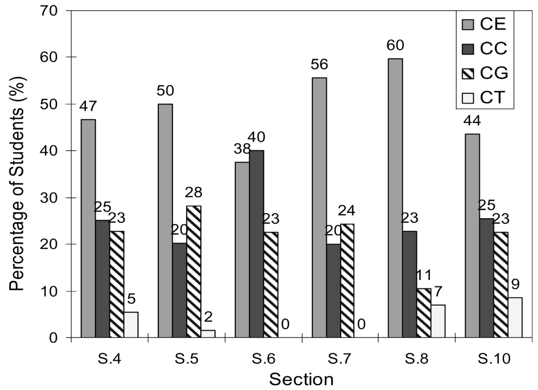


Fig. 2 *Relative proportions of different situations causing cognitive conflict.*

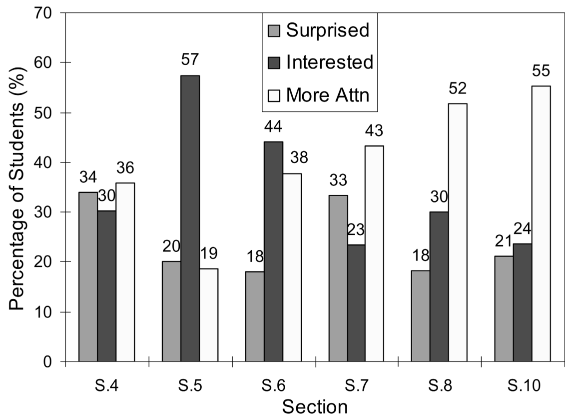


Fig. 3 *Relative proportions of students' reported feelings.*

data show that under 5% of students reported multiple feelings. The results in Fig. 3 are based on all reported cases; the effects of multiple reports by a single student in this study are small and are not analyzed separately.

The purpose of probing students' feelings is that such feelings are related to student recognition of anomalous situations and can affect future steps in student learning. Many researchers emphasized that the conceptual change process can be influenced at least partly by affective variables and value beliefs (Strike & Posner, 1992; Limón, 2001; Kim & Kwon, 2004; Pintrich *et al.,* 1993; Pintrich & Sinatra, 2003). To initiate a process of conceptual change, a cognitive conflict has to be "meaningful" for the student, which means that the students must be motivated and interested in the topic, activate their prior knowledge, and have certain epistemological beliefs and reasoning abilities adequate to deal with the given problem. In particular, students' personal interest in a topic might determine whether they even attend to a discrepancy that could lead them to become dissatisfied with their existing conceptual understanding. Therefore, the data collected on students' feelings can provide supplemental information about students' affective status during their conceptual change process.

From Fig. 3, we can see an interesting pattern. As the course moves towards the end of the quarter, the number of students reporting "interests" decreases, while the number of students reporting "paying more attention" increases. Topics do become more difficult towards the end of the course. In addition, anecdotal evidence from discussions with students suggests that students became more concerned about their grades as the final exam approaches and thus paid more attention to the topics that they had not understood. However, further research with detailed qualitative data is needed in order to determine whether the pattern is meaningful and what features of learning can this be related to. The results also suggest that students' interests and their attentions can be as dependent as they are independent. For example, it is not uncommon for students to be extremely bored by a content topic, but yet pay serious attention to it so that they can obtain good grades.

3. The level of anxiety vs. content topics and student performance for Section 4

iCARE gives a numerical estimate of student anxiety levels. It is interesting to examine how this variable is related to other variables such as the content topics and students' grades. As one would expect, student anxiety level varies over the different sections (content topics). Fig. 4 shows the percentage of students reporting a high level of anxiety (with an anxiety score greater than 8) in the various sections. With this measurement one can identify content topics which are more likely to generate a high level of student anxiety (e.g., Section 4 in this particular class).

As shown by research, anxiety is not necessarily a negative thing to learning; but rather, a small amount of anxiety may facilitate learning, especially if the task is not too difficult (Ball, 1995). However, students of different backgrounds can react differently in learning with respect to the impacts of anxiety (Cassady & Johnson, 2002; Movshovitz-Hadar & Hadass, 1990).

To study the relations between anxiety and other variables of learning, we correlate student performance with their anxiety scores. We start this analysis by grouping students in two groups based on their anxiety scores in Section 4. The low anxiety group contains twenty-three students whereas the high anxiety group contains six students. Out of the maximum of 15 points on the anxiety score, the low anxiety group has an average score of 5 points while

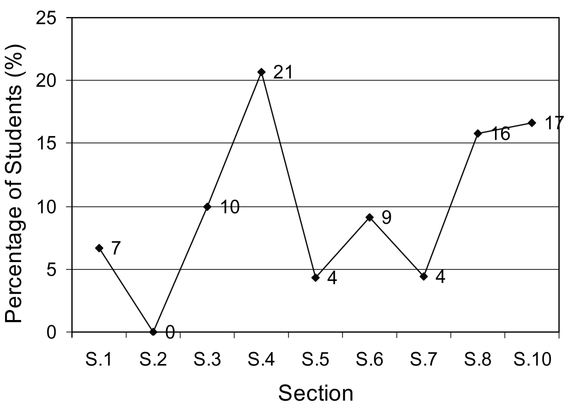


Fig. 4 *Students revealing a high level of anxiety in different sections.*

the high anxiety group's average score is 10 points. A midterm exam was given to students one week after they finished Section 4. This midterm is largely focused on the topics in Section 4; therefore, we expect a high correlation between students' performance on this midterm and their learning in Section 4. A comparison of the midterm scores of students with different anxiety levels is included in Table 5. As expected, the results suggest that the students who experienced high anxiety in Section 4 also had lower midterm exam scores. Although the absolute difference between the average scores of the two groups is small, it is statistically significant and meaningful.

Further, using part 4 of iCARE, we can obtain more details of students' affective reactions to the cognitive conflicts, which were coded into the eight categories shown in Table 1. From this study we found that among the six students exhibiting high anxiety, two students exhibited the type of "insistence on need for additional variables." Two students exhibited both "inability to resolve conflict with past experience" and "insistence on need for additional variables." One student exhibited "lack of self-confidence" and "confidence in preconceptions." The remaining student had "insistence on need for additional variables" and "confidence in preconceptions." These details were not used in this study, but are crucial to further studies for developing instructional strategies that help students resolve conflict situations and control their anxiety levels.

Table 5

Comparison of first midterm exam scores of students with different levels of anxiety in Section 4

Anxiety Level	N	Exam Mean	SD	t	p	Effect Size
Low	23	89%	6.0%	2.4	0.02	0.9
High	6	81%	10%			

In this study, instructors followed typical PBI instruction methods. They did not implement any additional strategies to address the anxiety issue. From the literature, educational psychologists have developed methods for alleviating test anxiety (Zeider, 1998; Schutz, & Davis, 2000); however, these methods are not appropriate to be used in the care of anxiety during cognitive conflicts in a PBI class. In future studies, we plan to develop new strategies to address students' anxiety based on measurement from iCARE.

4. Examples of curriculum components and the reported cognitive conflicts

In this section, we provide a detailed content analysis of a piece of the curriculum (Section 4), in which the largest fraction of students had shown a

Table 6

Students Experiencing Cognitive Conflicts in Different Exercises in Section 4 (N = 29)

Exercise/ Experiment	Topic	Students Reporting Conflicts (N = 29)
Exercise 1	Define series and parallel connections.	3 (10%)
Exercise 2	Apply definitions of series and parallel connections.	4 (14%)
Exercise 3	Identify series and parallel connections and networks.	5 (17%)
Exercise 4	Rank circuits in terms of the current through the battery.	10 (35%)
Experiment 5	Predict the brightness of bulbs in circuits.	11 (38%)
Experiment 6	Compare two students' comments about the brightness of bulbs in circuits.	2 (7%)
Experiment 7	Predict and observe the change in brightness when the switch in a circuit is opened and closed.	12 (41%)
Experiment 8	Predict and observe the brightness of the bulbs in more complicated circuits.	11 (38%)
Exercise 9	Categorize series and parallel circuits.	4 (14%)
Exercise 10	Match freeform and standard circuit diagrams.	7 (24%)
Exercise 11	Match freeform and standard circuit diagrams (harder).	9 (31%)
Experiment 12	Analyze functions of a circuit with SPDT switches.	13 (44%)
Experiment 13	Design room lights control using SPDT switches.	11 (38%)
Experiment 14	Analyze functions of a given circuit board.	6 (21%)

high level of anxiety. In Table 6, we list all the exercises and the experiments in Section 4 and the numbers of students who reported experiencing cognitive conflicts in each of the experiments and exercises.

As shown in Table 6, Section 4 has seven exercises and seven experiments on series and parallel circuits. On average, about one-quarter of the students (27% ± 12%) reported cognitive conflicts in these tasks. The variations match well with the complexity of the individual exercise. For example, Exercise 4 is the first one in the section in which many students reported conflicts. Fig. 5 shows the questions of Exercise 4: students were asked to redraw circuit diagrams and to rank the circuits according to the current through the battery.

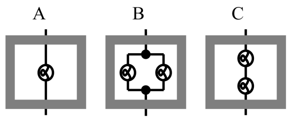
Problems similar to Exercise 4 have been used in many studies on student learning of circuits (McDermott & Shaffer, 1992; Shaffer & McDermott, 1992; Engelhardt & Beichner, 2004). Our observations during classroom interactions are consistent with the research result, which is that students often believe the battery is a source of fixed current. This type of understanding of the battery can also be a factor causing difficulties in Experiments 5, 7, and 8, in which students were asked to analyze the brightness or change in brightness of bulbs of various circuits. In order to solve these problems, it is crucial for students to understand that an ideal battery provides whatever current is needed to each circuit (i.e., a battery is not a source of fixed current).

On the first midterm exam, we gave a question similar to the one used in Experiment 7. This provides an opportunity to compare students' performance on a delayed test (the midterm exam) with their learning behaviors in the classroom. The problems used in Experiment 7 and on the first midterm are shown in Fig. 6 and Fig. 7, respectively.

Among the twenty-nine students in the class (coded with S1 … S29), two reported no conflicts through out Section 4; twelve reported having conflicts in exercises including Experiment 7; the remaining fifteen students reported having conflicts in exercises and experiments other than Experiment 7. These students' performance on the midterm question (see Fig. 6) is given in Table 7. Although not statistically significant, the results implies a trend that students who reported having conflicts in Experiment 7 seem to perform better than students who reported conflicts in experiments other than Experiment 7. It seems as if it is helpful for students to have recognized the

Exercise 4.

Suppose you have three boxes, labeled A, B, and C. Each box has two terminals. The arrangement of bulbs inside each box is shown below.



A. For each of the following circuit, draw a standard circuit diagram showing all the bulbs in the circuit. List the series and parallel combinations for each circuit.

B. Rank each of the circuits in part A according to the current through the battery.

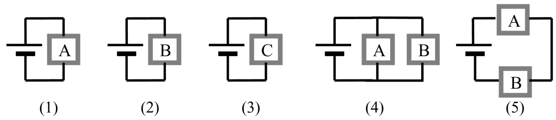
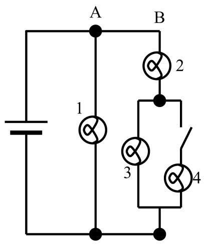


Fig. 5 *Exercise 4 (Recreated from Exercise 4.4 of Physics By Inquiry).*

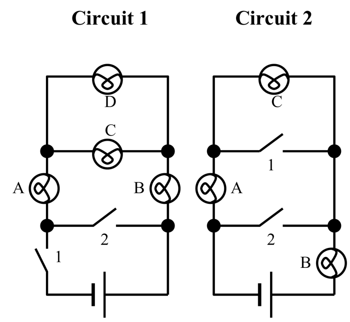


Experiment 7.

(A) Observe the change in brightness of bulb 2 when the switch is opened and closed. Now observe bulb 1 as the switch is opened and closed.

(B) Predict the effect on branch A (or B) of each of the following alterations of branch B (or A):
(1) Unscrewing bulb 2
(2) Shorting out bulb 3
(3) Unscrewing bulb 1
(4) Adding a bulb in series with bulb 1

Fig. 6 *Experiment 7 (Recreated from Exercise 4.7 of Physics By Inquiry).*



(P) Rank the bulbs by name from brightest (first) to dimmest (last) for each circuit (1 and 2), under the following condition
(1) Both switches are open;
(2) Switch 1 is open, switch 2 is closed;
(3) Switch 1 is closed, switch 2 is open;
(4) Both switches are closed.

Fig. 7 *The problem used in the first midterm exam.*

Table 7

Students' performance on the midterm question (N = 29)

Students reporting conflicts in Section 4	Answered Correctly	Answered Incorrectly
No conflicts in entire Section 4	2	0
With conflicts in Experiment 7	8	4
With conflicts, but not in Experiment 7	7	8

conflict explicitly. However, more studies are needed in order to determine the reliability and possible interpretations of this phenomenon.

Students' performance on the test question and their reactions to the related instructional components are also compared. Among the twelve students who reported having conflicts in Experiment 7, three had a high level of anxiety and nine had a low level of anxiety. Of the nine students with low anxiety, eight answered the midterm question correctly. All three students who exhibited high anxiety answered the midterm question incorrectly as shown in Table 8. This result should not be surprising since the students who had low anxiety are often better students. What is useful is that by using iCARE, we can collect details about students' reactions during the learning process, especially for those who failed on the test. This will allow us to build an understanding of possible common behavior patterns of students who may be successful (or unsuccessful) in learning. Such information could help instructors to identify at-risk students while learning is taking place (not after the exam) so that proper treatment can be implemented during the course of instruction. By combining the results from iCARE and detailed content analysis, researchers can also gain insights into how specific curriculum components affect student learning, which can help us develop better instructional materials.

VI. Summary and Implications

Instructional methods that engage students in an active process of constructing knowledge are becoming the basis for current-day education development and practice. The emphasis on the process of learning also demands consideration and control of a new set of issues such as social affective factors that cannot be assessed using only performance-based variables (Pintrich & Sinatra, 2003; Snow *et al.,* 1996). Therefore, it is important to develop assessment tools that probe behavior-related variables and affective factors. This study is one such attempt. We developed an instrument (iCARE) to probe a number of affective factors related to the learning process of a lab-based group-learning environment. The results shown in this paper are for the purpose of exemplifying the types of information that can be obtained with such an instrument. As an anecdotal implication, we have also observed that students can benefit directly from frequent use of iCARE in classes; it seems to help

Table 8

Reactions of students who reported conflicts in Experiment 7 and their performance on the midterm question

Students who reported having conflicts in Experiment 7			Students' performance on the midterm question			
Anxiety Level	Reactions	Students	Correct		Incorrect	
Low (9 students)	Multiple prediction	S10, S11, S18, S29	8	S10, S11, S18	1	S29
	Attempts to revise current theory	S9, S10, S11, S18, S19, S20, S22, S29		S9, S10, S11, S18, S19, S20, S22		S29
	Dependence on others' ideas	S8		S8		
	Use of past personal experience	S10, S18, S20, S29		S10, S18, S20		S29
High (3 students)	Confidence in preconceptions		0		3	
	Insistence of need for additional variables	S1, S2, S12				S1, S2, S12
	Lack of self-confidence					
	Inability to resolve conflict with past experience	S1				S1

them reflect their own learning process, bringing them more explicit knowledge about the problems experienced during their learning.

From this study, we can foresee interesting possibilities for using iCARE in research and instruction. For example, we might use the instrument to inspect how specific curriculum components affect student learning in terms of triggering cognitive conflicts and causing anxiety. From students' learning behaviors and reactions to conflict situations, we can also obtain additional assessment of students' preparation and learning styles. Further, we can construct a more systematic study in which all these behavior-based results and students' performance data can be correlatively analyzed to yield a better picture of student learning.

We believe that developing measurement methods and instruments that probe behavior-related variables is an important research area. This type of instruments can also be integrated into a formative assessment framework to benefit students and instructors directly. In our current research, we are further validating the stability, validity, and reliability of iCARE, developing new versions of iCARE for lecture courses and lab courses, and developing methods to apply the assessment to benefit teaching.

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Appendix: In-class Conflict and Anxiety Recognition Evaluation

Post-Evaluation SECTION ( ) GROUP NUMBER: ( ) NAME: ______________

During the class, you may have encountered situations that caused:

(1) Differences between your predictions (or what you believed) and the results of an experiment.
(2) Differences between your understanding of one experiment and your understanding of another experiment.
(3) Differences between your opinions and the opinions of other group members.
(4) Differences between your opinions (or what you believed) and the opinions of the instructor.
(5) Complete agreement with your opinions, instructor's opinions, and experiment results.

When someone encounters such differences, he/she may have different kinds of experiences such as

A. *The differences surprised me.*
B. *The differences increased my interests in the topic.*
C. *The differences made me want to pay more attention to the topic and spend more time to work on it.*

In the following table, please identify the experiments that may have given rise to the different situations discussed above. Identify the situations with (1) ~ (4) and your experience with A, B, C (see above). **Select all that apply.** You may add your own categories if not listed. If you need more space and/or have more comments, use the back of the page.

Experiment ID	The situation that caused differences	Your experiences with the difference	Now, can you completely resolve the difference by yourself?
	□ (1) □ (2) □ (3) □ (4)	□ A □ B □ C	□ Yes □ No
	□ (1) □ (2) □ (3) □ (4)	□ A □ B □ C	□ Yes □ No
	□ (1) □ (2) □ (3) □ (4)	□ A □ B □ C	□ Yes □ No
	□ (1) □ (2) □ (3) □ (4)	□ A □ B □ C	□ Yes □ No
	□ (1) □ (2) □ (3) □ (4)	□ A □ B □ C	□ Yes □ No

From the experiments you listed, select one that had the most impression to you and use it as the basis for answering the questions listed below:

▶ **Write down the experiment ID that you have selected (____________).**

1. The result of this experiment confused me. 1 2 3 4 5
NOT AT ALL TRUE SOMEWHAT TRUE VERY TRUE

2. Since I cannot resolve the differences, I am uncomfortable. 1 2 3 4 5
NOT AT ALL TRUE SOMEWHAT TRUE VERY TRUE

3. I am upset because I cannot understand the reason for the result. 1 2 3 4 5
NOT AT ALL TRUE SOMEWHAT TRUE VERY TRUE

4. Now add your answers to the above three questions and put **the number** here: (____________)

▶ If your number in 4 is less than 9 **(3~8)**, go to **Part 1** only. If your number is **9~15** go to **Part 2** only.

▶ Part **1 (Finish this part if your calculated number is 3~8):** Among the following statements, **check the item** that best describes the likely causes of the feelings you reported above.

□ 1. Before the experiment, I predicted multiple possible outcomes. From the experiment, I have seen one of my predictions proved. So I am satisfied with the experiment result even without detailed explanations.
□ 2. I was confident that by reevaluating my previous beliefs, I would be able to find an explanation without others' help.
□ 3. I accepted what instructors or my classmates had said. I didn't spend much effort to find an explanation on my own.
□ 4. I made my predictions for this experiment by thinking about my past experience. I also tried to make sense of what I saw in the experiment based on my understandings of my past experience.
□ 5. Others (please specify. Use the back of the page if necessary.)

▶ **Part 2 (Finish this part if your calculated number is 9~15):** Among the following statements, **check the item** that best describes the likely causes of the feelings you reported above.

□ 1. Before the experiment, I was highly confident in my original understandings of the subject. However, my understanding seems to be inconsistent with the outcome of the experiment.
□ 2. After I saw the outcome of the experiment, I tried to explain it by considering things that I might have ignored when I was making my predictions.
□ 3. I believe that there must be good reasons that can explain the experiment well. But right now I don't think I have learned enough physics to build a good explanation yet.
□ 4. On this experiment, the results are inconsistent with what I expected based on my experience and I haven't been able to resolve the discrepancies yet.
□ 5. Others (please specify. Use the back of the page if necessary.)