Conceptual Change in Two Middle School Science Students During Instruction about the Concept of Burning

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التغيير المفهومي لدى طالبين من طلبة المرحلة الإعدادية خلال دراسة مفهوم الاحتراق

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ملخص الدراسة

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إن الهدف من هذه الدراسة هو وصف التغيير المفهومي لدي اثنين من طلبة المرحلة الإعدادية خلال دراسة مفهوم الاحتراق. استندت هذه الدراسة إلى معلومات مأخوذة من شرائط فيديو لستة أيام دراسية، وعلى لقاءات يومية مكثفة ومقابلات مع الطالبين، وعلى إجاباتهما عن أسئلة محددة، وعلى فروضهما المدرسية سواء منها المنفذ في الفصل أو في المنزل وذلك خلال الأيام الدراسية الستة. وقد أظهر تحليل جملة المعلومات هذه أن الطريقة التي اكتسب بها الطالبان معلوماتهما والبنية المعرفية المنظمة كانت مشابهة لوصف عملية التعلم كما شرحها سترايك (١٩٨١) وذلك من خلال عملية التغيير المفهومي. (Conceptual change) علاوة على ذلك، أظهرت النتائج أن التأمل (Reflection) والصراع المعرفي (Cognitive conflict) يعدان عنصرين مهمين في عملية التغيير المفهومي التي مارسها الطالبان.

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Abstract

The purpose of this study was to describe conceptual change in two middle school students during instruction about the concept of burning. Sources of data included videotapes of six days of teaching, extensive daily interviews with the two students, responses to specific questions, and class work and homework assignments during the six days of teaching. Analysis of the data shows that the process by which the two students acquired information and increasingly more organized knowledge structures during instruction was comparable to Strike's characterization of learning within a conceptual change, constructivist framework. Moreover, results show that reflection and cognitive conflict were important components of the conceptual change process experienced by the two students.

Conceptual Change in Two Middle School Science Students During Instruction about the Concept of Burning

Science education research has consistently demonstrated that students hold scientifically unacceptable understandings about science concepts, laws, and theories. Research findings suggest that these understandings cut across age, ability, gender, and cultural boundaries, influence how students process new scientific knowledge, and hinder successful acquisition of formal scientific concepts (Wandersee, Mintzes, & Novak, 1994).

Additionally, research has shown that studentsí understandings may be modified through specific conceptual change teaching strategies. Examples of these strategies include exposing and contradicting students' existing conceptions (e.g. Darden, 1992; Dreyfus, Jungwirth, & Elovitch, 1990; Hewson, 1982; Hynd, McWhorter, Phares, & Suttles, 1994; Vosniadou, 1994), using the history of science (Jensen & Finley, 1997; Nussbaum, 1983; Vosniadou & Brewer, 1987), analogies (Brown & Clement, 1989; Gilbert, 1989; Harrison & Treagust, 1993), the Socratic method (Vosniadou & Brewer, 1987), concept maps (Fellows, 1993), and refutational texts (Guzzetti, Williams, Skeels, and Wu, 1997). Recently, research has been conducted on using computers along with specific teaching methods to engender conceptual change (see for example, Duffy & Barowy, 1995; Tao & Gunstone, 1997; & Windschitl & Andre, 1998).

Investigating the mechanisms of conceptual change and incorporating the findings in curricular and instructional materials and in teaching practices may help improve the quality of science teaching at all educational levels. Consequently, the purpose of this study was to examine, in detail, conceptual change in two middle school students during instruction about burning. This detailed examination may provide new insights about the mechanisms of conceptual change in middle school students.

Background

According to Piaget, the mechanisms for conceptual change are based on the ideas of assimilation and accommodation. Moreover, Piaget asserts that conflict between students' existing conceptions and new experiences motivates them to relinquish existing conceptions and replace them with new and more sophisticated ones. Vosniadou (1988), on the other hand, hypothesizes that students' knowledge changes when their constructed mental models of the world progressively develop from phenomenal to assimilatory to scientific. Phenomenal models are constructed from small units of intuitive knowledge called "experiential beliefs" (p. 5) and show no evidence of influence of scientific thought, scientific models are those held by experts in a given domain, while assimilatory models exhibit a combination of the characteristics of both phenomenal and scientific models.

Yet another description of conceptual change is advanced by Linn and Songer (1991). According to these authors, students start their knowledge acquisition by developing unreflective "action knowledge" (p. 382) in their first attempts to respond to events encountered in their lives. By using reflective abstraction, students combine action knowledge to produce "intuitive conceptions" (p. 382) which result from students' attempts to explain series of similar events encountered in their everyday experiences or during instruction. Furthermore, Linn and Songer maintain that "sometimes this process of combining observations is supported by instruction featuring multiple representations of the same idea" (p. 382). Eventually, effective instruction may help students to organize their intuitive conceptions into principles and abstract general rules that are consistent with those held by experts.

Using ideas from Kuhn (1970) and Lakatos (1978), Posner, Strike, Hewson, and Gertzog (1982) formulated another theory of conceptual change1. According to these authors most instructional problems arise when learners have to reject existing understandings and acquire new and different ones. Consequently, instruction should consider students' existing conceptions and provide them with opportunities to experience new conceptions that are intelligible, plausible, and fruitful. Recently, however, a number of science education researchers (e.g. Pintrich, Marx, & Boyle, 1993) have criticized models of conceptual change that do not consider motivational mediators of conceptual change such as studentsí goals, values, self efficacy beliefs, and control beliefs. Moreover, other researchers (e.g. Ebenezer & Gaskell, 1995; Linder, 1993) have emphasized the role of context as a mediator of conceptual change.

Research on conceptual change in science has been prevalent in the past several years. This research followed attempts to identifying students' understandings in the various science disciplines. In chemistry, researchers have investigated students' understandings in a variety of topics such as change of state

(Stavey, 1990), phase change (Bar, & Travis, 1991), electrochemistry and electrolytic cells (Garnett & Treagust, 1992), atoms and molecules (Griffiths & Preston, 1992), isomerism (Schmidt, 1992), sugar water solutions (Slone & Bokhurst, 1992), nature of gases (Benson, Wittrock, & Bauer , 1993), matter and molecules (Lee, Eichinger, Anderson, Berkheimer, Blakeslee, 1993), chemical change, dissolution, conservation of atoms, and phase change (Abraham, Williamson, & Westbrook, 1994; Boo & Watson, 2001), the mole concept (Tullberg, Stromdahl, & Lybeck, 1994), and burning (BouJaoude, 1991; Rahayu & Russell, 1999; Watson, Prieto, & Dillon, 1997).

BouJaoude (1991), used interviews to identify and characterize studentsí understandings about the concept of burning. Students participating in his study believed that wax and oxygen were not actively involved in burning, substances underwent no chemical change during burning, terms such as evaporation and burning could be used interchangeably when describing burning alcohol, and phrases such as physical change and chemical change could be used interchangeably when describing burning things. Moreover, BouJaoude showed that studentsí understandings about the concept of burning were cued by the visible aspects of the events they were asked to explain during the interviews. These understandings were fragmented, inconsistent, and task specific, and were at variance with the accepted scientific view of burning. The students seemed to use memorized scientific terminology to explain their observations. Similarly, in an investigation of primary school students' conceptions of burning, Rahayu and Russell (1999) found that students' conceptions of burning were both specific and contextually based, and that there was little coherence in the use of any one conception across phenomena. Yet another study on burning with similar results was conducted by Watson, Prieto, and Dillon (1997) who investigated the consistency of explanations about combustion of middle school students. Their results showed that, while many students had underlying coherent rationales for their explanations, a large group of students appeared to have inconsistent and incoherent understandings of combustion.

Several studies have investigated conceptual change in chemistry. Basili and Sanford (1991) studied the effects of using cooperative learning groups and conceptual change strategies on community college students' conceptions of conservation of matter and energy and the particulate nature of matter. Lawson,

[1] See Duschl and Gitomer (1991) for a critique of the theory of conceptual change presented by Posner et al. (1982)

Baker, DiDonato, Verdi, and Johnson (1993) studied the effects of physical analogues on university students' conceptions of molecular attractions. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993) investigated the effectiveness of alternative curriculum units in changing sixth-grade students' conceptions of matter and molecules, while Ebenezer and Gaskell (1995) studied Conceptual Change in Solution Chemistry.

Studies on changing students' conceptions about the concept of burning were very limited. Olson (1992) examined the effect of using computer simulations and classroom experiments on students' conceptions of burning and the possibility of conceptual change occurring under these two conditions. The results showed that computer simulations were not sufficient by themselves to engender conceptual change. Olson concluded that teaching methods that relied only on computer simulations usually neglected the fact that students have preconceptions and that addressing these preconceptions is necessary for conceptual change to occur. Consequently, for successful conceptual change to occur, computer simulations should be used in conjunction with classroom experiments. Nieswandt (2001) investigated the effect of using a conceptual change teaching unit on grade 9 students' everyday conceptions of four chemistry topics: pure substances and mixtures, air and combustion, metal oxides, oxidation and reduction, and particle or continuum. The results showed that students' learning of the scientific conception of combustion were not very successful. Consequently, Nieswandt (2001) suggested that for conceptual change to occur teachers need to provide students with opportunities to practice the new concept on similar tasks and to apply it in everyday situations.

Many useful conclusions can be drawn from the above studies and many other conceptual change studies. These conclusion include, but are not limited to, the following: 1) meaningful conflict does not necessarily ensure the construction of the desired knowledge; 2) conceptual change should involve changing students' ways of looking at phenomena from a local-personal view to a formal-disciplinary view; 3) hypotheticodeductive reasoning facilitates the rejection of non-scientific beliefs; 4) cooperative work on concept-focused instruction provides an environment for learners to overcome misconceptions; 5) physical analogues are helpful in changing students' conceptions about theoretical concepts; 6) many middle school students learn to use scientific language without substantially changing their conceptions; and 7) specially designed curricular units help teachers to use conceptual change strategies.

Although several studies were conducted to identify students' understanding of middle school science (Driver, 1983), few addressed issues related to the mechanisms of conceptual change and the factors that facilitate its occurrence. Consequently, the present study will focus on investigating conceptual change at the middle school level to gain insights that may be useful in improving middle school students' understanding of science concepts.

Setting and Participants

The study was conducted in 1991 in an eighth-grade classroom in a school that encompassed grades four through twelve in a large urban school district in the United States. The school is housed in a stone structure not far from the downtown area of a major city. It draws students from all parts of the city and is racially balanced.

After examining six classes in the school, this specific class of eighth-graders was selected because it represented a range of abilities, ethnic backgrounds, and socioeconomic groups. The 20 students in this eighth-grade classroom were a mixed-ability group and were randomly assigned to the class at the beginning of the year. The average age of the students was 13 years 10 months, ranging from 13 years 2 months to 14 years 11 months. Most of the students in this class had not been exposed to a detailed study of the concept of burning, although some reported using candles in several laboratory exercises.

Two students (Dean and Lina2) were selected out of the 20 (1 female, 1 male, average age =14.0 years) for an in-depth study of conceptual change during instruction. The two students had been in the school for three years and came to the school from two different schools. Both of them indicated that they enjoyed science classes and science related activities such as going to the zoo. However, they claimed that they did not have time to join science-related extracurricular activities because of their demanding schedules. In addition, they did not think that they would choose science-related careers in the future. The two students were purposely selected (Patton, 1990) for the study because pre-instructional interviews conducted with them in a previous study indicated that they had not had any formal science instruction about burning and had unacceptable understandings about burning (see BouJaoude, 1991), their academic files showed that they were above average academically, they were available for extensive interviews after class, and they were articulate and not shy around adults.

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[2] The names of the two students have changed to protect their anonymity

The science classroom in which the study was conducted was organized and equipped as a science classroom and laboratory. The students' desks were located on one side of the room while the laboratory tables were on the other side. Next to the classroom there was another room approximately one-half the size of the classroom. This room, which was used by the teacher as an office as well as a storage room, provided a convenient location in which the interviews were conducted.

The science teacher of this class had five years of teaching experience at the middle school level, had participated in a variety of science teaching workshops, and was very familiar with hands-on science and conceptual change teaching strategies. During the laboratory / hands-on activities, students typically worked in self-selected groups of two or three to complete their assignments. The laboratory activities were varied. One half of the activities observed during the eight weeks before the study could be considered guided discovery labs, while the rest were verification-type labs. When she was not conducting a laboratory activity, the teacher usually started the lesson by going over the previous night's homework and reviewing the lesson followed by a short lesson on the day's topic. The teacher teaches interactively and provides examples and applications of what she is teaching.

Methodology

For this study, qualitative research methods were employed. Several sources of data were used including audiotaped interviews with the two students before, during, and following instruction (7 interviews per student with an average length of 32 minutes per interview), videotapes of six days of teaching, written responses to a number of specific questions, and the classwork and homework assignments of all the students including Dean and Lina. Interviews and student-teacher interactions on the videotapes were transcribed and observer's comments were recorded on a daily basis to help the researcher adapt and focus the interview questions for subsequent days (Miles & Huberman, 1984). The students, including Dean and Lina, did not seem to be bothered by the videotaping during the classes and also seemed to have ignored the tape recorders during the interviews.

Interview transcripts, transcripts of student-teacher interactions on the videotapes, and the written material were analyzed using the technique of analytic induction (Burgess, 1982; Goetz & LeCompte, 1984) in which the researcher repeatedly examined the data to produce categories or themes under which the data could be organized. The final four themes used to organize the data included the students' references to 1) what is needed for burning to occur; 2) what is produced during burning; 3) what changes occur during burning; and 4) the definitions of burning. These themes were the ones that emerged after multiple analyses of the data. Finally, videotapes were viewed, videotape transcripts, classwork materials, and homework assignments were analyzed to validate and triangulate the four categories used to analyze the interview transcripts.

Description of Instruction

To make sure that the content of instruction was well defined, the teacher and the researcher prepared a few paragraphs to define the concept of burning in general and the burning of a candle more specifically. The first paragraph described: a) what happened when substances are burned, b) the products of different types of burning, and c) the conditions necessary for burning to take place. The second paragraph introduced and discussed different terms used to describe burning depending upon the nature and the temperature of the various substances involved in the process. Finally, the third paragraph discussed the differences between burning and decomposition. Furthermore, the teacher and the researcher used the above paragraph and students' prior conceptions to design 12 activities to be used during teaching (see Figure 1).

During instruction, the teacher attempted to focus on the specific existing students' understandings to help them bring those understandings in line with the accepted scientific explanations. By using hands-on activities (Figure 1) designed based on students' understandings about burning identified in a previous study (BouJaoude 1991), specially designed prediction work sheets, and focusing questions, the teacher helped the students to realize that when a candle burned some of the weight change could be due to evaporation and burning of wax. This was accomplished in activities 1 and 2. Activities 3, 4, and 5 were planned to help the students realize that evaporation and burning were different phenomena, when a candle burned oxygen was involved, and new substances were formed during burning. Activity 6 was used to contradict the notion that burning always resulted in the loss of weight. This activity was conducted after the teacher and the researcher found out that most of the students had developed the theory that burning causes things to be destroyed and consequently weighed less.

1. Changes of weight of a burning candle.
2. The role of wax during burning.
3. Differences between evaporation and burning.
4. Products of burning.
5. Role of oxygen in burning.
6. Change in weight when steel wool burns.
7. Reaction of magnesium with oxygen.
8. Percentage of oxygen on air.
9. Reaction of steel wool with pure oxygen.
10. Reaction of a wooden splinter with pure oxygen.
11. Reaction of a peeled apple with pure oxygen.
12. Reaction of hydrogen with pure oxygen.

Figure 1. Activities Conducted During the Six Days of Instruction

The rest of the activities were planned to give the students examples of different types of burning to reinforce their newly acquired understanding of burning. These activities showed examples of fast burning reactions (Activity 12), slow reactions with oxygen (Activity 11), reactions of oxygen with metals (Activities 7 and 9) and the percentage of oxygen in air (Activity 8). The rest of the activities were planned to illustrate the differences between reactions with air and reactions with pure oxygen. The teacher typically started the lesson by asking the students to predict and explain in writing the results of the hands-on activities. Following the students' predictions and explanations, the teacher conducted demonstrations or the students carried out individual and group activities allowing them to verify or reject their written predictions. Finally, the teacher discussed the results of the demonstrations and activities with the students to make sure that all of them were convinced of the results and explanations.

Results and Discussion

At the end of instruction all 20 students participating in the study took a test consisting of 7 short answer questions covering the subject matter covered during the unit on burning. The mean score on the test was 85% with scores ranging from 40% to 100%3 and a standard deviation of 13.20. Results of the test showed that 15 students gave an acceptable definition of burning (Question 1), 19 students correctly identified the products of burning gasoline (Question 2), 14 students gave an acceptable definition of corroding (Question 3), 16 students gave the correct product of burning magnesium (Question 4), 19 gave the correct product of burning iron (Question 5), 15 students correctly explained the reasons why a candle seemed to lose weight when it burned (Question 6), and 17 students gave an acceptable explanation for the increase of mass when steel wool, magnesium, and calcium burned (Question 7).

Dean and Lina, the two students selected for detailed interviewing, scored 90 % and 85% respectively on the test. Moreover, analysis of the daily interviews conducted before and during the six days of teaching together with the videotapes and the written materials produced by these two students showed that conceptual change occurred in both of them. These interviews showed that during instruction, Dean and Lina acquired new information and a more organized and abstract understanding of the concept of burning. Furthermore, Dean and Lina were conscious of the changes in their understandings as well as of the process by which the new concept was acquired.

Dean's and Lina's initial understandings

The interviews conducted prior to instruction, described in BouJaoude (1991), showed that students', including Dean and Lina, initial understandings about the concept of burning were cued by the visible aspects of events. They were fragmented, inconsistent, task specific, and at variance with the accepted scientific view of burning. Moreover, the students seemed to use memorized scientific terminology to explain their observations.

As illustrated in the following excerpts from the interviews described in BouJaoude (1991), Dean's and Lina's understandings about the concept of burning exhibited the same characteristics described above.

Dean:

Researcher (R): What do you see here?

Dean (D): A burning candle.

R: What do you mean by burning?

D: It is like how when heat is supplied to an object how some of it is changed into gas or energy or maybe some of it changes into gas.

R: What happens to the wax when a candle burns?

D: Under the effect of heat it melts and drips down, the heat causes its atoms to speed up and liquefies when it cools off at the bottom?

R: What causes the candle to start burning?

D: Well, you apply heat, the string ignites,

R: What happens to the string?

D: The string is consumed, some of it by . . . when it burns, well . . . Well I think when you light it and it starts giving light, the string burns.

R: Do you know what this is?

D: Yes, this is an alcohol burner

R: Can you explain what happens when it burns?

D: The string burns . . . I am not sure, and the alcohol soaks up and when it is heated . . . I guess it changes into gas and goes into the atmosphere.

R: What if we put the alcohol burner on a balance scale while it is burning? Would it weigh less, the same or more after some time?

D: The alcohol will be soaked up and released as a gas, it will weigh less.

R: What if we do the same thing for the candle?

*D: The candle, it will weigh pretty much the same because all that is lost is the string, the wax melts and c*omes back, it will weigh the same.

Lina:

Researcher (R): What is this?

Lina: A burning candle

R: What do you mean by burning?

L: It is hot, the heat it can kinda dissolve things and makes things into nothing.

R: What happens when a candle burns?

L: The wax becomes soft and nothing else, there is a chemical change.

R: What happens to the wax when a candle burns?

L: It melts and drops

R: Let's us say I put this candle on a balance and I light it up, take the reading at the beginning and after one hour, would the reading on the balance be less, the same or more?

L: I don't know . . . it changes . . . I don't know.

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[3] One student received a score of 100% and another received a score of 40%

R: How does the weight of the candle change during burning?

L: It stays the same because it will just fall down and make a solid and when it is a solid it will weigh the same thing as before.

R: Are there any changes that take place when a candle burns?

L: The wax becomes soft and nothing else.

R: What happens if we put an alcohol burner on a balance for some time, would its weight decrease, increase or stay the same?

L: The burner would weigh less because the alcohol is burning . . . the gas of the alcohol goes into the air and there is less alcohol.

Lina's and Dean's understandings seem to share the characteristics of the "phenomenal mental models" and "intuitive models" described by Vosniadou (1988, 1989), and "action knowledge" described in Linn and Songer (1991). Intuitive models, according to Vosniadou (1989), "give an account of the observed world as it is experienced through the human perceptual/cognitive apparatus" (P. 2) which is what Dean's and Lina's understandings seemed to accomplish because they were clearly cued by the visible aspects of the events they observed. Moreover, since these understandings "did not constitute a well-thought-out, explicit theory of burning" and "there was no evidence that all students used their observations to formulate a coherent theory of burning" (BouJaoude, 1991, page 700), these understandings can be called "action knowledge" defined by Linn and Songer (1991, p. 382) as "initial, unreflective responses that students make to events they encounter in their lives" (p. 382).

Construction of abstract understandings about burning.

Dean's and Lina's understandings were ascertained by asking them to predict and explain the results of selected experiments during instruction. In one of these experiments (Activity 1, Figure 1) a candle was placed on a scale and they were asked to predict the change in weight when the candle burned and to explain their predictions. Both students predicted that the candle would weigh less and asserted that the decrease in weight was due to the burning of the wick as illustrated in the following excerpts from their written responses when they were involved in Activity 1 during the first day of instruction:

Lina: The candle would weigh less because the wax will melt and the wick will be used up.

Dean: the candle will weigh less, but only a little because the wick will be consumed and some of it will change into gas. The wax only melts and then solidifies.

The above observations affirm the idea that Dean's and Lina's predictions were based on the visible aspects of the events they observed and on their belief that wax only melted during burning. It is noteworthy that Lina asserted that there would be no change in the weight of the candle in the pre-instruction interviews described above. In her response during the first lesson, however, she asserted that the weight would be less because the wick was "used up." This is an example of the fact that students' understandings were cued by the visible aspects of their experiences and that these understandings were inconsistent.

As described earlier (see description of instruction), the teacher attempted to focus on helping the students gradually bring their understandings in line with the accepted scientific theory of burning. To accomplish this goal, the students conducted five activities. In the first activity, the students realized that the loss in weight when a candle burned was greater than the weight of the wick (Activity 1); the second and third activities provided students with evidence that wax did not only melt but that part of it evaporated and that evaporation and burning were two distinct phenomena (Activities 2 and 3); the fourth activity showed them that soot was produced when a candle burned (Activity 4), while the fifth activity provided evidence that oxygen was needed for burning (Activity 5). The following excerpts illustrate the fact that the experiments were focusing Dean's and Lina's attention on their existing understandings and helping them to reflect on the results of the experiments and to incorporate the findings from these experiments into their existing understandings of burning. When they were asked about their interpretation of Activity 1 regarding the loss of weight of the candle in the post-instruction interview conducted after the first day of teaching, they responded as follows:

Lina: Well it was partly because of the wick, but it was not all of it. The weight of the wick was only 0.2 grams and the total loss in weight in a very short time was much more than the weight of the wick, so there had to be something else going on.

Dean: Well I mean because the decrease in weight is so much greater than the weight of the wick. The wick itself couldn't have been the only thing. I mean it could have been a little bit but not as much as I thought it would.

When Dean and Lina were asked about their definition of burning in the interview conducted after the second day of teaching , they responded as follows:

Dean: Well, I guess burning is a chemical reaction between oxygen and other substances and requires heat and then through . . . well a gas is given off . . . and heat and light . . . through the chemical change gases are released and when an object, you know, it weighs less when a gas is released.

Lina: Burning is . . . giving off carbon dioxide and carbon and also light, heat and other stuff . . . using oxygen and fuel. The chemicals or the carbon that was already in it is being given off so it makes the candle lighter.

Since Lina's and Dean's understandings of burning at this stage included a combination of phenomenal and scientific views constructed from reflecting upon the results of the experiments in which they were involved and from information presented by the teacher, these understandings share the characteristics of the "assimilatory models" or the "intuitive conceptions" described by Vosniadou (1989) and Linn and Songer (1991) respectively.

The above excerpts show that the activities conducted during the first few days of instruction demonstrated to Dean and Lina that burning involved giving off gases and other products and that it involved a weight loss. It is noteworthy that the activities with the candle were used at this stage because both the teacher and the researcher assumed that students' familiarity with candles might make the activities more relevant to their life experiences. In so doing, they might have led the students' to overgeneralize from this specific instance to all instances of burning. Indeed, this situation is not very different from what many classroom teachers do in their attempts to make teaching more relevant to their students.

But, since burning does not necessarily involve the production of a gas, the teacher and the researcher decided to demonstrate the reaction of oxygen with steel wool during the third day of teaching (Activity 6, Figure 1) to challenge Dean's and Lina's current definition. In this demonstration, equal quantities of steel wool were suspended from the arms of a scale and the students were asked to predict the direction in which the scale was going to tilt when the steel wool burned. In addition the students were asked to explain their predictions. The following excerpts provide Dean's and Lina's written predictions and explanations of the results of the experiment.

Lina: The balance is going to lean to the side that is not burning because when something burns it loses chemicals and weighs less.

Dean: The balance will lean to the side that is not burning like in other examples (candle, alcohol, and wood) the steel wool will weigh less after being burnt *because it will release gas or something.*

The results of the demonstration with steel wool contradicted Dean's and Lina's predictions. Consequently, they constructed a different explanation of the results for the demonstration. The following excerpts from the interview conducted after the third day of instruction provide Dean's and Lina's reactions to this demonstration.

Dean: Well I mean the oxygen had to be reacting so I figured if it wasn't making the balance do something to weigh lighter then I figured maybe it was just like reacting and forming a solid to make it heavier.

Lina: I said that it would go the opposite direction (the side that is not burning) because I thought that there are some chemicals being released but when it started going down I said that something has to be reacting with the steel wool to make it heavier.

Later during the same interview when they were asked to provide their definitions of burning, Dean and Lina said the following:

Dean: It (burning) is when oxygen reacts with a substance and a new substance is formed and sometimes substances are released like new stuff.

Lina: Well, I didn't think about burning much before, but burning is taking a fuel and having it react with oxygen and it does usually give things . . . It reacts with something to form something else, not necessarily a gas.

These definitions were much closer to the scientific definition of burning. It seems that the results of the demonstration with steel wool could not be accounted for by the students' previous definitions. This situation created a cognitive conflict and provided Dean and Lina with the experience necessary to formulate a new definition of burning as shown in the following excerpts from the interview conducted after class during the fifth day of instruction about burning.

Lina: Well the first couple of days when we talked about fuel and that something was released and then I believed that everything had something to be released and that's why things weigh less when they burn. Then we did the experiment with steel wool and I thought that something had to be released at first but then it reacted with oxygen and made it heavier and then I saw how much oxygen had to do with burning and the change in weight.

Dean: Well, the experiment with steel wool was the best since it showed us a lot of things. I mean even if the reaction is real slow or even if it makes an object heavier, it is still burning. The same reaction just different substances.

The demonstration seems to have provided Dean and Lina with a number of factors necessary for successful conceptual change. First, the conflict between their predictions and their observations required them to re-examine their prior conceptions. Researchers such as Burbules & Linn (1988), Darden (1992), Dreyfus et al. (1990), Hynd, McWhorter, Phares, and Suttles (1994), and Vosniadou (1994), have recognized the centrality of conflict and anomalous data in helping students' to reflect upon their prior knowledge and to change their conceptions. Second, the instructional and social contexts in which the demonstration took place were flexible enough to allow students to express their ideas freely, to suggest alternatives in a free environment, to test their ideas physically and logically, and interact freely with each other and with the teacher regarding content. Researchers such Caravita and Hallden (1994), Ebenezer and Gaskell (1995) and Linder (1993) have emphasized the role of contextual factors in conceptual change. Third, the conflict and the context may have motivated Dean and Lina to look for consistency between their ideas and their observations. The role of motivation has been emphasized by researchers such as Boyle and Magnusson (1993) and Pintrich, Marx, and Boyle (1993).

In short, Lina's and Dean's understandings before instruction were cued by the visible characteristics of the events they experienced in their everyday life. They were also inconsistent and task specific. Hence these understandings could be called "phenomenal models" (Vosniadou, 1988, P. 5) or "action knowledge" (Linn & Songer, 1991, P. 382). The sequence and results of the experiments conducted during the first few days of instruction and the teacher's encouragement helped Dean and Lina to reflect upon their understandings to formulate what Vosniadou (1988, p. 5) calls "assimilatory models" or what Linn and Songer (1991, p. 382) call "intuitive conceptions". These understandings were combinations of phenomenal and scientific views. Finally, the cognitive conflict created by the experiment with the steel wool seemed to have helped Dean and Lina reflect upon their intuitive conceptions to formulate an understanding that is closer to the scientific view of burning.

It seems that reflection is an important factor in helping Dean and Lina reach their final understandings about the concept of burning. Reflection and dialogue among the students and between the students and the teacher were encouraged throughout instruction. This course of action allowed the students to be watchful and thoughtful about their answers to questions in class. The following excerpts from the interviews conducted after the fifth day of instruction provides

Dean's reflections about the progress he achieved in class:

Dean: Well, I learned a whole lot about thinking . . . you know, not just about burning but about thinking and drawing conclusions from things . . . I mean besides learning I just . . . I learned a lot about burning and chemical reactions and how like things combine and on the thinking, well, I mean, I think it has helped me to reason like what is going on . . . at least where burning is concerned.

Learning as Conceptual Change

The process by which Dean and Lina constructed more organized knowledge structures during instruction is comparable to Strike's (1983, 1987) characterization of learning within a conceptual change, constructivist framework. According to Strike (1983, 1987), learning in a constructivist perspective involves relating new concepts to existing ones. The student who learns a new idea locates it in a network of concepts, uses evidence to test its plausibility, and attempts to reflect on its consistency with other concepts.

During instruction, prediction helped Dean and Lina to ascertain their existing understandings about burning. They then applied these understandings to the results of a number of demonstrations or activities that were performed in class. The experiments provided them with opportunities to collect evidence to test their understandings. When evidence showed that these understandings were unacceptable, they constructed new and more scientifically acceptable ones. Finally these new understandings were reinforced when Dean and Lina tested and applied them in familiar situations. As a result, they began to construct a more scientifically acceptable understanding of the concept of burning.

Dean's and Lina's initial understandings were characterized as phenomenal models or action knowledge because they were cued by the observable phenomena, inconsistent, and fragmented. Instruction, and possibly the interviews, seemed to have helped the two students to formulate intuitive conceptions or assimilatory models that contained elements of the phenomenal models and scientific views. Finally, the cognitive conflict created by the experiment with steel wool helped the students formulate their final understandings of burning. Dean and Lina changed their initial understandings when convincing evidence was presented for this purpose and when they reflected on this evidence in relation to their existing understandings. Moreover, during instruction Dean and Lina seemed to organize their newly acquired concepts to construct a more abstract understanding of burning. The importance of cognitive conflict in the process of conceptual change, however, should not be underestimated. The excerpts provided above showed that the steel wool experiment provided an important stimulus for the students to re-examine their existing understandings and attempt to adjust these understandings based on the new observations.

Implications for Teaching

While generalizing from case studies must be done cautiously, the following comments might provide insights into the problems that students face while studying science. First, the detailed description of conceptual change in Dean and Lina highlights the importance of providing students with a variety of concrete examples covering a wide range of instances of a concept to overcome the problem of over-generalizing or under-generalizing. Second, prediction seemed to be an effective technique to allow the students to disclose their understandings. Additionally, recording the predictions provided the students with a "paper memory" (Rowell & Dawson, 1985, p. 335) to assure the retention of predictions for later comparison with observations. Another technique that seemed to work well was providing students with ample opportunities to relate their newly constructed explanations to everyday events, thus minimizing the possibility of compartmentalizing their scientific information. Third, cognitive conflict and reflection seem to be efficient mechanisms that help students to examine their existing understandings and to attempt aligning these understandings with accepted scientific theory. Fourth, providing students with enough concrete experiences of the right type and with appropriate opportunities to reflect upon these experiences is an important determiner of successful conceptual change. These experiences should be presented in a supportive environment, in which making mistakes is not penalized, to maximize students' engagement and motivation. Finally, the role of contextual and motivational factors in conceptual change warrants more attention because of the possible contribution to the success of conceptual change.

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