JOURNAL
OF BALTIC
SCIENCE
EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

BARRIERS TO STUDENTS' CREATIVE EVALUATION OF UNEXPECTED EXPERIMENTAL FINDINGS

Hakki Kadayifci

Abstract. *Science lecturers usually do not pay special attention to giving students the chance to evaluate persistent unexpected experimental findings that they cannot explain with their existing theories, propose alternative hypotheses and develop new theories in inquiry tasks at schools, despite the importance of these processes in scientific discoveries. Students' reactions to this type of findings have been a subject for conceptual change studies that new theories were presented to explain the findings. This research, in contrast, examined students' ways of interpreting their unexpected experimental findings about the molar mass of the sulfur element while hiding a new theory, and their barriers to discovering the scientific explanation of these findings, which is new to them, in the framework of the creativity paradigm. The research was conducted with 155 first-year undergraduate students who were enrolled in a chemistry laboratory course. A majority of the participants said that the unexpected findings might have resulted from experimental errors or methodical problems. Few students stated that these findings might be valid and have a new explanation. The barriers to students' discovery of new scientific explanation for findings were classified as: lack of pre-knowledge, obstacles of existing structures, failure of creative cognitive processes and social-personal blocks.*

Keywords: *creativity barriers, laboratory work, students' explanations, unexpected findings.*

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Introduction

At the beginning of an experiment, scientists mostly have some predictions that reflect their theoretical approach for experimental findings. Sometimes, the experimental findings might not be consistent with the initial hypothesis and might not be explained by the current theory. Kuhn (1962) emphasized that coping with persistent and unexpected findings was important since they can be a source of discovery in science. Unlike the inductivist-accretionist approach, the rationalist- eurekaist scientific approach claims that new theoretical developments occur thanks to the mental structures of scientists and the application of brand new perspectives to new findings (Clement, 2008).

Novel and suitable production has been called creativity, which is a historically natural concept (Starko, 2013; Sternberg & Lubart, 1999). However, there are two conflicting perspectives about how creative production occurs. Most psychology researchers believe that creativity requires handling situations in totally different ways and mental leaps (Smith, Ward & Finke, 1995; Sternberg & Davidson, 1999; Thagard, 2010). On the other hand, some researchers regard unconventional production as a result of ordinary cognitive processes (Perkins, 2000; Weisberg, 2014). Even though experimental (Metcalfe & Wiebe, 1987) and neuroimaging (Subramaniam, Kounios, Parrish & Jung-Beeman, 2009) data mainly support the first view, conflict about this subject has yet to end. Either by abandoning the previous theory and using a new perspective or by producing a new theory through ordinary thought processes based on the previous theory, both views see the development of a new theory that explains unexpected findings as a creative act (Garg & Garg, 2002).

Until now, cognitive functions such as perception and memory have been the most studied factors in creative problem solving. In early twentieth century, associationists conducted studies on problem solving that highlight the positive contribution of knowledge and experience (Thorndike, 1911). In later years, Gestalt psychologists studied the illumination stage of Wallas' (1926) four-stage model of the creative process and explained creative problem solution with the restructuring of the problem, which they termed productive thinking. They claimed that creative problem solution was only possible through the wholesale abandonment of current structures and a sudden leap. They supported this idea with experimental studies on process fixation, functional fixedness and perceptual fixation, all of which hinder problem resolution (Dodds & Smith, 1999). A newer cognitivist view focused mainly on cognitive processes and emphasized the use of memory and heuristics as well as perception (Weisberg, 2006).

The idea that insightful problem solving differs from the analytical problem solving, which is based on knowledge and experience, is still valid today. For instance, Ohslon (1992) explained insight with representative change theory, which he used to describe the "switch when stuck" heuristic, based on the information-processing perspective. However, there is considerable criticism of this approach for including the failure of restructuring in several problems that require creative thinking if there is not sufficient pre-knowledge, and the possibility that the solution may not be as simple as it is in the experiments analyzed by Gestalt psychologists even if restructuring occurs (Weisberg, 2006). Personality and social environment are also particularly important for creative production in addition to knowledge and thinking styles (Amabile, 1983).

According to Kind and Kind (2007), one framework of creativity in science education is assisting students to understand how scientists work creatively to develop new theories. It might be more challenging for science students to develop a scientific explanation for a phenomenon that they cannot explain at first sight with current conceptual structures than simply reasoning about the situation. This might require students to make major changes in categories, rather than just including the concepts isolated from the phenomenon they were experiencing in the conceptual categories they had in mind. In science, this type of a radical conceptual change is what explains unexpected findings, and it is found in many types of creative thinking and reasoning, including the production of new theories (Chiu, 1999; Magnani, 2009; Nersessian, 2008; Thagard, 2012). It is also possible to explain the ability to think of an element of an ontological category in the context of another ontological category with flexibility, which is also accepted as a component of creativity (Chi, 1997). The concept of "p-creativity" (Boden, 2004) or "mini-c" (Kaufman & Beghetto, 2009) describes science students' discovery of the explanation of a phenomenon, even if it has been previously demonstrated by scientists. In this context, the formulation of new theoretical explanations for unexpected findings by science students is qualified as a creative activity (Gang & Gang, 2002).

In authentic scientific inquires, unexpected findings are very common (Dunbar, 2000). Even though it is accepted as critical for learning the nature of scientific knowledge that students come face to face with insistent unexpected findings, suggest alternative hypotheses and have the opportunity to develop theories, this is not so for the tasks of inquiry-type lessons (AAAS, 1994; NRC, 1996). This research reflects on this type of initiative.

Science Students' Reactions to Unexpected Findings

The rejection or ignoring of unexpected findings by science students is a quite common reaction. In science education, students' reactions to unexpected findings are usually studied using the conceptual change paradigm in research that presents the new theory as well as students' current conception. Chinn and Brawer (1993) proposed taxonomy of students' responses to anomalous data, which begins with the stage of ignoring the data and culminates in the stage of theoretical change. In another study with a larger sample (Chinn & Brawer, 1998), they used this taxonomy to examine university students' evaluation of a number of data that were consistent with the asteroid theory of dinosaur extinction and of an unexpected iridium datum that could be explained with the alternative volcano theory. The participants had three common justifications for rejecting the anomalous data: 1) methodological error, a fundamental methodological error in obtaining the data, which makes the data erroneous, 2) random error, the data being only the product of the current random diversity, and 3) the data being a joke or completely fake.

Lin (2007) did a study of university students' reactions to the anomalous data they obtained from laboratory experiments. The discussion sections of more than 500 reports written by the participants on a) melting point and crystallization, b) simple distillation and c) electrochemistry experiments were described using the taxonomy by Chinn and Brewer (1993). Unlike Chinn and Brawer (1998), the study classified students' reasons for rejecting anomalous data as personal error, instrumental error, methodical error and indefinite error. Students' persistence in their initial theories as they ignored anomalous data or deemed the data invalid was explained by resistance to conceptual change.

Studies in experimental psychology usually do not present a new theory for unexpected findings. In relation to this point, there are two spaces (experiment and hypothesis), according to the Scientific Discovery as Dual

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Search (SDDS) model proposed by Klahr and Dunbar (1988) based on the information processing approach, to explain the search for an interpretation to explain unexpected experimental findings. According to this model, the experimenters initially suspect the validity of the unexpected findings and look for problems in the experiments that would confirm their current hypotheses (the space of experiment). When there are no problems detected in the experiment, experimenters abandon their initial hypotheses and try produce alternative hypotheses to explain the findings (the space of hypothesis). Similar studies conducted with non-scientists observed their problem-solving processes when one or more angles of the real world science were isolated, and they were conducted in the general field (e.g., Croker & Buchaman, 2011; Davis & Fischhoff, 2014; Dunbar, 1993; Dunbar & Fugelsang, 2005). These studies may be regarded as general examples of the SDDS model.

Fugelsang, Stein, Green and Dunbar (2004) held a study with both scientists and students. They observed scientists in their natural working environment. The study determined that the scientists blamed the experiments' methods for a majority of the findings that were inconsistent with their hypotheses and suggested different theoretical explanations for few of them. They also found that there were major changes in scientists' perspectives when the inconsistent findings reoccurred. In such cases, they offered more theoretical explanations than methodological explanations. The continuation of the study indicated that the students who used the controlled scientific thinking simulator developed to use thinking methods in scientific environments had similar reactions to the scientists.

There are few studies that examine how science students cope with unexpected findings in hands-on experiments, which are in a specific field and closer to the real environments where scientific discoveries happen. Lim and Kang (2010) examined the perception of unexpected experimental findings by university chemistry students when doing hands-on problem-solving experiments. In this study, the students were posed the question, "What would you consider the reason for the results if you derive unexpected results despite the given experimental method?". The types of perception in the participants that particularly focus on the method were categorized into three groups: the difference between the theory and practice, missing factors between the lines of the survey sheet and lack of experimental skills.

Proposing a Novel Hypothesis to Explain Unexpected Findings and Barriers to Creativity

In the process of testing hypotheses, the studies usually focused on confirmation bias, which has been studied for a very long time as a human tendency, being the main reason for looking for errors in cases of unexpected findings (Wason, 1960). Confirmation bias refers to the predisposition to look for data that will confirm current hypotheses or interpret data so as to confirm them (Nickerson, 1998). It prevents thinking about alternative hypotheses and is considered an error in creative thinking (Garg ve Garg, 2002, Mumford et al, 2006).

Confirmation bias and other mental fixations prevent the creation of alternative hypotheses when people have the problem of inconsistency between findings and current hypotheses. There are other thinking types about search of scientific theoretical explanations in the space of hypothesis. In this context, studies of the mental functions that shape scientific creativity are distributed in a variety of fields, including: imagery (Clement, 2008), establishing innovative correlations between concepts (Hadzigeorgios et al 2012; Thagard & Stewart, 2011), analogical thinking (Dunbar Fugelsang, 2005; Gentner, 2002; Hadzigeorgios et al, 2012; Holyoak & Thagard, 1996), using weak methods (Klahr & Simon, 1999) and collaborative thinking (Dunbar, 2000) as well as content knowledge and reasoning.

In general, there are more holistic studies of barriers to creativity. A number of scholars have suggested different classifications for barriers to creativity. For instance, Parnes (1967) divided these obstacles into two groups which are internal factors and external restrictions. Rickard and Jones (1991) modeled these obstacles as strategic factors, values, perceptual factors, and self-image factors. Probably, the most remarkable classification that can be accepted as a foundation for scientific obstacles to creativity was proposed by Adams (2001) who focused on creative problem solving. Davis' (1999) classification resembles that of Adams (2001). It includes learning and habit, rules and traditions, perceptual barriers, cultural barriers and emotional barriers. In addition, obstacles to the establishment of a theoretical correlation between the creation of a new theory to explain unexpected findings and scientific creativity, a complex operation, have not been studied considering only barriers to creativity, even though it is possible to establish this correlation.

The analysis of the factors preventing creativity in the learning environment has been the subject of the limited studies of inventory implementation and introspective studies. There are a variety of classifications of creativity barriers suggested by these studies. For instance, de Alencar (2001) suggests four factors that hinder university students' creativity, which are inhibition/shyness, lack of time/opportunity, social repression, and lack of motivation.

De Alencar (2001) also says that the most frequent barriers are lack of time/opportunity and inhibition/shyness. Hilal, Husin and Zayed (2013) also conducted a study with university students and examined the barriers of self-concept, compliance need, abstract ability, systematic analysis, task achievement, and task environmental circumstances. They conclude that the most critical barriers are those related to task achievement. Man, Susanti and Indrajaya (2007) identified students' creativity barriers before the activities about the training of creative thinking. Based on their interviews, they determined the types of barriers as lack of practice/skill, forgetfulness, laziness, lack of time, cultural/environmental reasons, lack of materials and complexity/difficulty.

The Importance of the Research

As science students develop an understanding of the nature of scientific discoveries, it is important that they realize how to cope with unexpected experimental scientific findings, taking their role in scientific discoveries into consideration. In many cases, scientists use thinking methods that hinder their scientific creativity when working with unexpected findings. Science students' perspectives on the obstacles of explaining unexpected findings in an innovative manner have not been analyzed holistically.

This issue was the biggest motivation for this research to reveal how science students interpret unexpected findings and their barriers to discover the new theoretical scientific explanation which clarified these findings. The researcher believed that the suitable way to achieve this would be:

- not providing students with a new theoretical explanation that clarified the unexpected findings before they interpreted these findings, which was a different practice from the relevant studies of conceptual change in the education field;
- including the statement "the findings being inconsistent with the existing hypotheses of students" in the format of an ill-structured insight problem with the purpose of making an effective determination of the barriers beyond the confirmation bias which is frequently observed in scientific studies; and
- conducting the research with an inquiry-type hands-on laboratory experiment related to the domain-specific subject, since it was made in a similar environment to those of real scientific experiments, which was also different from many studies in psychology.

Problem Situation

The researcher has been teaching a chemistry laboratory course to first-year students in science teaching programs (physics, chemistry, biology, and science) in a faculty of education for many years. The course includes an experiment aimed at determining the molar mass of the elemental sulfur, and students expect that the result would be 32 g/mol, which is sulfur's atomic mass. However, the experimental findings are very different and show that the result is approximately 256 g/mol since sulfur is found in molecular structure (S_8) in nature instead of atomic structure.

The researcher found it noteworthy that students fail to discover the scientific explanation of the unexpected findings, which were new to them, about the molar mass of sulfur and students are very much surprised when they learn this explanation for the findings, wondering why they could not figure it out. This reaction is very similar to the surprised reaction people give when they learn about an unrecognized solution to a problem that can only be solved by getting out of regular thought patterns and using creative thinking (Batchelder & Alexander, 2012). In this sense, the researcher determined that the experiment was applicable to identify students' barriers to discovering the unexpected findings' scientific explanation, which was also new to them.

Taking all of these points into consideration, the research questions are:

1. How do students interpret the unexpected experimental findings related to molar mass of sulfur which are consistent with the findings of the other experiment groups in the laboratory?
2. What are students' barriers to discovering the scientifically-accepted theoretical explanation of the unexpected experimental findings related to molar mass of sulfur?

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Methodology of Research

Research Method

This research consists of qualitative research since the researcher endeavored to determine the participants' perceptions of an event (Ary, Jacobs, Sorensen & Walker, 2010). The researcher performed document analysis on the discussion sections in the lab reports to determine the students' approaches to the interpretation of unexpected experimental findings. It is a common method to analyze students' lab reports to answer these types of research questions (e.g., Lin, 2007; Toplis, 2007).

Participants

In the research, the cluster sampling has been preferred as sampling method. The research included all students in all 11 groups attending to the experiment of 'The Determination of the Molar Mass of the Elemental Sulfur by Freezing Point Depression' in the 2014 spring, 2014 fall and 2015 spring semesters, which was the eighth experiment in the basic chemistry laboratory course, one of the first-year courses in the education faculty of a Turkish public university. The basic chemistry laboratory course is one of the fall semester courses in the physics and chemistry teaching programs and a spring semester courses in the biology and science teaching programs. It is taught with the same content in all of these branches. The research included 155 students from the programs of physics (16 and 12 participants), chemistry (15 and 9 participants), biology (18 participants), and science (15, 17, 14, 14, 16 and 9 participants) teaching.

Obtaining valid findings in the research was primarily dependent on the participants' lack of information about polyatomic elements before the experiment. In Turkey, students are placed in universities based on their achievement in a general entrance exam. The participants of this research took chemistry lessons in high school for four years (grade 9 to 12) before the research, obtained similar scores on the entrance exam and were placed in departments. They were taking the basic chemistry course four hours a week during the research. Grades 9-12 chemistry curriculums in Turkey involves the examples of hydrogen (H_2), nitrogen (N_2) and ozone (O_3) indicating that molecular elements could be diatomic or triatomic, but does not provide any examples for polyatomic elements such as phosphor (P_4) and sulfur (S_8) (TTKB, 2013). There were also no findings showing that the students were informed about the polyatomic elements in the basic chemistry course they were attending during the research. For this reason, the researcher assumed that the students knew the conceptual categories of the diatomic and triatomic molecular elements before the research, but were not informed about the polyatomic elements.

Procedure

The research was conducted during a two-hour laboratory period, and the experiment was performed using the structured inquiry method. In a structured inquiry method, the lecturer determines the research question and the data collection method, and the students collect, analyze and interpret the data (Blanchard et al, 2010). The researcher participated in this research's experiment as the lecturer and a participant observer. The participants did the experiment in self-selected groups of two or three, or rarely, four students.

"The Determination of the Molar Mass of the Elemental Sulfur by Freezing Point Depression" is a widely-known experiment, and its details are included in the laboratory manual of Zumdahl and Zumdahl (2013). The experiment involved Blagden's Law, which analyzed the relationship between the decrease in the freezing point and the concentration of solution, and the methodological operations using this law to calculate the molar mass of sulfur dissolved in naphthalene.

Here are steps of the lesson:

1. Introduction: At the beginning of the experiment, the lecturer drew attention to the students' pre-knowledge to use to explain their experimental findings. The lecturer reminded students of the act of pouring salt on the roads in winter to prevent them from freezing. Based on experience, the students argued that the freezing point depression was related to the salt concentration. Then, the lecturer introduced Blagden's Law. Afterwards, the students solved some exercise problems about simple instances of Blagden's Law, the molar mass values of different substances and the molecular structure of substances. The students were very successful with the problems about the molar masses and molecular

structures of diatomic and triatomic elements. Before the experiment, the lecturer and the students discussed the experimental measurements needed to calculate the molar mass of sulfur dissolved in naphthalene using Blagden's formula for freezing-point depression.

2. Posing a Hypothesis: Each student wrote a hypothesis reflecting their estimation of the molar mass of the sulfur. The students anticipated that the molar mass of sulfur would be 32 g/mol, based on its atomic mass.
3. Reach the (Unexpected) Findings: All the experimental groups did the experiment. They wrote their measurements and the molar mass value they calculated for sulfur using Blagden's formula on the board to be seen clearly by the other groups. The experimental groups calculated similar values for the sulfur's molar mass, which were approximately eight times (~256 g/mol) the expected value (32 g/mol), thus repeatedly obtaining unexpected findings.
4. Refuting/Confirming the Hypotheses and Explaining the Findings: The participants evaluated their initial hypotheses as well as their methods and the evidence they collected in order to confirm or refute their initial hypotheses. Then, they wrote their explanations of the unexpected findings on the discussion section of their own lab report.
5. Scientific Explanation of the Findings: At the end of the experiment, the lecturer explained the unexpected experimental findings scientifically as the result of sulfur's polyatomic molecular structure (S_8), which gives it a molar mass close to the value calculated in the experiment (~256 g/mol).
6. Discovery Barriers: The participants wrote down their reasons for not discovering this scientific explanation of the unexpected experimental findings.

Data Sources and Analysis

Students begin interpreting their result immediately after they reach unexpected experimental findings. Similarly, they most strongly focus on creativity barriers just after they learn about the scientific explanation. In addition, it is not desirable for students to share the scientific explanation with students who would perform the experiment during a later course meeting since the experiment was conducted with different participant groups at different times. For all these reasons, the researcher decided to receive participants' opinions as written statements during the lesson.

Participants' approaches to interpreting the unexpected experimental findings were determined by analyzing their statements from the discussion section of the written lab reports. Participants' barriers to discovering scientific explanations for unexpected findings were determined by the analysis of the written statements they created using their introspections. As a psychological resource of information, introspection is a person's analysis of own conscious thoughts and feelings (Schultz & Schultz, 2007). Right after they learned the scientific explanation, the participants were asked to re-read the discussion section of the lab report, recall what they were thinking while interpreting the findings, and write the factors that prevented them from discovering the scientific explanation of the unexpected findings and interpret the findings in a different way. These written statements were analyzed using the creativity barriers paradigm (Amabile, 1983; Davis, 1999; Weisberg, 2006).

The participants' statements about discovery barriers were encoded with content analysis of the statements. Since none of the participants knew about polyatomic elements before the experiment, they did not know about sulfur's S_8 structure. The general structure of the accepted discovery barriers included a cause and effect relationship, which was explained as follows: "My interpretation of the experiment result (Ma=256 g/mol) was not that the sulfur element could have a molecular structure. Instead, I made a different interpretation. Because ... / The reason that I made this interpretation was ... / The reason that I could not discover it was ..."

Codes were determined and categorized by two separate researchers to increase the internal validity of the research. Final categories were determined with consensus. Tables 1 and 2 present the samples of participants' direct statements for the categories. The classification of similar categories under themes was based on the existing theoretical framework in the relevant literature. There was no significant difference between the distributions of interpretation and barrier themes in the participant groups (respectively $\chi^2 = 25.29$, df = 20, p = .191 and $\chi^2 = 53.79$, df = 50, p = .332). Therefore, the analysis had an acceptable external validity. In the reliability analysis, approximately 10% of the data were encoded by two field experts, and there was a strong uniformity between the coders (Kappa = .82 for interpretations, Kappa = .73 for barriers).

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Results of Research

A. Students' Interpretations of Unexpected Experimental Findings about The Molar Mass of Elemental Sulfur

More than four-fifth of the participants (128 students) wrote one or more acceptable interpretations to explain the unexpected experimental findings. There were three different approaches in participants' interpretations, which were (a) explaining with an experimental error, (b) proposing a methodological problem, and (c) accepting the findings as valid (Figure 1).

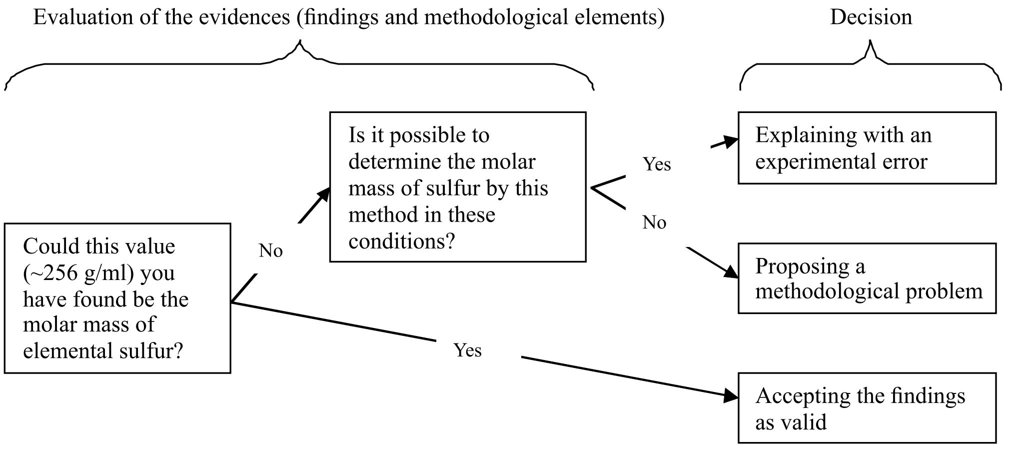

Figure 1: The ideational structure of participants' interpretative approaches to the unexpected findings.

Each participant had one or more interpretations of the findings. Table 1 presents the interpretation categories, sample participant statements, and the number of participants. A majority of the participants said in their interpretations that the experimental findings could be invalid since there might have been experimental errors (78 students) or methodical problems (63 students). There were fewer students (24 students) who said that the experimental findings could be valid; that is, there could be a new theoretical explanation which was different from the one they hypothesized at the beginning.

Table 1. Students' interpretations of unexpected experimental findings.

Interpretive approaches	Number of students	Sample participant statement
Explaining with an experimental error	78	
personal errors in temperature measurement	42	The temperature could have been measured incorrectly.
random errors caused by the sensitivity of the measuring instruments	9	I believe factors caused by the sensitivity of the thermometer were influential.
personal errors which led to a change in the concentration of the solute (sulfur)	20	I believe this was caused by the fact that there was some naphthalene left around the thermometer during the experiment, which reduced the amount of solvent, and we did not take this into consideration when doing the calculations.
personal errors in calculation	7	I might have done the calculations carelessly.
other experimental errors without any given source	15	There might have been some experimental errors.
Proposing a methodological problem	63	
use of an incorrect/wrong method	5	We found an incorrect value for the molar mass of sulfur using this method.

Interpretive approaches	Number of students	Sample participant statement
experimental conditions being inconsistent with the standards	36	Laboratory conditions might have affected the experimental result.
equipment errors caused by scales that were also used by other students	5	Is it possible that we made errors in the amount of the material we used.
specific changes in solute concentration	14	The mass of naphthalene changes since it vaporizes when heated.
errors in the mathematical formula	12	There might have been a problem caused by the units we used.
Accepting the findings as valid	24	
and proposing a new theoretical explanation	10	The structure of the sulfur particles changed after reacting to naphthalene.
yet not proposing a new theoretical explanation	14	The molar mass of elemental sulfur may be close to the value we calculated.
Other	27	
no answer or comment	21	
unsuitable interpretation	6	It is necessary to use Kelvins instead of degrees.

Explaining with an experimental error

According to this approach, students reached unexpected findings (approximately 256 g/mol) due to random experimental errors, and they believed it was possible to determine the molar mass of sulfur in the expected amount (32 g/mol) using the prescribed methodology. Random experimental errors can influence on the findings of experimental groups because many individuals are using different amounts of substances and sharing equipment and thermometers; this influence can be in a variety of directions and severity. Thus, it is an expected outcome that the random errors in an average result are reduced as the number of the experiment groups in the laboratory increase.

Experimental error sources which were most frequently stated by the students were measuring temperature with a thermometer (42 students) and the change in the concentration of the solute (sulfur) due to reasons such as spilling or sticking to the wall of the tube. Other sources for experimental error were the sensitivity of measuring instruments, calculation errors, and experimenter error. The remaining participants did not state a possible source of experimental error (Table 1).

Proposing a methodological problem

According to this approach, incorrect findings were generated since it was not possible to determine the molar mass of the sulfur as being close to the expected value (32 g/mol) due to problems with the methodology and experimental conditions. In contrast to the random experimental errors, systematic errors and problems cannot be eliminated by increasing the number of experiment groups and instead the result from the experiment method itself. The environmental conditions and jointly-used scales were included in this category. The similar findings reached by the experiment groups made it more rational to propose methodological problems as the reason for the findings than proposing random experimental errors. However, the possible effects of the methodological problems indicated by the participants were not enough to explain why the findings were nearly eight times larger (approximately 256 g/mol) than the expected value.

The most common interpretation proposed by the participants using this approach to explain unexpected findings was that they performed the experiment in conditions different from the standards (36 students). According to the participants, some dimensions in the formula used to calculate the freezing point, such as the cryoscopic constant and freezing point, were affected by environmental conditions, including external pressure. They claimed that all experimental findings were influenced by this factor since all groups performed their experiments in the same environment.

The other important methodological problems proposed by the participants were the remarkable change in the concentration of the solute due to various reasons such as solubility (14 students) and using an inappropriate unit in the mathematical formula (12 students). In addition, several participants stated that the overall methodology was incorrect or that measurement errors caused by shared scales affected the findings of each group in a similar way.

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Accepting the findings as valid

According to this approach, the unexpected findings of the experiment were correct. Therefore, the main problem lies in the expectations about the experimental findings made before preforming the experiment. Participants who interpreted the results in this way believed that the molar mass of sulfur may in fact be this unexpected value (approximately 256 g/mol) and the findings may have a different theoretical explanation. All participants proposing that the unexpected experimental findings which were consistent with the findings of the experimental groups could be valid, that they might be correct and have a different theoretical explanation other than the known explanation (10 students), and those trying to make a new theoretical explanation to explain these findings (14 students) were included in this category.

B. Students' Barriers to Discovery of Molecular Sulfur (S_8)

A majority of the participants (135 students) identified one or more acceptable barriers to discovery. As taking account of problem solving steps, categories of barriers gathered under the themes at Figure 2.

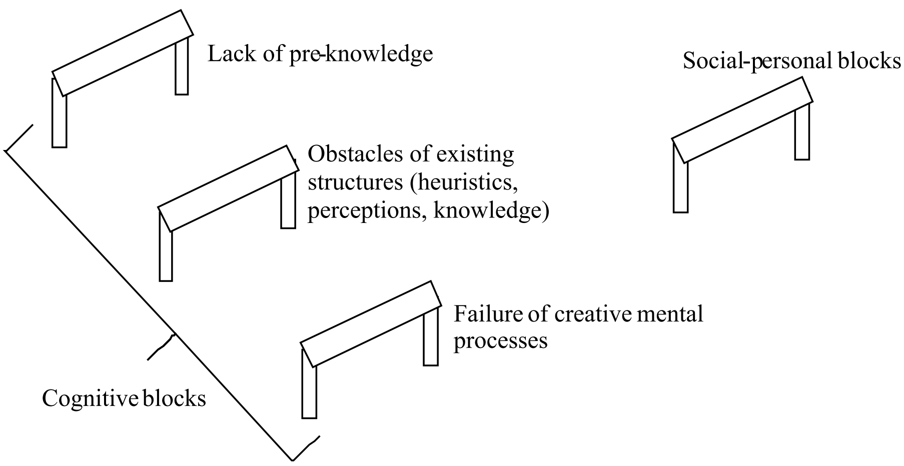

Figure 2: Students' barriers about discovering of S_8 molecular structure.

The barriers to discovery reported by the participants and their frequencies are shown in Table 2. The number of the participants who reported cognitive barriers was bigger than those who reported social or personal barriers (22 students). Table 2 shows that there was in general a balanced distribution of cognitive barriers: lack of pre-knowledge required to creatively evaluate unexpected findings (40 students), having mental structures that prevented them from making the discovery (heuristics: 44, perceptions: 17 and knowledge: 37 students), and failure to do the required cognitive process (42 students).

Table 2. Barriers to discovering that sulfur has a molecular structure by thinking creatively.

Discovery Barriers	Number of students	Participants' Statements
Lack of pre-knowledge	40	To be honest, I failed to estimate the result since I did not have sufficient chemistry knowledge.
Obstacles of existing heuristics	44	Because we always think that we did the experiment incorrectly when the experiment result is different from our expectation.
Obstacles of existing perceptions	17	We could not make the discovery because we got stuck with the indication of 32 g/mol in the periodic table.
Obstacles of existing knowledge	37	
A majority of the commonly-known elements being monoatomic.	17	When I thought of the elements, I first considered the monoatomic ones.

Having mostly used the atomic mass of the elements as their molar mass.	6	We considered the molar mass for all elements in the periodic table as their atomic mass and use that value for calculations. I did not think that we should use their forms in nature since we had not seen this before.
The widely-known elements being either diatomic or triatomic (e.g. H2, O3, Cl2).	9	I did not consider that it could have a structure of S8 or S10 since we were always taught that it could only have a certain molecular structure.
Learning related to the subject from unknown sources	6	Our prior knowledge prevented us from making the correct estimation.
Failure of creative cognitive processes	42	
Failure to make the suitable mental connections among the pre-knowledge	15	I could not make a connection between the types of knowledge, and I could not explain the reason for the result.
Failure to imagine the S8 molecule	11	I didn't even think that it could have eight atoms when I thought of the molecular structure of S8 and its connections.
Failure to think that sulfur could have an atomic structure with more than two or three atoms	12	If the result was twice the value I had estimated, I would think that its structure could be S2 . The reason we did not make the correct estimation was that we did not think sulfur could be found in a molecular or polyatomic form in nature.
Being prevented by the consideration of a different theoretical explanation	6	The fact that we heated sulfur prevented me from thinking further. I thought that the molar mass had an unexpected value due to a possible chemical change.
Social-personal blocks	22	
The structure and rules of the school	18	It is probable that I did not look for a new perspective because the educational system directs us to memorize things and promotes acceptance more than thinking.
The pressure to seek approval	7	I considered that it could be a different situation, but then I decided that it could be hard to understand if I wrote such a statement.
Unaccepted responses	20	
Participants who wrote down only unaccepted barriers to discovery	4	I did not know that sulfur was found in a S8 molecular state in nature.
Participants who did not respond or did not include any barriers to discovery in their responses	16	

Lack of pre-knowledge

The participants who stated that they had barriers related to their pre-knowledge said that they could not produce new ideas since they did not have sufficient content knowledge. These participants said that they had deficiencies in their general knowledge rather than specific missing points or mistakes.

Obstacles of existing structures

Another barrier was that the participants had mental structures that prevented them from thinking that unexpected findings could have a new theoretical explanation that differed from what they initially thought. These structures were studied under three headings.

Heuristics: Some participants said that they preferred to use the heuristic of experimental error or methodological problems to explain unexpected experimental findings. They said that they used this heuristic based on their previous laboratory experiences. Sticking to their heuristics prevented these students from proposing new hypotheses.

Perceptions: Some of the participants stated that they had certain perceptions in the laboratory environment that supported their initial hypotheses. These perceptions were the S symbol and the 32.00 atomic mass for sulfur they saw on the periodic table hung in the laboratory. This perception supported their belief that sulfur is monoatomic, and its molar mass is equal to its atomic mass. Thus, it prevented them from considering that the molar mass they obtained (~256 g/mol) could be valid, and that sulfur could have a polyatomic structure (S_8).

Knowledge: In contrast with the lack of pre-knowledge, this heading indicates the obvious knowledge that the participants already had to support their initial hypothesis. The participants occasionally gave examples of experi-

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

ences for supporting their prevented knowledge. These experiences were: considering elements as monoatomic when studying them in the past (17 students), using the atomic mass values of elements in their calculations in general as molar mass values (6 students), and the molecular elements they had learned being either diatomic or triatomic (e.g., H_2, O_2, O_3 and Cl_2) (9 students). In addition, six participants said that previous learning related to the subject prevented them without specifying what they had learned.

Failure of creative cognitive processes

Beyond lack of pre-knowledge or having mental structures that prevented the students from making the discovery, this deficiency indicates the inability to perform the mental operations required to produce innovative and useful ideas. Some of the participants said that they were not able to perform the necessary mental operations to make the suitable theoretical explanation (polyatomic molecular element) even though they recognized the possibility of a new theoretical explanation for the unexpected findings. The mental operations that the students said they could not perform were building suitable correlations with their pre-knowledge (15 students), imagining the 8-atom sulfur molecule (11 students) and considering that molecular elements could have more than three atoms like molecular compounds (12 students). This theme also included the consideration of different theoretical explanations by some of the students (6 students) instead of the scientific explanation (S_8 molecule).

Social-personal blocks

Finally, some of the participants indicated factors other than cognitive factors, which were related to the structure of the school (18 students) or the pressure to seek approval (7 students). These barriers were categorized as social-personal blocks. Some participants said that they could not think in a creative manner in this type of environment due to the school's rules which restricted them from generating new opinions in general. They said that the educational system and learning environments they had experienced until then provided them only with theoretical knowledge, directed them to memorize things and gave them the ready-made information, advocated passive acceptance and did not support questioning, thinking or researching, all of which killed their curiosity. Some participants also said that they had considered the possibility of sulfur having a molar mass of 256, a theoretical explanation for that result or sulfur being molecular. However, they did not write down their opinions since they were not completely sure and thought that their idea did not make any sense. This means that they did not explain personal opinions due to the pressure to seek approval created by social adaptation.

Discussion

This research initially determined that science students had three ways of interpreting repeated unexpected findings they personally derived in a hands-on chemistry experiment, a type of structured inquiry. These were: (a) experimental error, (b) methodological problems and (c) accepting the findings as valid. This classification is highly consistent with studies in psychology (Croker & Buchaman, 2010; Davis & Fischhoff, 2014), studies conducted with scientists who were observed doing their own research (Dunbar, 2000) and conceptual change studies based on students' reactions to unexpected findings (Chin & Brewer, 1998; Lin, 2007).

Even though the experimental findings (~256 g/mol) were quite different from what was expected (32 g/mol), and these findings were repeated when the other experimental groups obtained similar findings, a majority of the participants did not consider that the findings might be valid and thought that the unexpected findings were erroneous. Previous studies also observed that scientists tend to change their hypotheses when unexpected findings were repeated (Dunbar, 1993; Fugelsang et al, 2004). Inexperience might be the reason why most of this research's participants did not change their hypotheses.

Seeing unexpected findings as invalid can result from confirmation bias (Dunbar, 2000), the idea of the possibility of something going wrong with the experiment (Chinn ve Brewer, 1993) and resistance to conceptual change (Chi, 2008), all of which have already been described. In this research, the researher focused on identifies additional reasons. The discovery of the scientific explanation by evaluating unexpected findings analyzed in the research was examined from the perspective of creativity since it was an open-ended insightful problem that required being flexible about current conceptual categories. The research demonstrated the factors that prevented the participants from discovering the eight-atom molecular structure of sulfur by interpreting the unexpected findings, which was a creative production. The barriers to creativity were classified as: (a) lack of preknowledge, (b) obstacles of existing structures, (c) failure of creative cognitive processes, and (d) social-personal blocks. This classification was guided by information-processing theory, creative problem solving and social theory. Some characteristics of these barriers are specific to scientific creativity in terms of subject matter knowledge and types of thinking.

Some students do not have the pre-knowledge required for mental operations whether they see unexpected findings as valid or not. It is commonly known that scientific creativity is based on content knowledge (Hu & Adey, 2002; Weisberg, 2006). Also, content domination is a barrier for creativity in the science lessons (Cheng, 2010). Moreover, deficient or incorrect knowledge is generally accepted as an effective barrier to generating new ideas (Adams, 2001; Garg & Garg, 2002). From a conceptual perspective, students had to change their concept of diatomic/triatomic molecular elements by the concept of polyatomic elements to propose that sulfur had an 8-atom structure to explain the unexpected findings. According to Chi and Hausmann (2003) the lack of alternative categories is one of the barriers to ontological shifts.

In addition to lack of content knowledge, the participants had mental structures that prevented them from generating innovative ideas. Some participants continued their habit of using the heuristic of explaining unexpected experimental findings with experimental errors or methodical problems. They did not prefer the heuristic of proposing a new hypothesis in repetitive unexpected situations (Ohlsson, 1992; Kaplan & Simon, 1990). Some other participants got fixated on the symbols and the value 32 in the classroom's periodical table, which perceptually prevented them from thinking that sulfur could have a molecular structure. This barrier is mentioned by Gestalt psychologists (Wertheimer, 1968) and included in the classifications of barriers to creativity (Davis, 1999; Adams, 2001). Their knowledge of atomic elements, atomic mass, and diatomic or triatomic elements that have episodic source led them to stick to their initial hypothesis. Similarly, Furió, Calatayud, Bárcenas and Padilla (2000) proved that students' habits related to the Le Chatelier principle caused them to make mistakes in applying it, and their habits in using the Lewis structures caused them to make mistakes in estimating molecular geometry.

Some students said that they recognized the possibility of a new meaning for unexpected findings, yet failed to perform some of the mental operations required to discover the scientific explanation. This situation showed that the students had difficulty doing the mental operations which support the discovery of the S_8 molecule. These mental operations included building innovative correlations between concepts of elements, molecules and molar mass; imagining an 8-atom circular structure by linking each sulfur atom to two neighboring sulfur atoms and making analogical connections with polyatomic compounds. These mental operations are common in creative production such as building innovative correlations between of knowledge (Thagard ve Stewart, 2011; Hadzigeorgios et al, 2012), imagination (Colello, 2007, Kind & Kind, 2007; Kim, 2006) and analogical reasoning (Gentler, 2002; DeHaan, 2009, Thagard, 2012; Hadzigeorgiou, Fokialis & Kabouropoulou, 2012).

Some of the participants said that there were social and personal barriers to approaching the situation creatively. One was the structure of the school, which prevents flexible thinking. Conventional school environments and instructional approaches restrict creative thinking (Kind & Kind, 2007; Hadzigeorgiou et al, 2012; Davies et al, 2013). Furthermore, some participants preferred not to reveal their innovative thoughts since they were not sure of them or thought that they were meaningless. The pressure to seek approval from others caused them to criticize their thoughts before revealing them. Conceptual innovations are not usually acceptable in their social and cultural context (Nersessian, 2009). For instance, Garg and Garg (2002) claim that the fear of being seen as a fool derives from the pressure to seek approval. The severity of this pressure of approval, which is observed in every culture, is generally shaped by the individualistic or collectivist character of that culture (Goncalo & Staw, 2006). Davis (1999) said that this type of cultural barrier hinders the sharing of opinions.

There were some limitations in the implementation of this research. The greatest limitation in the research was the use of the participants' written statements as the data resource. Although the participants had written interpretations of experiment results in lab reports many times before, this was the first time that they wrote their mental barriers to discovery by analyzing their interpretation strategies. The statements that participants form by introspection can only provide information about their conscious mental operations that can be expressed verbally, and it is not certain that this information is precise (Reisberg, 2010). Moreover, it is required that the research findings should be supported by different types of data resources. The researcher suggests that the future studies make a deep analysis of the creativity barriers.

Another limitation in this research was that it only included one experiment. Students' approaches to this experiment might not have revealed their general approaches. However, including more experiments in the research could lead to the maturation of the students' approaches and decrease the validity of the research. As Dunbar and

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Fugelsang (2005) state, the interaction between scientists studying the same problem cannot be disregarded in scientific discoveries. In this research, the participants did not make any interactions with the other members of their groups while interpreting the findings. It could be the subject of another study that science students' social interaction with the other members of their experiment group, as well as their distributed or collaborative reasoning, plays a role in their interpretation of the unexpected findings.

Science laboratories, where students make inquiry-type experiments, are the environments that allow students to improve their hand crafts, scientific process skills, and higher-level thinking skills and learn the nature and main concepts of science (Lunetta, Hofstein & Clough, 2007). Studying unexpected experimental findings is accepted as an important element of the students' ability to comprehend the nature of scientific discoveries. However, this kind of experiment is not common in schools. Students need to encounter unexpected findings more frequently so that they can overcome confirmation bias, resistance to conceptual change, and the other discovery barriers. Lecturers who act as guides need to understand how their students interpret unexpected experimental findings and also need to know the factors that prevent them from making scientific discoveries. This research proves that there is a need for more studies that include unexpected experimental results in context of school science.

Conclusions

The first conclusion of the research was that a majority of the students doing an experiment to find out the molar mass of the sulfur element explained the unexpected findings as an error in the experiment even though these findings were repetitive and highly different from their expectations. This result showed that confirmation bias, which is known to prevent proposing alternative hypotheses to explain unexpected findings, is very strong in science students who are performing an inquiry task.

The second and comparatively more important result of the research was obtained by giving students the chance to describe the factors that prevent them from evaluating the findings and discovering the polyatomic structure of the sulfur element. Considering the barriers revealed by the students about the development of new theories as a creative process, this process mainly depended on their content knowledge, but involved cognitive functions such as a flexible approach to conceptual structures, avoiding fixed perceptions and habits, imaging, and analogical transfer and was affected by certain environmental factors. These results imply that science students' reactions to unexpected findings may be a subject for scientific creativity studies in addition to conceptual change studies.

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Received: *March 25, 2017* Accepted: *June 08, 2017*

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