Using Facial Recognition Technology in the Exploration of Student Responses to conceptual conflict phenomenon

Hongming Leonard Liaw [a], Mei-Hung Chiu [a*], Chin-Cheng Chou [b]

Affiliations:
[a] National Taiwan Normal University, Graduate Institute of Science Education, Taipei, Taiwan

[b] National Taipei University of Education, Department of Science Education, Taipei, Taiwan

Correspondence*:
mhchiu@ntnu.edu.tw, 88 Ting-Chou Road Sec. 4, Taipei, Taiwan 11677

Abstract

It has been shown that facial expression states of learners are related to their learning. As part of a continuing research project, the current study delved further for a more detailed description of the relation between facial microexpression state (FMES) changes and learning in conceptual conflict-based instructions. Based on the data gathered and analyzed through the lenses of two theoretical frameworks, it was revealed that not only is there a significant relationship between FMES changes and students' macro-submicroscopic understandings, FMES was also shown to be a viable reference for differentiating students who are more likely to undergo conceptual change or able to provide, at a minimum, a scientifically accurate description of the concept taught.

Keywords: Conceptual conflict, Conceptual change, Facial expressions, Facial states, Chemistry education, Science learning

Introduction

Conceptual change is important in science, as well as chemistry, education. Transforming learners' naïve conceptions into scientific conceptions is not only challenging but also difficult. Conceptual conflict is one of the many ways educators have explored to achieve conceptual change. Simultaneously, it is also known that facial expressions are one of the most direct and immediate feedbacks one can obtain during learning (Chiu, Chou, Wu, & Liaw, 2014). Yet, either due to cultural conditioning or other reasons, not all expressions are easily visible with naked eyes and many last only a fraction of a second. However, if captured, these facial microexpression states (FMES), i.e. facial states lasting less than half a second (Matsumoto & Hwang, 2011), could perhaps give us a glimpse into what learners were thinking. Knowing these, it makes one wonder if there is any relation between learner's FMES changes and conceptual conflict induced conceptual change. As part of a continuing research project, the current study explored the relations between conceptual conflict-induced FMES changes and conceptual changes further. In addition to the previously published finding of a significant relationship between FMES changes and conceptual change (Chiu et al., 2014), the current study sought to find out specifically if there were any relations between FMES changes and learners' understanding of the scientific conception taught, namely, the relations among air pressure, boiling point, and submicroscopic views of science. Based on learners' answers, the current study provided a deeper look into how FMES is related to conceptual change and in particular, their understanding of chemical phenomenon at macroscopic and submicroscopic levels. Learners' thoughts and feelings were discussed in conjunction with their respective FMES.

Theoretical Framework

The following review has been divided into two major parts. The first reviewed past and current literature on the theories and research on conceptual change and conceptual conflicts. The second part, meanwhile, discusses works on the relations between learning and facial recognition technology.

Conceptual Change via Conceptual Conflicts

Rooted in the concepts of schemata, assimilation, disequilibration, and accommodation, , conceptual change has emerged as one of the main research areas in science education (Fosnot & Perry, 2005; Piaget, 1977). Since Piaget, many works have been done to improve students' learning in the science education domain (e.g., Slotta, Chi, & Joram, 1995; Vosniadou & Brewer, 1992; Vosniadou & Brewer, 1994). Some investigated affect in learning (Linnenbrink, 2006; Pekrun, Goetz, Titz, & Perry, 2002) while others explored intentional processes (Pintrich, Marx, & Boyle, 1993; Sinatra & Mason, 2008). Through these works, and others, it is now known that various preconditions must exist before conceptual change can take place. For example, Posner, Strike, Hewson, and Gertzog (1982) listed four preconditions for conceptual change, one of which, learner must be dissatisfied with their existing conception, plays a key role in conceptual change through conceptual conflict scenarios.

As suggested decades ago, learners would actively attempt to resolve cognitive dissonance (Festinger, 1962). Therefore, instigating such cognitive disequilibrium, as suggested by both Festinger (1962) and Posner et al. (1982), has become one of the ways to achieve conceptual change. In the work of Merenluoto and Lehtinen (2004), they proposed that there are three different tracks to conceptual change. These tracks are no-relevant perception track, illusion-of-understanding track, and experience-of-conflict track. Only the experience-of-conflict track can potentially lead to conceptual change. It is therefore also argued that conceptual conflicts are a necessarily step in the process of conceptual change (Niaz, 1995).

Nevertheless, in order to achieve conceptual change through conceptual conflicts, learners must, first, be able to understand both competing concepts; second, recognize the existence of a conflict between their existing conception and the competing concept; third, become aware of the shortcomings of their existing conception in terms of explaining the evidence, and fourth, to be willing to change their conception (Hewson & Hewson, 1984; Mason, 2000). The existence of the aforementioned preconditions could explain why Chinn and Brewer (1993, 1998) had identified as many as eight different response types, ranging from ignorance and being uncertain to complete theory change, among scientists when they came across anomalous data. This also corresponds well with the arguments of other scholars who stated that conceptual change can be influenced by various factors ranging from having sufficient prior knowledge regarding the topic to motivation (Limón, 2001; Sinatra & Mason, 2008). Yet, given the multitude of factors that could influence the outcome of conceptual change (Dreyfus, Jungwirth, & Eliovitch, 1990), it is not surprising that results of achieving conceptual change via conceptual conflict also vary (Limón & Carretero, 1997).

In sum, achieving conceptual change through conceptual conflict is a difficult but essential task in science education. Given the complex nature of conceptual change, a myriad of preconditions must be met before conceptual change can take place. Conceptual change through conceptual conflicts is no exception.

Facial Recognition Technology-Enhanced Learning Research

Many of today's facial expression research have been based on Ekman's proposal that there are six universal facial expressions among humans (Ekman, 1970, 1999). These expressions are happy, surprised, disgusted, sad, angry, and scared. Along with the neutral state, the aforementioned expressions make up the basic facial states that all humans share. Since the publication of Ekman's work, research on facial expressions had flourished (A search of "facial expressions" on the Web of Science online database yielded 16,041 academic papers; search date: April 10, 2014). For example, some researchers explored the technology involved in the automated recognition of facial expressions (Ahonen, Hadid, & Pietikainen, 2006; Littlewort, Bartlett, Fasel, Susskind, & Movellan, 2006; Shan, Gong, & McOwan, 2009). Other studies were conducted to explore the relations between facial expression and other variables, such as aging (Calder et al., 2003), brain effect (Sato, Kochiyama, Uono, & Yoshikawa, 2010), and gender (Hoffmann, Kessler, Eppel, Rukavina, & Traue, 2010).

As for education, there were very few studies that are based on facial expressions. Most of the studies available were centered on the perception or interpretations of facial expressions in the context of special education, and physiological or psychological developments of such abilities in the context of early childhood education. For example, the ability of children with Down syndrome to recognize facial expressions was examined in a recent study (Pochon & Declercq, 2013). A study from the other perspective was on how people interpreted the facial expressions of people with Rett syndrome (Bergström-Isacsson, Lagerkvist, Holck, & Gold, 2013). On young children, researchers explored the development of strategic attentional bias among children in terms of facial recognition (Birmingham et al., 2013). There were few, however, that focused on learning.

As for using technology in the identification of facial expressions, the focus has mostly remained in the development of facial recognition technology. Anderson and McOwan (2006), for example, built an automated real-time facial expression recognition system. Similarly, Hammal, Couvreur, Caplier, and Rombaut (2007) found that using characteristic distances on facial structures can be adapted for facial expression classification. Sebe et al. (2007) created a facial expression database that matched expressions to the subject's emotional state and used that database to test potential algorithms for emotion detections. More recently, Majumder, Behera, and Subramanian (2014) adopted the system identification approach that showed an improved recognition rate when compared to multi-class support vector machines and Lei, Bennamoun, Hayat, and Guo (2014) explored a 3D facial recognition approach based on the Angular Radial Signature.

As shown above, conceptual change and facial recognition technology appeared to be two separate fields with very little overlap. Consequently, as part of an effort to test the use of facial recognition technology in the field of conceptual changes in science education, our research project adopted FaceReader^{TM} 4.0 (Noldus Information Technology, 2013) as the tool to analyze participants' FMES. The software was based on Ekman's seven facial states (the six expressions and the neutral state) and analyzed facial videos accordingly based on its internal database of facial expressions. It would identify new FMES when the detected new FMES persisted longer than half a second. In the current study, FMES changes are not limited to any specific FMES.

In addition to the facial video data, both quantitative (multiple-choice-based tests) and qualitative (interview) data were collected. Quantitative data, including pretest and posttest, were first analyzed and its findings published (Chiu et al., 2014). Students were considered to have undergone conceptual change if they were shown to hold erroneous beliefs on the concept concerned in the pretest and capable of applying such scientific concepts accurately in the posttest. The findings revealed a significant relationship between conceptual change and FMES changes and implied the possibility of adapting facial recognition technology in education in the future (Chiu et al., 2014). Analysis of the data continued with the qualitative data so as to better reflect students' perspectives on anomalous events and its corresponding FMES changes, and the current paper provides the findings of these analyses.

Research Questions

Previously published findings of the current research project revealed that there is a significant relationship between FMES change and conceptual change (Chiu et al., 2014). Specific details on students' understandings and changing conceptions, however, remained unknown. In the current paper, the interview data gathered were analyzed and provided us a glimpse into how these students' conceptions may have morphed in the process.

Accordingly, the current study sought to answer two main questions:

1. What is the relation, if any, between FMES changes and the accuracy of students' explanations of the scientific demonstration shown?, and
2. What is the relation, if any, between FMES changes and students' attainment of submicroscopic views in science?

These answers would be based on the interview data gathered.

Methodology

Research Framework

The current study examined the data based on two frameworks. The first was the framework published in the previous paper of the current research project (Chiu et al., 2014). In this framework, students' conceptual understanding and changes are viewed in a series of spectrum (see Fig. 1). As shown in Figure 1, the first layer represents the varying level of prior knowledge on a concept or phenomenon among students, ranging from no prior knowledge, through partial knowledge, to complete knowledge. Where students fall on this spectrum would influence how he/she reacts to conceptual conflict generating demonstrations. On one extreme, students with no prior knowledge on the subject matter may not react to the demonstration at all since they simply did not have sufficient prior knowledge to even recognize there is a conflict between their existing knowledge and the demonstration. Towards the other extreme, students with partial knowledge would recognize the contradictions between their prior knowledge and the demonstration and consequently experience conceptual conflict. In between are the students who have experienced varying degrees of conceptual conflict, with those who are uncertain of how to make sense of the demonstration in the middle.

At this point, instruction comes into play. Influence of instruction would guide students to the next level of spectrum: Spectrum of Conceptual Change. Students who did not experience conceptual change would most likely undergo little to no conceptual change, or at the "initial" to "synthetic" end of the spectrum (Vosniadou, 1994; Vosniadou & Brewer, 1992). On the other end of the spectrum, students who had experienced conceptual conflict, with effective instruction, could potentially reach full conceptual change, or the "scientific" end of the spectrum. In the current study, changes in students' conceptions were traced accordingly; in conjunction with the next framework, this framework offered possible theoretical explanations to the changes observed in the current research.

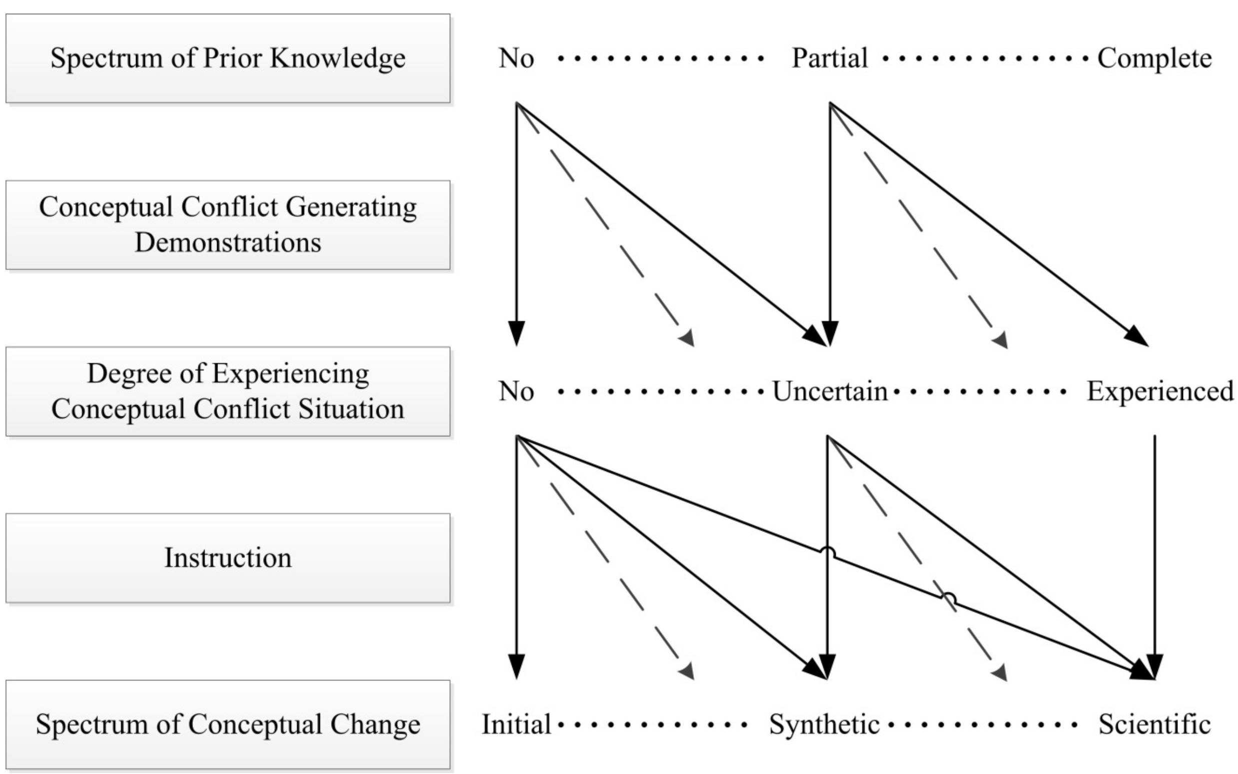

Figure 1 Layers of specturm in conceptual change through conceptual conflicts (Chiu et al., 2014)

The second framework was based on the triangle first proposed by Johnstone (1993, 2000, 2006) and later elaborated by other researchers. Johnstone's triangle has been much debated and exerted great influence over the science, especially chemistry, education community. Gilbert and Treagust (2009), for example, not only supported but also intended to promote the use of the three types of representation from Johnstone's triangle, namely macro, submicro, and symbolic. Moreover, large number of discussions and adaptions of the triangle evolved over the years and varying assumptions were built within each adaptions (Talanquer, 2011). One version of the Johnstone's triangle was Taber's triangle (Taber, 2013). Taber's rendition focused more on the interaction among the three components of the triangle and emphasized how inextricably linked one's symbolic knowledge is to both the macroscopic and the submicroscopic domains. Accordingly, Taber adjusted the triangle to better reflect such relations by removing the symbolic and replacing it with the experiential. The three corners of Taber's triangle were the scientific phenomenon itself (the experiential level), macroscopic conceptualization (the theoretical descriptive level), and submicroscopic conceptualization (the theoretical explanatory level). The three corners are connected to one another as learners could explain scientific phenomena both macroscopically and submicroscopically depending on his/her level of understanding. Macroscopic and submicroscopic conceptualizations are also not mutually exclusive but influence one another, and both are represented through the symbolic.

In accordance to Johnstone's, as well as Taber's, triangle, the framework of the current study has four main categories: macro correct/incorrect and submicro correct/incorrect. As such, the current study determined the categories of each student's descriptions and responses based on whether they consisted of macroscopic terminologies and concepts or submicroscopic terms and concepts, such as atoms, molecules, particle movements etc. Students were further categorized according to the scientific accuracy of their explanations. Additional categories of do not know, unsure, and NA were assigned when students professed that they were unable to explain the phenomenon, uncertain of their explanations, or simply did not offer relevant answers to the question.

Research Design

The current research project was designed based on the Prediction – Observation – Explanation – Visualization – Comparison (POEVC) process. The POEVC process itself was based on White and Gunstone's (1992) Prediction-Observation-Explanation (POE) concept. The POE concept itself, as well as it variants, have previously being applied in other conceptual change related studies (Coştu, Ayas, & Niaz, 2010; Kearney, 2004; Kearney, Treagust, Yeo, & Zadnik, 2001). In the work of Chiu et al. (2005), Comparison was added to form POEC to accentuate the need for students to compare and contrast what they have just learned to what they had previously believed. In the current project, Visualization was inserted to facilitate student learning with visualized submicroscopic views that are often difficult to conceptualize in chemistry learning, which in term formed the POEVC process (see details in Chiu et al., 2014).

Accordingly, a quasi-experimental research was designed. The research began with a pretest to gauge students' existing conceptions. The topic of the concept concerned was the relations among temperature, air pressure, and the boiling point of water. Following the pretest was the first part of the scientific demonstration video. In the video, a flask half-filled with water was brought to a boil. After boiling, the heat source was removed, and the flask was sealed and turned upside down. A bag of ice was then placed onto the now inverted flask. At the end of this video, students were asked to predict the outcome, and offer an explanation for their prediction.

Immediately after students' prediction and explanation, the result was revealed. The result video showed that the water boiled again after the bag of ice was placed onto the flask. At this point, students were first asked again to explain to the best of their ability verbally why the water in the demonstration appeared to have boiled again. Then, students were offered a set of choices to choose from as the most likely explanation to the observed phenomenon.

The instructional phase of the experiment then began, commencing with a text-based explanation of the water's renewed boiling, followed by an animation video. In the animation, a submicroscopic view of the event was shown and explanation offered.

Afterwards, students were tested again on their understandings of the relations among temperature, air pressure, and water's boiling point. Like the pretest, the posttest was offered in the form of multiple choice questions. Semi-structured one-on-one interviews followed with each interview about 30 minutes long. During the interview, students were once again asked to explain the renewed boiling scientifically and compare these new understandings with their previous conceptions. Figure 2 gives a graphical representation of the entire process in relation to the POEVC process. And finally, students' FMES changes were determined by the aforementioned software FaceReader.

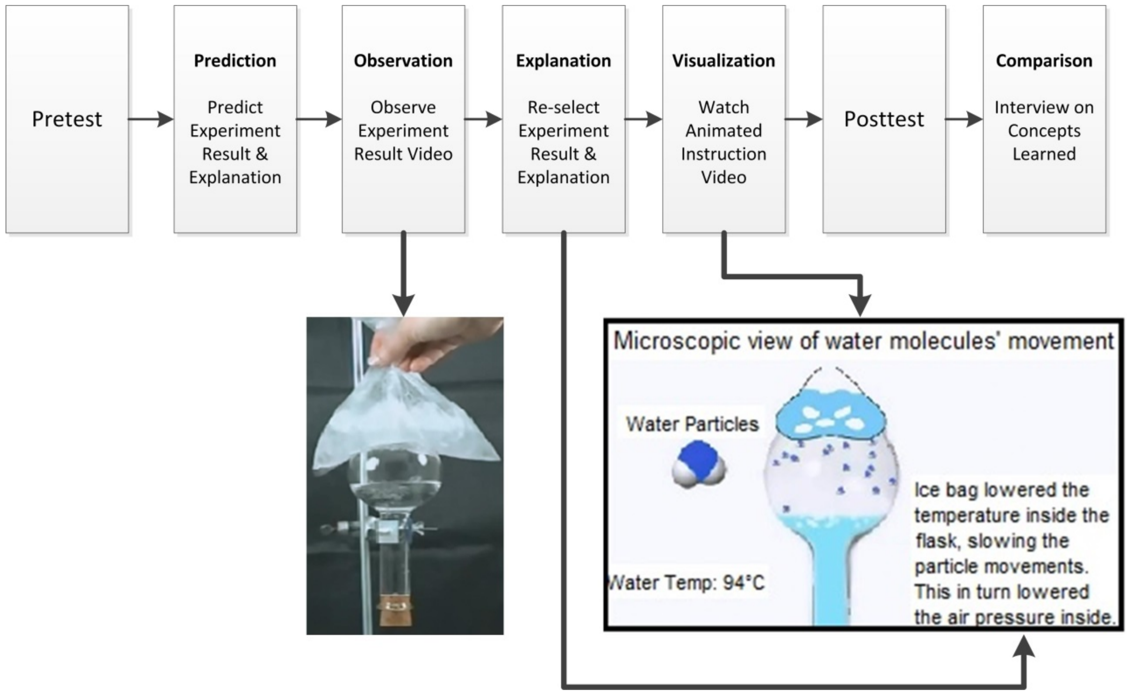

Figure 2 Graphical representation of the research process in relation to POEVC (Chiu et al., 2014)

A total of 48 high school students from four public senior high schools in metropolitan Taipei volunteered to participate. Permissions from schools and teachers of the participants were also received prior to data collection. Informed consents from all students (as well as those of the legal guardians of students who were under the age of 18 at the time of data collection) were obtained. Student performance in the study had no impact on student's school grade and assessment; all students received the same instruction in the study. Students were exposed to no greater chance of harm than those of their daily life. Students were also informed that they were free to terminate their participation in the study at any point for any reason and their decision will have no bearing on their school grades or assessments whatsoever. All students received a book/stationery store gift certificate as thanks for their participation.

Data Analysis Procedure

As per the first framework of the current paper, determination of conceptual change was based on pre- and posttests, where students' ability to apply scientific principles taught was tested. The current study focused on students' explanations of the renewed boiling. The data used included student's pre- and post- instruction verbal explanations of the phenomenon demonstrated.

Also, the determination of whether students exhibited FMES changes when they observe the renewed boiling was based on the analyses of the facial recognition software FaceReader 4.0. When analyzing students' FMES, the software's individual calibration setting was employed to minimize the impact of each student's unique facial features. After analyses, FaceReader would generate a series of values based on Ekman's six primary facial expressions (along with the neutral state). FMES changes were determined when newly observed facial states persisted longer than half a second per the definition of the software. Figure 3 below shows examples of students who exhibited FMES change and no FMES change.

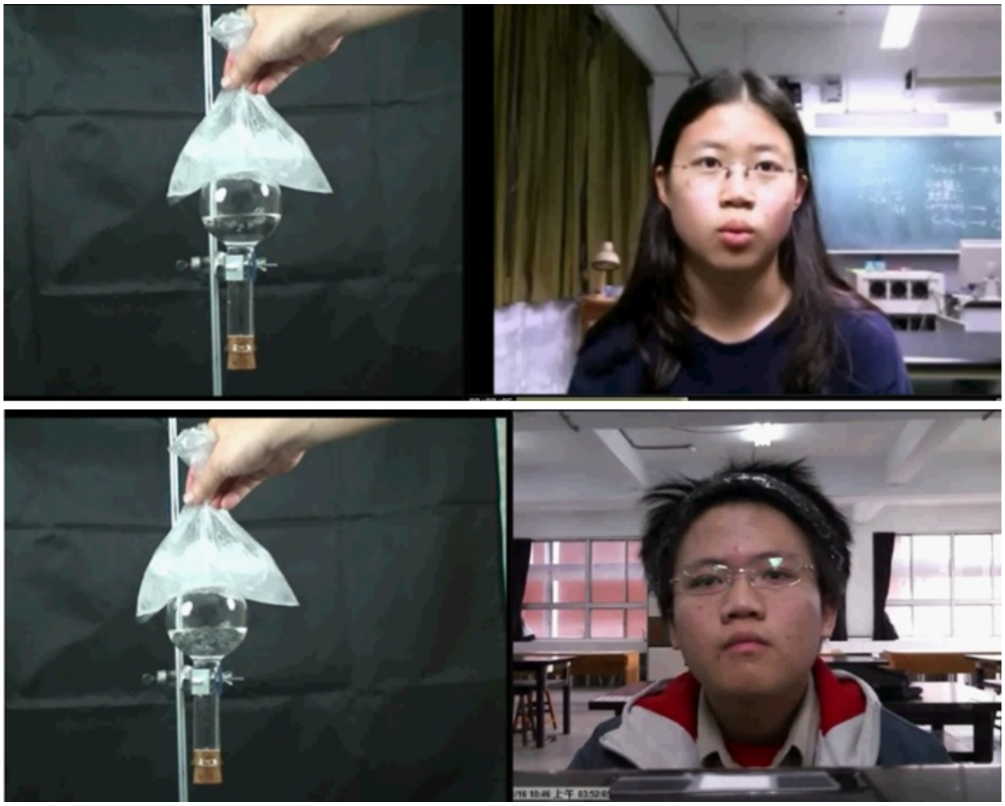

Figure 3 Sample students with (top) and without (bottom) FMES change when they saw the renewed boiling.

For the interview data, they were initially parsed into students' conceptions before and after instruction. However, all data were analyzed with the second framework, which was based on Johnstone's and Taber's triangles (Taber, 2013). Three raters examined and coded the data. The correct/incorrect determination of students' conception was based on scientific accuracy. The macro and submicro distinction was based on Johnstone's and Taber's triangles, i.e., if students' descriptions were at the theoretical descriptive (macro) or explanatory (submicro) levels. Factors that were taken into account in such determinations included students' vocabulary and concepts described. After each rater had finished his/her own coding, codes were compared and discussion ensued to resolve the differences. In cases where disagreements remained, the majority code was assigned. In the end, inter-rater reliability was 97.3%.

Results & Discussions

Finding A: FMES change a significant factor in macro-submicro accuracy distribution

To answer the first question of the current study, two statistical tests were carried out. The first test was on the difference in distribution between with FMES changes (n = 23) and students with no FMES changes (n = 14) before instruction in terms of their conception levels (macroscopic vs. submicroscopic). The test revealed that there is no significant difference in distribution between the two groups of students. The majorities of students in both the FMES change group (n = 13, 56.5%) and the no FMES change group (n = 6, 42.9%) were either unsure about or did not know why the water in the demonstration boiled again. Similar distributions were also found in both groups in terms of correct (FMES change group: n = 3, 13.0%; no FMES change group: n = 3, 21.4%) and incorrect macroscopic conceptions (FMES change group: n = 7, 30.4%; no FMES change group: n = 5, 35.7%; see Table 1). None of the students exhibited submicroscopic conceptions. For example, SM008, a student who exhibited FMES changes, believed erroneously that the water boiled again because the air inside the cork that was used to seal the flask had leaked into the bottle. Similarly, WF025, who exhibited no FMES changes, stated that because water's temperature was much higher than that of the ice, it was not impacted by the ice in any way, and consequently, it started boiling again.

Table 1 Pre-Instruction Conception between Students with/without FMES Changes in terms of Macro-Submicro Accuracy Distribution

	Macro Correct	Macro Incorrect	Unsure / Do Not Know	Total
FMES Changed	3	7	13	23
No FMES Change	3	5	6	14
Total	6	12	19	37

After instruction, however, as the second statistical test revealed, a significant difference was observed in the distributions between students with and without FMES changes in terms of students' conceptions ($\chi^2 = 7.2$, $\alpha = 0.1$, df = 3) when they were categorized as macroscopic and submicroscopic correct and incorrect on the question of renewed boiling in the demonstration. Over half of the FMES change students ($n = 13$, 56.5%) were able to give macroscopically correct explanations after instruction, compared to about one fifths of the students ($n = 3$, 21.4%) among the no FMES change students (see Table 2). For example, when asked if she understood why the water boiled again, WF028, a student with FMES change, said yes, and continued "The ice cubes… cuz it's low temp, that then made the pressure inside the bottle to lower, and then after the pressure was lowered, the boiling temperature inside also lowered, so the water was able to boil."

Table 2 Post-Instruction Conception between Students with/without FMES Changes in terms of Macro-Submicro Accuracy Distribution

	Macro Correct	Macro Incorrect	Submicro Correct	Submicro Incorrect	Total
FMES Changed	13	2	6	2	23
No FMES Change	3	1	4	6	14
Total	16	3	10	8	37

In terms of incorrect submicroscopic explanations, no FMES change students (n = 6, 42.9%) outnumbered FMES change students (n = 2, 8.7%). An example would be MF059, who believed that the volume of the air inside the bottle would decrease due to lowered kinetic energy among air particles.

Based on the above statistical results, it is clear that there is a significant relation between FMES changes exhibited by students during conceptual conflicts and the distribution of students' scientific explanations. In other words, it could be said that the learners fulfilled the two preconditions of conceptual conflicts proposed by (Hewson & Hewson, 1984). Such an indication could explain why the majority of the FMES change students were able to give scientifically accurate explanations on the renewed boiling (n = 19, 82.6%) compared to only half of those without FMES changes (n = 7). Based on the framework of (Merenluoto & Lehtinen, 2004), it could also be argued that more students with FMES changes took the experience-of-conflict track than students without FMES changes. Given that only those who have taken the experience-of-conflict track can ultimately undergo conceptual change, FMES changes appeared to be a sign of heightened probability of conceptual change.

Finding B: FMES a significant reference for macro-submicro understanding

To answer the second question of the current study, the relation between student's FMES changes and their respective macro-submicroscopic understandings were examined. Through the analyses, it was revealed that there is a significant difference in distribution between students with FMES changes and students without FMES changes after instruction in terms of the macroscopic and submicroscopic levels of scientific explanation when scientific accuracy was not taken into account ($\chi^2 = 3.3$, $\alpha = 0.1$, df = 1). It was observed that explanations given by most students with FMES changes remained at the macroscopic level (n = 15, 65.2%). On the other hand, most of the students who showed no FMES changes mentioned submicroscopic terminologies and exhibited primitive submicroscopic conceptions (n = 10, 71.4%; see Table 3).

Table 3 Macro-Submicro Level Comparison between Students with/without FMES Changes

	Macro	Submicro	Total
FMES Changed	15	8	23
No FMES Change	4	10	14
Total	19	18	37

When scientific accuracy is taken into account, however, it was found that while the majority of students with FMES changes remained at the macroscopic level in terms of their explanations of the renewed boiling, most of these explanations were scientifically accurate (n = 13, 86.7%). In contrast, while the no FMES students appeared to have improved to the submicroscopic level, more than half of these supposedly improved cases were in fact scientifically inaccurate (n = 6, 60.0%).

As such, at first glance, it appeared that students with FMES changes were more likely to give scientifically accurate explanations than students who did not exhibit FMES changes. However, many reasons could have contributed to such an observation; an example would be that students generally will not volunteer to give their answers in submicroscopic terms since it is easier and more natural for people to describe events in macroscopic terms. Therefore, although it appeared that students without FMES changes were more likely to advance to using submicroscopic terminology, it does not necessarily mean that the FMES change students do not have submicroscopic levels conception. Moreover, factors such as students' pre-existing knowledge will also play a role in the result of the conceptual conflict-based methods for conceptual change (Limón, 2001). Consequently, the distributions of macroscopic and submicroscopic levels of conceptions of the FMES change and no FMES change groups of students post-instruction could be described as complicated at best.

Meanwhile, for students with FMES changes, it appeared that they remained in the macroscopic level in terms of their scientific explanations; yet, these students were also more likely to give scientifically accurate explanations. For example, JM044 explained "When the ice cube touches that flask, that air, it made the air inside… made the temperature decrease, and made the air pressure lower, then that makes water's boiling point lower. And because the temperature inside was at that [newly lowered] boiling point, so the water boiled again." It was clear that JM044 was able to provide an accurate macroscopic explanation of the demonstration. The student's learning path is shown below (see Fig. 4).

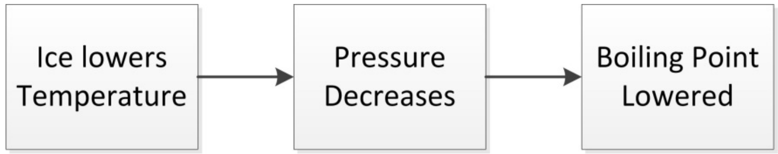

Figure 4 Learning path of JM044

On the other hand, students without FMES changes were more likely to use submicroscopic level terminology in their explanations. Yet, the majority of these explanations were scientifically inaccurate. This can be observed in the case of WF025. Answering the same question regarding the cause of the renewed boiling, WF025 said:

WF025: Because with continued heating, it will make the particles more active, and when its particles were more active, it will make the water bubble even more.
Interviewer: What about afterwards? After removing the heat source and the ice was placed? Why would the water boil again?
WF025: Because… I didn't pay much attention in the end. It might be because it was cold over there, making the temperature at the top lower, but it might have also made all the particles more active?
Interviewer: More active? The colder it gets more active it gets? Or less active?
WF025: I don't know either.
Interviewer: Do you think the instruction was clear?
WF025: I understood it at that time, but I cannot explain it afterwards.

The discrepant patterns of macro-micro correct-incorrect explanations between the FMES change and no FMES change students appeared perplexing at first, but upon closer examination, one would realize it can be partially explained by the model on conceptual change by Merenluoto and Lehtinen (2004).

Data has revealed that a majority of the students who gave erroneous post-instruction explanations peppered with submicroscopic scientific terms had previously also given macroscopically incorrect explanations pre-instruction (5/8). As shown in the case of WF025, when she was asked why she predicted water would freeze when the bag of ice was placed onto the flask pre-instruction, she replied:

WF025: Just my instinct.
Interviewer: Did you base [anything] on what you've learned before?
WF025: No.
Interviewer: Can you tell me a little a bit about where that instinct might have come from?
WF025: Just didn't really think about it. I just thought, there's ice, so freeze.
Interviewer: So, with the ice on it, water's temperature would be lowered?
WF025: Yes.
Interviewer: And then it'll freeze?
WF025: Yes.
Interviewer: What about afterwards, when the water boiled again? You answered previously that you believe this demonstration to be true, so can you explain scientifically why it would boil again?
WF025: It's probably that the water's temperature was higher than that of the ice, a lot higher, so it wouldn't be affected as much.
Interviewer: So… the water's temperature was higher than that of the ice… so it'll boil again?
WF025: Yes.

The case of WF025 exemplified what was described in the model of Merenluoto and Lehtinen (2004). The illusion of understanding track in Merenluoto and Lehtinen's model described students who were high in certainty of their existing knowledge and were less likely to achieve conceptual change. A sub-type of the illusion of understanding track was an enrichment type of change that gives the illusion of conceptual change. In the current study, students such as WF025 used a more definite voice in their pre-instruction explanations of the renewed boiling (i.e., high certainty). After instruction, they were able to mix their newly acquired submicroscopic view terminology in their explanations (i.e., enrichment); all the while their explanations, both pre- and post-instruction, were scientifically inaccurate. Another example was WM024. Before instruction, this is what WM024 believed:

> Interviewer: Why don't you believe that [the demonstration] was real?
> WM024: Because water would only boil when the temperature is high.
> Interviewer: Then how would you explain this phenomenon, what you just saw?
> WM024: Maybe air was running through somewhere… that is, it's not related to boiling.

After instruction, WM024's view changed and appeared to have understood the scientific concept involved. However, some details remained erroneous:

> Interviewer: Based on your current understanding, can you explain what just happened?
> WM024: You mean that experiment? Ok, the water particle was already dispersing when the heat was still on, [the particles] just kept on rising, then when it was sealed and inverted, there were still some water particles in the air, in the gaseous form. Then when the ice was placed onto [the flask], it made the internal pressure smaller, and lowered temperature will lead to lowered boiling point, then the liquid form water particles in the water would move into the air, and the bubble on the surface was their strong reaction, collisions.
> Interviewer: Why would the ice alter the air pressure inside?
> WM024: Cuz the temperature is lowered.
> Interviewer: What happens when the temperature was lowered?
> WM024: The pressure decreased.
> Interviewer: Why would lowered temperature decrease pressure?
> WM024: Heat expands and cold contracts.

While WM024 was able to explain the basic principles involved and added the concepts of particle movement in his description, the concept of "heat expands and cold contracts" was brought in. While the "heat expands cold contracts" principle itself is scientifically correct, it was erroneously applied. Details such as lowered temperature leading to the slowed movements of the particles and the condensation of gaseous water particles were ignored and conflated with the "heat expands cold contracts" principle. In other words, submicroscopic perspectives were missing in WM024's description. Although "heat expands and cold contracts" principle itself can also be explained in submicroscopic terms, WM024 had confined his description to the macroscopic realm. The following figure depicts the learning path of WM024 (see Fig. 5).

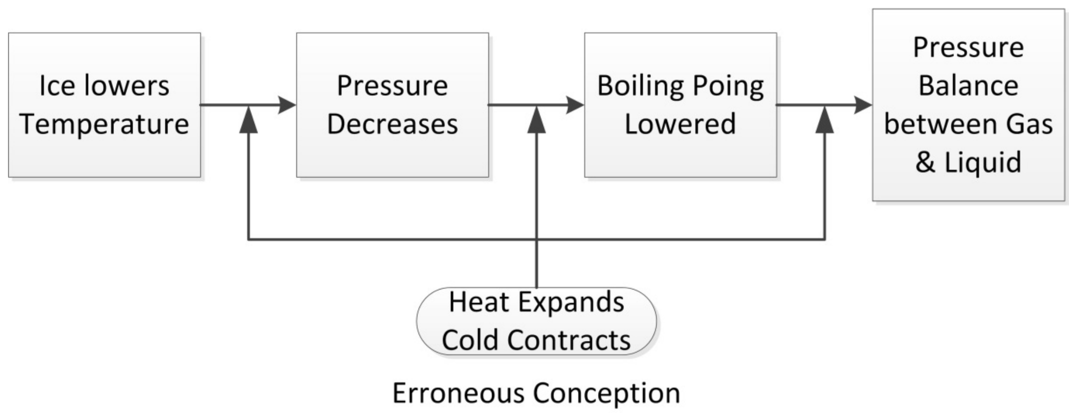

Figure 5 Learning pathway of WM024

In short, FMES changes seemed to be related to improvements in macroscopic level scientific conceptions in a conceptual-conflict-based instructional scenario. Whether due to high certainty of their existing conception (Merenluoto & Lehtinen, 2004), the inability to recognize the conflict presented (Hewson & Hewson, 1984), or various other reasons (Gilbert & Treagust, 2009), students who do not exhibit FMES changes were less likely to give scientifically accurate explanations in a conceptual-conflict based instructional scenario.

Finding C: FMES as a differentiating reference for abilities in explaining and applying new concepts

Furthering our understanding of the relationship between student's FMES changes and their levels of understandings, it was found that there is a significant difference in distribution among no conceptual change students after instruction in terms of whether students were able to explain accurately why the water boiled again ($\chi^2 = 3.0$, $\alpha = 0.1$, df = 1). Most of the students who exhibited FMES changes were able to provide correct scientific descriptions of the demonstration after instruction (n = 19, 82.6%). Among the no FMES changes students (n = 14), there was an even split when it comes to whether their post-instruction descriptions of the demonstration were scientifically correct or not (see Table 4).

Table 4 Macro-Submicro Conception Distribution between Students with/without FMES Changes among No Conceptual Change Students

	Macro Correct	Macro Incorrect	Micro Correct	Micro Incorrect	Total
FMES Change	9	0	5	0	14
No FMES Change	3	1	3	5	12
Total	12	1	8	5	26

As mentioned earlier, the no conceptual change students were classified as so because they were unable to apply the newly taught concept in different scenarios in the posttest (Chiu et al., 2014). In contrast, the current study examined if students were able to explain why the water in the flask boiled again. As such, the current finding suggests two things: first, in conjunction with the findings of our previously published work (Chiu et al., 2014), FMES change is a viable reference in identifying students who are more likely to either undergo conceptual change or learn the new concept. With the current finding, it was found that even among those who were said to have not undergone conceptual change, the degree to which they were able to explain the demonstration scientifically was also different between those with and without FMES changes.

Therefore, although it has been known that cognitive conflict-based instructional strategies do not always lead to conceptual changes (Limón, 2001), FMES can still serve as a gauge to differentiate students with varying levels of understanding. In other words, a student is more likely to be, at a minimum, capable of explaining the scientific concept taught accurately at the macroscopic level if he/she has exhibited FMES change.

Contrasting the current finding with that of our previously published work, it could be said that our previous work showed a larger picture of the possible relationship between FMES change and conceptual change and the current finding revealed a more detailed picture of the nature of that relationship. In other words, the current finding suggests FMES to be a viable reference of different levels (i.e., from the shallower level of simple description and macroscopic explanation to deeper levels of conceptual change) of student learning.

Conclusion & Implications

Conclusion

Based on both qualitative and quantitative data collected, numerous findings were revealed in the current study regarding the relations between FMES changes and conceptual changes. With regard to the first research question of the current study, namely, what is the relation, if any, between FMES changes and the accuracy of students' explanations of the renewed boiling, the results showed a significant difference in the distribution between those with FMES changes and those without FMES changes in terms of the accuracy of students' explanations. In the case of question 2, that is: what is the relation, if any, between FMES changes and students' attainment of submicroscopic views in science; the results of the current study showed that FMES was unable to predict students' attainment of submicroscopic view in science. FMES can, however, predict students' understanding at the macroscopic level.

Aggregating the above findings with a reference back to the first conceptual framework adopted in the current study (see Fig. 1) gives us a slightly different presentation of how students' conceptual changes take shape (see Fig. 6). The first change was the removal of "Uncertain" from the "Degree of Experiencing Conceptual Conflict Situation" since students in the current study were bifurcated into those with and without FMES changes. A more refined differentiation among students based on the strength of their reaction will require better technology. Then, at the bottom, "Spectrum of Conceptual Change" was replaced with "Conceptual Accuracy" and the provision of the varying learning paths revealed in the current paper. Conceptual Accuracy is based on Taber's triangle (Taber, 2013) and lies on a true-false linear fashion. While we recognize possible problems in depicting student understandings in a linear fashion, the presentation still provides a useful way to look at the likely paths students may take in a conceptual conflict induced conceptual change learning context. Such a presentation, while still a work in progress, could serve as a new reference for any future works.

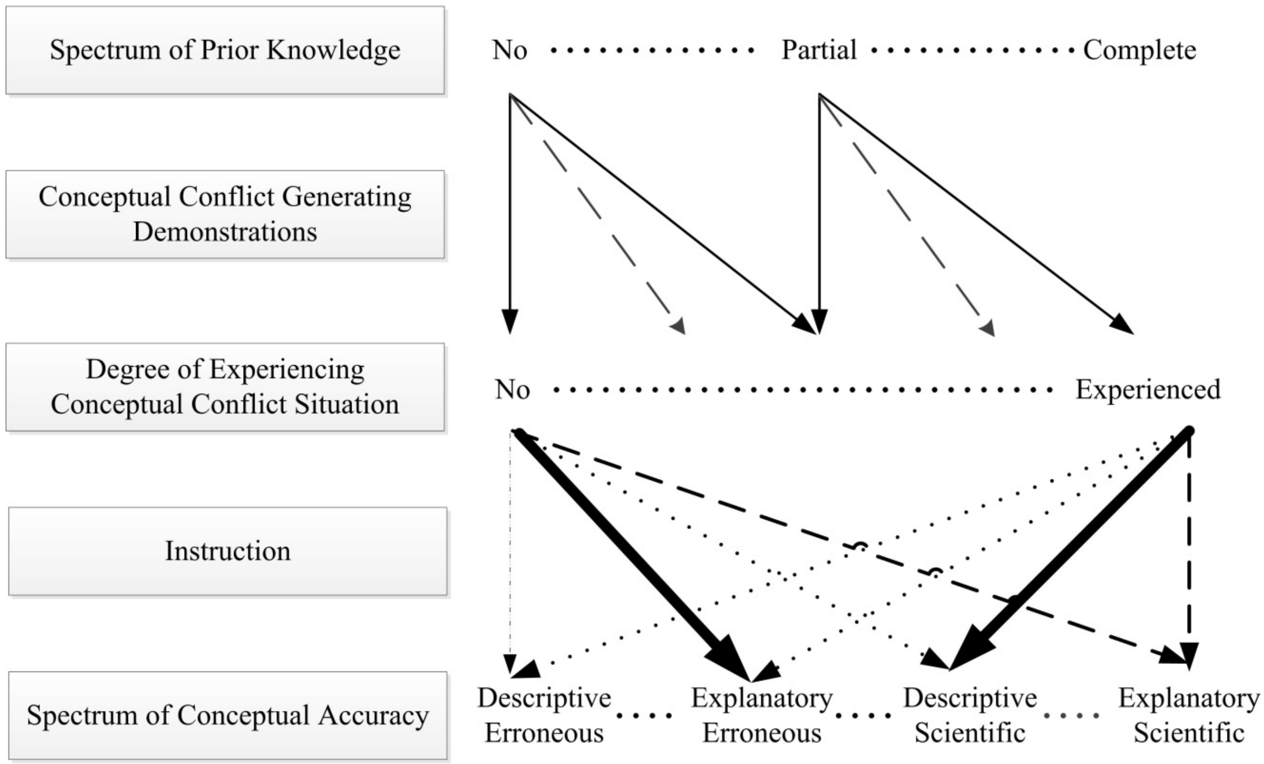

Figure 6 Student conceptual accuracy learning pathway

Implications

In the current study, it was revealed that FMES changes can predict student's understandings at the surface level. FMES change generating conceptual conflicts, it was shown, can lead to macroscopic understanding among students. Submicroscopic concepts need more scaffolding, however. On the implementation level, this means that schools must pay special attention to linking macroscopic concepts to submicroscopic concepts. As different assessments serve different purposes, schools must realize that a student's ability in the description of scientific concepts in one assessment may not indicate a full understanding. Application of the concept concerned as well as corresponding assessment methods will be required to better reflect students' true level of understanding.

It may also be speculated that there may be a relationship between students' response types (Chinn & Brewer, 1993, 1998) and the magnitude in FMES changes. That is, the likelihood of students offering theoretically sound answers will increase with stronger FMES signals. Such a finding will enrich the conceptual accuracy framework above (see Fig. 5) further. Yet, this can only be answered when better facial recognition technology becomes available.

Nevertheless, the findings of the current paper have made the idea of using FMES monitoring as a way to gauge student learning even more plausible, whether it is in a large class setting where individualized attention from the instructor was difficult or in an online learning setting where the instructor is physically absent. The significant relation between FMES changes and changes in students' macro/microscopic levels of view of science also suggests that FMES changes have the potential to be applied in areas beyond the monitoring of student attention during learning. Provided with more research and enhancement in technology, more detailed understandings of students' learning and progress can be gleaned from these minute changes in expressions as well.

However, as shown in Figure 5, one still cannot say that exhibiting FMES changes during a conceptual conflict event guarantees conceptual change since so many other factors will also influence the outcome (Limón, 2001). In fact, students do not always experience conceptual conflicts (Hewson & Hewson, 1984), and even when they do, that will not always lead to conceptual change since various preconditions must be satisfied first (Posner et al., 1982). In short, conceptual conflict may be necessary but is insufficient for conceptual change. The complexity of conceptual change as a process makes a broad fix-it-all claim unlikely. It is possible, however, to utilize student response types to conceptual conflict-inducing events as a tool to identify students who are in need of more help or explanations. Nevertheless, further studies in the area will be required to advance our understandings of such a complicated process especially since it remains unclear to what extent FMES could be used in the understanding of student conceptions in the learning process. Simultaneously, the influence of other variables such as age, gender, and perhaps also culture, on students' FMES changes also remains unexplored. Given the aforementioned limitations, the findings of the current study would suggest not the end, but a starting point to further decode the complex mental process that is conceptual change.

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