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Pre-Service Teachers' Use of Visualizations in the Science Classroom: A Case Study

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Introduction

Scientific visualizations of phenomena can enhance the way learners understand scientific concepts (Honey & Hilton, 2011). Scientific concepts can be abstract and difficult for students to understand and visualizations can help make these abstract concepts more concrete for students. For example, chemistry students often struggle with understanding how atoms bond since they cannot directly see atoms. Using a visualization to show students how the electrons are shared or transferred can help students understand these abstract concepts. In addition, many visualizations are freely available online and can be a key element to maintain quality science instruction with limited resources.

Scientific visualizations are meant to supplement, not supplant instruction. Teaching methods greatly impact the effectiveness of visualizations in the classroom (Kali & Linn, 2007). Teachers need to select accurate and appropriate visualizations, provide supporting instruction with the visualization, and help students reflect upon how the visualization connects to learning objectives (Kali & Linn, 2007). Teachers should discuss limitations and affordances of visualizations, making sure that students understand what visualizations do or do not represent (Gilbert, 2005). Therefore, understanding how teachers plan for and utilize visualizations in the science classroom is an important area for science education.

Pre-service teachers are new to teaching and to implementing the use of visualizations. Their experiences planning and teaching a lesson with visualizations for the first time may influence whether they chose to do so in the future. Therefore, understanding how pre-service

teachers plan for and utilize visualizations in lessons may help us understand how instruction in pre-service courses needs to be modified or changed. It could also help us determine if there are any mitigating factors that hinder pre-service teachers from using visualizations or certain types of visualizations. This study focuses on how pre-service teachers plan for and implement the use of visualizations in the science classroom. This case study answers the following questions:

1. In what ways do pre-service teachers plan for and utilize visualizations in the science classroom?
2. What types of visualizations do pre-service teachers use in a science classroom?
3. How do students respond to the visualizations used by pre-service teachers?

Rationale

Defining Visualizations

For the purpose of this study, we define five categories of visualizations commonly used by science teachers. The first visualization category is defined as "the systematic and focused visual display of information in the form of tables, diagrams and graphs" (Tufte, 2001). This type of visualization is categorized as a static image in this study. Examples of static images include digital images, graphs, tables, diagrams, etc. PowerPoints™, the second category, incorporate static images but differ in that they merge static images and text to create a presentation for students. Other types of visualizations may be dynamic in nature including animations, simulations, and videos. Animations and videos, the third category, are "computer-generated dynamic models that present theoretical or simplified models of real world components, phenomena, or processes" (Bell & Smetana, 2008, p.23). Animations and videos are sequences of static pictures that depict dynamic processes but do not enable user manipulation besides simple controls such as stop, play and rewind. Examples of animations and

videos include Brain Pop, videos found on YouTube, or the videos that often accompany curriculum. The fourth category, simulations, are similar to animations but have an interactive piece that allows the student to "observe, explore, recreate and receive immediate feedback about real objects, phenomena, and processes" (Bell & Smetana, 2008, p.23). Commonly used science simulations include PhET simulations (Perkins et al., 2006) and molecular simulations (e.g., Xie & Tinker, 2006).

Visualizations in the Science Classroom

While there are many forms and categories of visualizations, all can be used to support instruction in the science classroom. Science concepts are often abstract and difficult to understand for students. Visualizations have been shown to help students develop scientific conceptions (Bell, Gess-Newsome, & Luft, 2008; Flick & Bell, 2000; Hoffler & Leutner, 2007; Honey & Hilton, 2011). Visualizations can also be used to simulate data collection in situations where field-based data collection is not possible, too expensive, or dangerous (Winn et al., 2005). When a visualization is based on familiar experiences, built on prior knowledge or utilized in a manner that is student-centered, it can be effective and useful in helping students understand scientific concepts.

However, there are some limitations in using visualizations in the science classroom. When a visualization is isolated from prior knowledge or attempts to teach too many concepts it can be ineffective and even cause alternative conceptions. In general, visualizations are simplified models of a phenomena in the real world; thus, it is critical to emphasize the limitations of the model (Gilbert, 2005). If the differences between the visualization the reality is not explicitly discussed, students may develop alternative conceptions. Therefore, it is critical to implement visualizations effectively in the science classroom.

This study uses a constructivist approach to learning, which focuses on individuals actively making sense of their experiences (Cobb, 1994). This framework suggests the importance of building on prior knowledge, making instruction relevant and student-centered (Bransford, Brown & Cocking, 2000). In order for a visualization to be effective in helping a student construct new knowledge, a student needs to be actively engaged with the instruction featuring visualizations. Additionally, it is critical that teachers understand how students think about the concepts they are teaching with visualizations and integrate opportunities to refine, reflect and sort their ideas (Linn et al., 2010). This study explores how pre-service teachers create their lesson plans to incorporate prior knowledge, relevance, and student-centered instruction. Furthermore, it will investigate how students respond to the use of visualizations in the construction of their own knowledge.

Best Practices for Instruction with Visualizations

When visualizations are implemented in the science classroom, teachers need to recognize visualizations are tools to support learning. Bell & Smetana (2008) make the following recommendations when using visualizations to teach science:

1. Use visualizations to supplement, not replace, other instructional modes.
2. Keep instruction student centered.
3. Point out the limitations of simulations.
4. Make content, not technology, the focus. (pp. 26-28)

When these recommendations are followed, students' ability to learn with the visualization may be increased.

It is critical pre-service teachers receive instruction about the best practices for visualization use. However, there is very little research to indicate what type of instruction is implemented with pre-service teachers. Flick and Bell (2000) recommend the following guidelines be used to prepare pre-service science teachers in using technology in general:

1. Technology should be introduced in the context of science content.
2. Technology should address worthwhile science with appropriate pedagogy.
3. Technology instruction in science should take advantage of the unique features of technology.
4. Technology should make scientific views more accessible.
5. Technology instruction should develop students' understanding of the relationship between technology and science. (p. 40)

These recommendations are for using technology in general; however, they could also apply to visualization use.

Understanding the training pre-service teachers have to support instruction using visualizations in the science classroom sheds insight into how to develop effective pre-service programs and successful use of visualizations in classrooms. Few studies have investigated the use of visualizations in pre-service science programs. For instance, Ferreira and Arroio (2009) investigated the beliefs and practices of 24 pre-service chemistry teachers in one of the few studies on this topic. Results indicated that the methods courses only covered the use of visualizations superficially, which translated to pre-service teachers having some misconceptions about the use of visualizations. Specifically, some of the pre-service teachers believed visualizations could be used to supplant instruction or the reading of the text, while others viewed visualizations simply as entertainment or an opportunity to engage students. Results also suggested that pre-service chemistry teachers find value in the use of visualizations in the classroom, but feel they need more explicit training in order to use them effectively in their instruction.

Methods

Interpretivism

This study focused on how pre-service teachers planned for and utilized visualizations in the science classroom and on how students responded to teacher's use of visualizations.

According to Schwartz-Shea and Yanow (2012) interpretive research is used to "understand what a thing 'is' by learning what it does, how particular people use it, in particular contexts…interpretive research focuses on context-specific meanings" (p.23). In this study, we were interested in what types of visualizations pre-service teachers used, what they did with those visualizations in the context of a science classroom. This study also focused on how pre-service teachers constructed lesson plans and how students constructed their knowledge as they responded to the use of visualizations in the lesson plans. Therefore, a qualitative case study approach taken from within constructivist and interpretive paradigms was most appropriate.

Context and Participants

This study occurred within the context of a science methods course and field placement assignment for pre-service teachers at a mid-Atlantic University. The first author served as the instructor for the field placement assignment. As part of the field placement, pre-service teachers were assigned in pairs to classrooms. They observed approximately 21 hours in their assigned classrooms, had two informal interactions with students and taught two formal lessons. Pre-service teachers consulted the classroom teachers to determine what topic they would teach for the formal lessons. Pre-service teachers submitted lesson plans for the formal lessons and co-taught the lessons with their assigned partner. After teaching the lesson, the field placement instructor debriefed the lesson with the pre-service teachers.

Six pre-service teachers who were enrolled in the methods course and field placement were selected as a convenience sample. They were assigned in pairs to three different classrooms in a small urban school district (see Table 1). Two classrooms were in elementary schools and one classroom was in a middle school. Two of the classroom teachers were female

and one was male. Four of the pre-service teachers were male and two were female. All of the pre-service teachers had little to no experience in elementary and middle schools.

Table 1

Pre-Service Teacher Team Assignments and Sites[1]

School	Classroom Teacher	Pre-Service Teacher Names	Grade Level Teaching	Lesson Topics
James E. Lewis Elementary School	Ms. Jones	Don George	6th	Moon Phases Solar System
James E. Lewis Elementary School	Ms. Smith	Brooklyn Matt	5th	Sound Light
South Creek Middle School	Mr. Walker	Patrick Katherine	7th, 8th	Newton's 2nd Law Newton's 3rd Law

Data Collection Methods

Over the course of seven weeks, data collection included observations of pre-service teachers' science lessons, informal interviews and the collection of lesson plans. To understand how and what type of visualizations pre-service teachers utilized in science lessons, we used a combination of observations, informal interviews and document analysis. In order to gain an understanding of how students responded to the visualizations selected by the pre-service teachers, observations of the lessons and informal interviews were conducted to collect data (Table 2). Each of these methods is described more fully below.

Lesson observations. Observations of each pre-service teaching team were made on two formal and two informal occasions over the seven-week period. Each team was observed a total of four times. The informal observations occurred in the methods course as an opportunity to practice their formal lesson for the classroom. The formal observations took place when the

[1] School, teacher and pre-service teacher names have been assigned pseudonyms.

teaching teams arranged to teach their formal science lesson plan in the classroom. Lessons ranged from 20 minutes to 80 minutes in length.

During the observation, field notes were recorded on a computer using the Visualizations Observation Protocol (Appendix A). The Visualizations Observation Protocol was developed and based on a team of science educators' and educational researchers input and ideas. It focuses on the type of instruction, type of visualization used, how it was used in the classroom and how students responded to the visualization.

Unstructured, informal interview. Unstructured interviews were conducted as needed as part of the lesson debrief with pre-service teachers. Questions were based on the lesson observed and followed up on the decisions made to use or not use visualizations. Questions also focused on how pre-service teachers perceived students to respond to the visualization. The interviews lasted a maximum of 15 minutes. Field notes were taken during the interview.

Lesson plans. Lesson plans for each of the science formal lessons were collected two days prior to the lesson. The purpose of lesson plan collection is to analyze how pre-service teachers planned for visualization use and to determine the types of visualization used.

Analysis of the Data

An analytic induction (Erickson, 1986) approach to data analysis was used in this interpretive study. This approach is used to identify the structure or the organization of meanings in the data through a two-step process. In the first step, the first author spent time studying the data holistically in order to inductively generate assertions. Throughout the seven weeks of fieldwork in this study, the entire data set was read and re-read. Assertions were generated through this process.

In the second step of the analytic induction model, the first author searched for evidence to warrant the assertions. Data confirming and disconfirming the assertions were searched for during the reading and re-reading of the evidence. In this study, NVivo qualitative research software was used to code the data for the incidence of confirming and disconfirming evidence. These instances of evidence in the data were used to revise and support the assertions. Support for the assertions developed is provided in the form of quotes and observational notes.

Table 2

Research questions, data sources and analysis plan

Research Question	Data Source			Analysis Plan
	Observation	Interview	Plans	
In what ways do pre-service teachers plan for and utilize visualizations in the science classroom?	X	X	X	• Code plans for visualization use • Confirm coding with observation and interview field notes
What types of visualizations do pre-service teachers use?	X		X	• Code lesson plan for type of visualizations • Confirm coding with observation field notes
How do students respond to the visualizations used by pre-service teachers?	X	X		• Code observation field notes for student response • Confirm coding with interview field notes

Findings

The pre-service teachers all received explicit instruction on the use of visualizations and digital resources during science methods class. The second author served as the instructor for the methods class. The total instructional time lasted around 3-5 hours where the instructor went over best practices for use of visualizations. Instructed consisted of a whole-class discussion, activities where the pre-service teachers used simulations in pairs to learn about certain science

concepts, and then another instructor-led discussion to reflect upon what they saw as additional benefits or difficulties using visualizations in science classrooms. Pre-service teachers were assigned to find ten visualizations to use in their specific content areas (chemistry, physics, earth science, biology) as part of class homework. The assignment also forced the pre-service teachers to describe how each visualization would be integrated into instruction, making explicit learning goals and student support strategies. In a subsequent lesson, students shared their visualizations with peers in their same domain area and then presented their top ten visualizations to the class. The pre-service teachers went into their school placements after this instruction.

The four assertions generated in this study through analytic induction are presented in relation to the research questions (Table 3). These assertions are presented and then discussed in detail with supporting examples from the data.

Table 3

Relationship of Assertions to Research Questions

Research Question	**Assertion**
1. In what ways do pre-service teachers plan for and utilize visualizations in the science classroom?	Assertion 1 Assertion 2
2. What types of visualizations do pre-service teachers use in a science classroom?	Assertion 3
3. How do students respond to the visualizations used by pre-service teachers?	Assertion 4

Assertion 1: In planning and implementing lessons, pre-service teachers use teacher-centered visualizations because it seemed less intimidating.

All of the visualizations planned for and utilized by pre-service teachers were teacher-centered. When asked why they did not use a student-centered visualization, Brooklyn said:

> This is the first time we've tried out teaching so I wasn't sure how it was going to go and I wanted to try something more hands-on than doing something with computers. Our topics had a lot of good hands-on activities too, so it didn't seem necessary to do a simulation with students. Also, I wasn't sure how much access our class would have to

> computers because our teacher doesn't like technology very much, so I wasn't sure how that would go over. (Informal Interview, 11/30/2012)

The use of computers in the classroom to implement a more student-centered visualization was intimidating to the pre-service teachers for several reasons. Like Brooklyn, the other pre-service teachers indicated they were unsure of the technology available at the school and weren't sure how to procure it if it wasn't in the classroom. They also indicated it was overwhelming to think about monitoring students on computers as it was one of their first or second times to teach a lesson. Finally, pre-service teachers indicated they preferred trying to engage students in hands-on activities or demonstrations rather than student-centered visualizations.

Assertion 2: Pre-service teachers planned for and used visualizations to help explain abstract or difficult concepts.

The pre-service teachers used visualizations when they needed help explaining difficult or abstract concepts. The visualizations were used to add to their discussion and to aid them in their instruction. Don and George utilized a simulation to illustrate and explain the phases of the moon. This is a very difficult concept to explain with students and Don and George chose a simulation to help students understand where the moon and sun were in relationship to Earth during each phase of the moon. During their second lesson, Don and George utilized static images to help students visualize the distance between and the relative sizes of the planets in the Solar System. Relative size is an abstract concept for students and the images Don and George chose to use provided concrete images to help students understand the differences.

Brooklyn and Matt showed a static image of sound waves during their first lesson. They used this image to help students understand why they heard different pitches when the level of water was lowered or increased in a bottle. Students can hear the difference in pitches but understanding how sound waves are related to the pitch they hear can be difficult and abstract.

In their second lesson, they used static images to help students understand what was happening to light waves during reflection and refraction. These concepts are abstract as light waves cannot be seen; thus, using the static images helped students to understand what was happening to the light waves.

In both of Patrick and Katherine's lessons, they used static images to help students understand the forces that were acting on an object. These images helped students understand where the force was being applied and what effect the forces would have on an object. Again, force is an abstract concept for students and the visualizations used helped make the content more concrete for students. During the second lesson, Patrick and Katherine also used a static image that showed how to set up the activity. This image helped students understand what and how they needed to set up their materials as they engaged in the activity. It is clear from these observations that in every lesson, the pre-service teachers chose visualizations to help students understand difficult or abstract concepts; none were used to engage or explore a topic.

Assertion 3: Pre-service teachers planned for and used mainly static images and were influenced by classroom teachers when choosing the visualizations they used in the science classroom.

The main type of visualization used by pre-service teachers in the science classroom was static images. As this is the first or second lesson for most teachers, it may be that using a static image is easier than using a type of visualization that requires more interaction or attention during instruction. Other types of visualizations included a video, simulation and PowerPoint. Table 4 describes the visualizations pre-service teachers planned to use and the visualizations they actually used.

Table 4

Types of visualizations planned for and used in the science classroom

Pre-Service Teachers	Lesson Topic	Visualizations Planned For	Visualizations Actually Used
Don	Moon Phases	Simulation, Static Image	Video, Simulation, Static Image
George	Solar System	Static Images	Static Images
Brooklyn	Sound	Static Images	Static Images
Matt	Light	PowerPoint, Static Images	Static Images
Patrick	Newton's 2nd Law	Static Images	Static Images
Katherine	Newton's 3rd Law	Static Image	Static Images

The types of visualizations planned for use by pre-service teachers was different from the visualizations actually used. This change was influenced by the classroom teacher's ideas or everyday practice in the classroom. For example, Don and George added a BrainPop video to their lesson based on the everyday practice and resources of Ms. Jones. George said:

> Ms. Jones often shows BrainPop videos to introduce a topic. She showed us some that applied to moon phases and so we decided to include a video in our lesson. The students are used to them and there is a lot of good information in the video. (Informal Interview, 11/12/2012)

Brooklyn and Matt were planning on using a PowerPoint in their light lesson, but they decided not to because Ms. Smith never uses them in her classroom. In the case of Patrick and Katherine, they planned to use only one static image in their lesson on Newton's Third Law, but ended up using multiple images based on feedback they received from Mr. Walker. It is clear the classroom teacher's practices and input had influence over what types of visualizations the pre-services implemented.

Assertion 4: Students were engaged with the visualizations and respond to questions asked by the pre-service teachers; however, they did not ask any questions regarding the visualizations.

Students were highly engaged, as evidenced by their attention and participation, during the use of visualizations. When using visualizations, the pre-service teachers asked questions of the students in every instance. These questions ranged in purpose. Some of the questions were meant to focus student attention on certain aspects of the visualization, others were problem questions and some were higher reasoning questions. Students responded quickly and with enthusiasm to these questions, but despite being given the opportunity to ask questions, students did not ask any questions regarding the visualizations. In fact observations show there was very little student questioning during the lessons in general. This may be attributed to the fact that pre-service teachers are "guest teachers" and students are not as comfortable with them. However, given that not one question was asked by a student during visualization use, it is important to note this as a finding of this study.

Limitations

Pre-service teachers were observed a total of four times, twice informally and twice formally, for a total of twelve observations, but students were only present for six of these. An increased number of observations in the field would help in understanding the student response to the visualizations utilized. Furthermore, pre-service teachers were only interviewed informally following lessons. The development and implementation of a formal interview protocol would further understanding of the pre-service teachers' thinking and planning process. Finally, only 3 pre-service teacher teams were observed. Increasing the number of hours in the field, implementing a formal interview protocol, and observing more pre-service teacher teams would help to increase the validity of this study.

Discussion & Implications

The purpose of this study was to investigate how pre-service teachers plan for and use visualizations in the science classroom. The evidence clearly shows pre-service teachers used teacher-centered visualizations to help explain difficult or abstract concepts. It is also clear the classroom teacher influenced the choice of visualizations used and that pre-service teachers mainly used static images. Finally, students were engaged by the visualizations pre-service teachers use, but did not ask questions about the visualizations.

These findings warrant further study to determine if these results are similar to other pre-service teacher teams. There are also implications for educators of pre-service teachers. Educators may need to consider how to support pre-service teachers' use of visualizations using student-centered methods. This is critical in order to support the learning of science more effectively (Bell & Smetana, 2008). Furthermore, educators may need to model how to teach with all different types of visualizations, not just static images. Finally, educators may need to think about how to help pre-service teachers promote more student questioning in the science classroom. The findings are significant in terms of the increasing availability of visualizations to support science instruction. Even though the findings of this case study should only be generalized to other settings with caution, they support future efforts to investigate how pre-service teachers use visualizations in the science classroom.

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Appendix A

Visualizations Observation Protocol

Teachers: **Date:**

Time:

1. In what ways do pre-service teachers plan for and utilize visualizations in the science classroom?
2. What types of visualizations do pre-service teachers use in a science classroom?
3. How do students respond to the visualizations used by pre-service teachers?

Time in minutes	0-5	5-10	10-15	15-20	20-25	25-30
Instruction						
Organization						
Student Attention						
Visualization Use/Type						
Questions Asked						

Time in minutes	30-35	35-40	40-45	45-50	50-55	55-60
Instruction						
Organization						
Student Attention						
Visualization Use/Type						
Questions Asked						

How do students interact with each visualization?
Is it student centered or teacher centered?
What is the purpose of each visualization? (to illustrate or to get at understanding)
Do teachers address the affordances/limitations of the visualization?
What type of questions do students ask?

Notes: