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Teachers' use of visual representations in the science classroom

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Abstract
In the current science education literature, most of the attention has focused on understanding the impact visual representations in textbooks and multimedia materials have on students and their learning, but very few studies have focused on teachers' use of these graphics in the classroom. The purpose of this study is to investigate how seven high school science teachers use visual representations in their teaching. A case study approach was used in this research. First, mini-cases were developed to examine the research question from the participants' perspective; then, a cross-case analysis was used to examine the similarities and differences among participants to develop an overarching case in order to understand the factors involved with teachers' use of visual representations. The findings of this study indicate that course content, student characteristics, and resource availability affect how teachers select and use graphics in their science courses.

Keywords: Case study, science teaching, secondary education, visual representations

Introduction
Visual representations play a very important role in the communication of science concepts (Ametller & Pinto, 2002). Visual learning can foster the obtainment of knowledge that students may not get from verbal explanations alone (Patrick, Carter, & Wiebe, 2005), and improve the retention of ideas presented (Mayer et al., 1996). Thompson (1994) called thoughtfully designed illustrations "instructional obstacles," or devices that create a cognitive "hurdle" in the mind of the learner. As the learner studies the details of the picture, s/he begins to overcome the cognitive hurdle. As a result, a fuller understanding of the concept is acquired. According to Lemke (1995, p. 110), "our visual discrimination is far better than our linguistic system at dealing with complex ratios and continuous variations in space, line, shape, and color."

Graphics have a variety of functions, which include decoration, representation, organization, interpretation, and transformation (Carney & Levin, 2002). Unfortunately, not all visual displays will cause the same degree of improvement in comprehension and retention. Therefore, research on the impact of visual representations sometimes leads to contradictory results in which the value of these representations is called into question (Harrison & Treagust, 2000). Concepts can be represented pictorially in numerous ways and not all will be equally understood (Pozzer-Ardenghi & Roth, 2005). As with verbal communication, illustrations have to be "read." In order to bring about more consistent improvement in knowledge acquisition, researchers have explored what factors enhance the readability of illustrations.

In science especially, visual images are preferred for displaying multiple relationships and processes that are difficult to describe. Research studies indicate that the type of visual representation could determine how powerful the illustration will be as a learning aid (Carney & Levin, 2002; Mayer, 1993). Mayer (1993) summarized four types of illustrations, modified from Levin's system of classifying illustrations (see Table 1). Mayer concluded that explanative illustrations, those illustrations with a verbal explanation that describe how scientific systems or processes work, elicit the highest level of cognitive processing. Other types of illustrations, like decorative color pictures, may not even affect cognitive processing. Research has shown that promoting cognitive interest is more important than promoting emotional interest. Students perform worse on retention tests when entertaining text and/or illustrations have been added (Harp & Mayer, 1997). Therefore, explanative illustrations are more effective than illustrations designed for affective purposes; illustrations designed to promote interest in and motivation toward content materials have not been found to improve student learning (Park & Lim, 2007)

Table 1. Mayer's Four Types of Illustrations

Illustration Type	Explanation
Decoration	Graphics not directly related to the text (written or spoken)
Representational	Graphics that show one element described in text (written or spoken)
Organizational	Graphics that show relationships between elements described in text (written or spoken)
Explanative	Graphics that show how a system works

Other factors can affect what students comprehend from visual images. For example, different features of images affect the comprehension of the message transmitted by the image (Ametller & Pinto, 2002). The use of color, the use of arrows to display the flow of events, mixing of real and symbolic entities, highlighting of certain words or images, wording of verbal explanations, and integrating several images into one all have been shown to affect students' understanding of images (Styliaiduo & Ormerod, 2002). Difficulties have been documented in learning from realistic drawings and photographs than from simplified diagrams (Winn, 1996). Simple diagrams of relevant structures were more beneficial because the important parts could be more easily viewed and identified while other details could be de-emphasized. The background of the photograph is troublesome for some students who have difficulties distinguishing relevant objects (Pozzer-Ardenghi & Roth, 2005). Some students attach too much importance to artificial color in photographs and become confused when they see the real thing (Holliday, 1980). Mayer et al. (1996) found that the length of verbal explanation accompanying the illustration is also important. Short explanations with simple illustrations are more effective than illustrations with lengthy verbal explanations.

Research has shown that several characteristics of learners can affect illustration processing. A learner's preferred cognitive style is important to consider. Riding and Douglas (1993) found that students displaying an "imager" cognitive style benefited more from the integration of text and illustrations than did students displaying a "verbalizer" style. Prior knowledge is another important consideration. Students with less prior knowledge are helped more by illustrations than students with more prior knowledge (Cheng, Lowe, & Scaife, 2001). In addition, research has indicated that children fixate longer on illustrations and are not as skillful as adults in selecting informative areas of pictures (Patrick, Carter, & Wiebe, 2006).

Contradictory results have been found on the ability of the learner and their understanding of visual images. Most studies indicate that illustrated materials may involve requirements more readily met by intellectually capable students. Students need to comprehend abstract and difficult concepts, decide on which sequence text and illustrations should be studied, distinguish between pertinent and nonpertinent information, and integrate related pieces of information. Hannus and Hyona (1999) found that comprehension scores improved with the presence of illustrations for high ability students, but not for low ability students. In addition, high ability students are more strategic in their processing; they spend more time on pertinent segments of verbal explanations and illustrations. Reid and Beveridge (1986) found that pictures with text were more distracting to some lower level students. Because low ability students are less able to integrate information in text and illustrations, they spent more time on illustrations and accessed them more frequently. Kalyuga (2007) has provided contradictory evidence. Their research indicated that lower ability students, who often struggle with verbal communication, benefit the most from visual learning, while high ability students do not.

As the amount of information acquired though visual mediums multiplies, visual literacy, or the ability to understand, evaluate, and produce visual messages, has become increasingly important in education (Ferk et al., 2003). Considerable attention has been devoted to the effect of visual learning on the construction of knowledge and the understanding of relationships and processes in science courses (Ametller & Pinto, 2002; Girwidz et al., 2006; Mayer et al., 1996). The typical visual displays used in the science classroom are photographs, diagrams, charts, graphs, maps, and drawings. Currently, most of the attention has been focused on understanding the impact visual representations in textbooks and multimedia materials have on students and their learning, but very few studies have focused on teachers' use of these graphics in the classroom. The purpose of this study is to investigate how high school science teachers use visual representations in their teaching. Specifically, through a layered case study, this research will explore how course content, student characteristics, and resource availability affect how teachers select and use graphics in their science classes.

Methodology

Data Collection

A case study approach was used in this research. The design of the case study used a layered approach (Patton, 2002; Stake, 1995). An overarching case was developed to look at science teachers' selection and use of graphics as a whole. To develop an understanding of this research goal, nested or mini-cases (Stake, 2006) were developed to examine the research question from the participants' perspective.

The site for this study is a high school serving approximately one thousand students in the southeastern region of the U.S. The participants were seven teachers (Dave, Debbie, Chris, Bob, Janet, Ellen, and Margaret), each teaching different science courses (see Table 2). These teachers represent a convenience sample, since they are all located at the same school. However, within the school, maximum variation sampling was applied. Common patterns that arose out of the variation were of particular importance. For a period of 6 weeks, classroom observations were conducted in four courses: Earth Science, Physics, Chemistry, and Biology. Each science course was taught by two different teachers (except Physics) and was observed six times (three times per teacher), for a total of 21 observations. Of primary interest were instances where teachers made use of visual representations during the class period. Extensive field notes were recorded for each observation. A standard observation protocol was not used, however field notes were used to document what type of graphic was used, salient features of the graphic identified by the teacher, explanation of the graphic given by the teacher, the teacher's rationale for selecting the graphic, instances of student confusion, and student interpretation of the graphic. Immediately after the observations, videotaped recordings of the class were reviewed to expand on the field notes initially taken. Also, copies of the visual materials used in the class period were collected.

Table 2. Teacher Pseudonyms and Number of Observations for Each of the Four Science Courses Examined

Science Course	Teacher 1 (# of Observations)	Teacher 2 (# of Observations)
Earth Science	Debbie (3)	Dave (3)
Physics	Chris (3)	
Chemistry	Bob (3)	Janet (3)
Biology	Margaret (3)	Ellen (3)

Each teacher was interviewed twice, at both the beginning and end of the semester. The initial interviews focused on how teachers selected and used visual displays in their science teaching. Although the questions were catered to the specific visual representations used by individual teachers, the following questions served as a guide:

> Why do you use visuals in your teaching?
> What features of visuals make them "good" ones?
> How does the amount or type of visual used differ depending on student? the course? the topic?
> What are your resources for finding visuals to use? How do the resources available or lack of resources available affect the visuals you use?
> What are some limitations you may have experienced using visuals?
> How would you describe the quality of visuals in your textbook? How do you think students make use of illustrations in their textbooks?
> How were the visuals used for classroom decoration selected?

In the final interviews, teachers were asked to reflect on the use of visual representations over the course of the semester. Specifically, probing questions were asked about the use of visual in the lessons observed by the researcher. Each interview lasted between 25-35 minutes. Brief notes were taken during the interview and all of the interviews were audio taped. Shortly afterwards, the interviews were transcribed.

Data Analysis

The data collected from multiple sources (field notes, visual materials, responses from interviews) were analyzed in order to identify themes that emerged from the data. The qualitative data were analyzed inductively through open-coding (Straus & Corbin, 1998), which allowed the researcher to identify "possible categories, patterns, and themes" (Patton, 2002, p. 453) based on the major ideas repeatedly surfacing. The four categories developed included: content-related, student characteristics, teacher characteristics, and resource availability. The data for each individual were then grouped together with participants of their own group (e.g., teachers that teach the same content area). From the grouped data, mini-cases were developed. After the mini-cases were created, cross-case analysis was used to examine similarities and differences of the participants (Patton, 2002). Through this process, the researcher developed the overarching case in order to understand the factors involved in the teachers' use of visual representations.

Results

Findings from the classroom observations regarding the number and type of graphic used in each of the four science courses are summarized in Table 3. From the interviews and observations, teachers either directly or indirectly indicated the influence of the following factors on their use of visual representations in their teaching: course content, student characteristics, and resource availability. Teacher characteristic were rarely observed or discussed in interviews, suggesting it is not an important factor influencing the teachers' selection and use of visual representations.

Table 3. Types of Graphics Used by Teachers in Each Science Course

Science Course	Decoration	Representational	Organization	Explanative	Total
Earth Science	3	22	9	7	41
Physics	0	5	28	0	33
Chemistry	0	13	11	5	29
Biology	7	19	13	8	47

Influence of Course Content

Earth Science

The importance of selecting real pictures was evident in both earth science courses. In her interview, Debbie stated the most important criterion used to select a visual display is if the illustration is the "real thing." Similarly, Dave tries to "stay away from cartoons" that do not provide "an accurate depiction of what it entails." He follows up with an example:

> Sometimes you see that a lot of science textbooks will bring in, let's say…umm, let me use an example…a cartoon of a volcano, and what it does is that it makes it look almost like a uh cartoon network depiction of what a volcano looks like when in real life uh a lot of time you don't see smoke billowing out of the top. It's usually in a dormant state and something like that would confuse a child and that they would actually think that a volcano would look you know very uh Fred Flintstone like or something. It doesn't…that's not the way it usually works in real life. It contradicts what is real. So I try to stay as real as possible.

Both Earth Science teachers preferred photographs when representing processes also. Although they are difficult to find, these teachers felt that real pictures with arrows relating the steps of a process (i.e. the water cycle) are better representations than diagrams. If photographs cannot be found or do not show the features the teacher would like to highlight, only then would they use diagrams. However, both teachers felt it was important to explain the inaccuracies of the diagram. For example, in class Dave used a diagram of a soil profile to show the multiple soil layers. He followed up this diagram with a photograph of the transition from one soil layer to the next. Even with the preference for real pictures, these teachers identified two limitations of these displays: lack of color contrast in nature and the absence of labeling. However, both teachers recognized the importance of explaining the graphic to direct student attention to important features.

Biology

Much of the content material covered during my observations of biology was abstract in nature. To teach biology, Ellen relied heavily on diagrams and graphs. During observations, she represented concepts such as species survival curves, biomass pyramids, and nutrient cycles. Ellen explicitly stated that she kept photographs to a minimum when teaching biology. When she did use photographs, they were for decorative purposes. For example, as she was discussing ecological disaster on Easter Island, she displayed a photograph of the statues on the island. The photograph was not imperative in understanding the content material, but served more to give students a context.

Similarly, Margaret visually represented material with both graphs and diagrams. She included graphs of free energy, graphs of enzyme activity, and diagrams that illustrated relationships between processes (ex. endergonic and exergonic reactions). Although she relied heavily on diagrams, contrary to Ellen's ideas, realism remained an important factor. For example, Margaret used a visual representation of an enzyme that was very realistic in nature, even though the common textbook illustration represents an enzyme having an oval shape. Animations were used often in this course to teach processes like diffusion across the cell membrane. In her interview, Margaret states, "It really is amazing how they look at an animation and go 'Oh, okay.' We've talked about [diffusion] all week, but seeing it, now they really get the idea." Likewise, when teaching anatomy and physiology, real pictures of tissue cross-sections were preferred in this course. The only diagrams used represented structures that could not be shown in a photograph. For example, a cross-section of the layers of the skin cannot be seen with a photograph as they can in a diagram. Although she sees value in real pictures, she recognizes the lack of labeling can be a problem for students. Therefore, she focuses their attention on important features with questions such as, "Do you see the branching?" and "Do you see the nuclei all squeezed down in there?"

Physics

In this course, Chris only used diagrams and graphs to teach force. No photographs were used to represent direction of forces; instead, Chris demonstrated this concept with materials in the classroom. There was a heavy emphasis on the connections between physics and everyday life. Also, another unique aspect of the visual representations used in physics is the emphasis on teacher and student created graphics. Most of the force diagrams were drawn by the teacher and/or students to solve word problems. Likewise, graphs needed to solve problems or analyze laboratory work were created by students on the computer using Graphical Analysis. One of Chris' goals is to "prepare students for college physics" where they will need expertise in graphing and problem solving.

Chemistry

Almost of the visual representations used in chemistry teaching were abstract in nature. Bob and Janet co-planned all of the lessons and used similar instructional materials. Many of the representations used to teach chemistry were at the molecular level. They illustrated the arrangement and movement of molecules. Rarely were their macroscopic counterparts shown. As Janet stated, "It does the kids no good to see a picture of a beaker with liquid, if they have no idea what is going on with the molecules." The remainder of the representations used in the course was symbolic—presenting formulas, equations, or structures. Bob used a greater number of symbolic representations than Janet. As he stated in his interview, "You have constantly show them equations. If they don't know what they mean at this point in the semester, it is only going to make it harder later on."

Influence of Student Characteristics

Learning style

Leaning style was the most discussed of all the student characteristics. All of the participants recognized the importance of catering to the visual learning style. As Debbie explained in her interview, "So I try to integrate the visual aspects as much as possible, because I learned as I

was going through teaching classes that the majority of uh pupils were visual learners and definitely reinforced any kind of auditory stuff I was conveying in class."
Although they recognized other learning styles, many seemed to feel that incorporation visuals was a much more tangible goal than incorporating tactile stimulus. Sue elaborated, "Visualization is important, but along with that they have to have more tactile feedback with the visualization. So you have to reach more than one…more than two senses. But after auditory, visualization is the most doable."

Ability level

Overall, all of the teachers felt that high ability students needed just as many visual representations as low ability students. As Margaret recently found out, "Now this year I've got AP students and I thought I wouldn't have to do as much visually, but boy, I still do." Although they feel the amount of visual used should remain consistent, most recognized some important differences with high and low ability students. For example, Debbie feels that visuals are important in helping students understand concepts, but she recognizes another role of visuals that is equally important. Debbie believes visuals are needed to "keep the interest" of her low ability students. She also feels that low ability students cannot "pick out the important parts of pictures" and therefore need more explanation. Ellen thinks the "type of visualization changes" for low ability students. In her opinion, low ability students need less complex visuals; the visual displays should include less realism so that the student will have less to analyze.

Prior knowledge

As stated in his interview, Dave uses less visualization when he recognizes students are already familiar with a topic. He uses the following example:

> In biology, they have life experiences already in their head. And if I mention a certain species of animal, they already have usually sometimes that certain species of animal in their head and they already either had some kind of life experience with that. With astronomy, a lot of times they don't. The can't relate to let's say a protostar…So I think life experiences in the subject matter can be beneficial and you would have to use less visualization because they already have the concept or life experience in their head.

Margaret holds a different opinion. Regardless of the students' prior knowledge, she feels it is important to continue to use ample visualizations to clarify misconceptions. For example, although her students have learned about cell membranes before they take her class, she finds that many still do not realize that plant cells also have cell membranes in addition to cell walls.

Influence of Resource Availability

All four participants acknowledged resource availability as a major factor in their use of visual representations. Each science classroom has several computers and a data projector. Teachers can easily project visual representations to the class or have students look at them on their own computer. They have ample textbook resources and supplements. Internet access is not an issue in the school. In addition, the science department has the money to purchase software, visual aids, and anything else the teachers might request. As Bob said, the department has "a budget that says ok, you know 'What you do need in your class to make it work?' Uh…that really helps out a lot as far as visualization, so we are very, very lucky."

Discussion

The participants had many reasons for using the visual representations observed in their courses. The prevalence of photographs in both Earth Science courses seems to stem from the nature of the material. Most of the concepts discussed in this course can be readily seen outside. Dave and Debbie are concerned that if they show diagrams instead of real pictures, their students will have misconceptions and may not be able to identify the illustrated material out in the field. These teachers were more comfortable showing diagrams of material that cannot be seen by students from field work in their course; examples mentioned by these teachers included astronomy topics and the Earth's magnetosphere.

Ellen and Margaret's use of diagrams and graphs in Biology seems to stem from the content material being covered, not because they assume that many students have prior experience with the content. At the beginning of the year, may biology teachers review biochemistry and energy before they begin teaching topics such as cells and genetics. Biochemistry and energy are more abstract and photographs of much of this material are not possible. However, Margaret does try to incorporate more realistic drawings and diagrams of structures so that she does not give students misconceptions. In one of the observations, a student noticed that the enzyme representation Margaret had chosen was drastically different from the representations she has seen in the past. The use of animations in this course is a result of the process-oriented nature of the biology. Processes involving movements are best represented though animations.

Margaret's rationale for using real pictures in Anatomy and Physiology is similar to that of Dave and Debbie in Earth Science. Ultimately, she would like her students to see the tissues under the microscope during a laboratory exercise. Margaret reasons, "It wouldn't be helpful to students to show them a diagram and then expect them to recognize real tissues in lab." She uses color as an example; in diagrams, illustrators do not always use realistic colors. This difference in coloration may cause them to misidentify structures. Finally, although Margaret showed animations in her biology course, she doesn't in Anatomy and Physiology. She believes this course should "focus on structure, not process."

The visual representations in Physics and Chemistry were markedly different from the other courses. Students were required to create their own diagrams to represent force problems in Physics. Because diagrams are student-created, they do not have any realistic features and lack the context most diagrams have. Chris believes, "[Students] just have to draw [diagrams]. They just can't look at them in the book. If they rely on it too much, they can't do it for themselves." He also requires his students to create a number of graphs because he feels "graphing is a skill that links everything." In Chemistry, all but a few of the representations were molecular or symbolic. There were very few instances were macroscopic representations were used.

Out of all of the student characteristics described, learner characteristics seemed to be the most influential in teachers' use of visualizations. Chris states that the "helpfulness of visuals depends more on if they are visually oriented," not on their ability or prior knowledge. The teachers recognized that ability level does influence their visual representations but offered different rationales. Teachers may use less complex visuals, more inviting and stimulating visuals, or many diverse visuals representing the same material for low ability students. Overall, most teachers do not factor in prior knowledge when they select visuals for classroom use. Although Chris recognizes that prior knowledge may "determine what students will take away from the class," he has to assume that students do not have any prior knowledge of the topic.

The teachers recognize the importance of resources for using visual representations. Most teachers used PowerPoint presentations and content-specific software displayed with the LCD projector. As Debbie said in her interview, "I use visuals because we have the resources" and because "the school is technologically up to date." Chris recognizes that teachers in this science department have the ability to "overcome obstacles that other schools cannot readily overcome."

Implications

The findings of this study suggest that science teachers take into account multiple considerations when selecting and using graphics in the classroom, including course content, type of visual, realism, learning styles, prior knowledge, and ability level. The results indicate that researchers must broaden their focus when investigating visual representations. Current studies in the literature concentrate on what features of illustrations best enhance learning, how student characteristics play a role in comprehending visual displays, and how different modalities interact to construct meaning (McLuckie et al., 2007). The findings of this study indicate that in the quest to develop a set of principles for the design of graphics, we must also consider how teachers make use of these visual displays in their teaching. Design principles will not have much meaning unless they are studied in the context of the classroom. In the future, research on how teachers make use of visual representations in the science classroom should be expanded to encompass more typical school contexts.

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