AC 2009-372: GRAPHIC LITERACY IN ELEMENTARY SCIENCE EDUCATION: ENHANCING INQUIRY, ENGINEERING PROBLEM SOLVING, AND REASONING SKILLS

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Graphic literacy in elementary science education: Enhancing inquiry, engineering problem solving and reasoning skills.

Abstract

The demand for high quality science and engineering graduates continues to outstrip supply. The response must be a science and engineering education pedagogy that considers multiple modes of learning and teaching tailored to the various grade levels. Graphic literacy, the use of visual representations and their offspring including but not limited to pictures, models, graphs and other visual symbols can enhance K-12 scientific and engineering inquiry and problem-solving skills. The Grade 5 *Motion and Design STC* curriculum is one of several science units where technology and engineering concepts are introduced as part of the science inquiry cycle. The challenge is to identify and support student meaning-making and reasoning through the use of graphics and other support documentation. Over the past year the research team have been working with teachers to enhance the use of student-generated graphics. This study provides insight into the process of improving graphic pedagogy by leveraging semiotic analysis of student notebooks, in-class observations and ongoing support, the introduction of graphic tools (e.g., graphic taxonomy and master images), and formative assessment strategies to facilitate student science and technology learning. It is not enough to create representations; students must work through and revisit their graphics in context of the inquiry and problem solving cycle.

Introduction

Research in elementary graphic literacy is an emergent area of study, just as the integration of elementary science[1] and elementary engineering education research is a relatively new area of investigation. One such project is Engineering is Elementary (EiE), an NSF funded engineering curriculum project focused on integrating engineering, reading literacy and elementary science topics[2,3]. Another engineering education initiative is Project Lead The Way (PLTW), which promotes technology education in the classroom for middle and high school students[4]. As well, the American Society for Engineering Education (ASEE) has provided guidelines for hands-on, standards-based, interdisciplinary engineering activities[5], and the National Academy of Engineering with their publication *Technically Speaking* encourages technological literacy[6]. These curriculum initiatives and publications promote engineering as a career choice. But there are opportunities in elementary science education where engineering design and technological problem-solving can be leveraged to integrate connections between science, technology and engineering.

One example is the Grade 5 kit-based science unit, the *Motion and Design*[7] curriculum, one of 16 science units approved by the school district the research team are supporting. Science concepts such as force, friction and momentum are investigated by integrating scientific-inquiry and engineering problem-solving activities. Teaching students to move between inquiry science and engineering problem-solving is not an easy task. There are clear overlaps, but each has its own unique ways of thinking[8]. How these two worlds come together is not explicitly taught or described in the science kits. Even though national standards in science and technology emphasize the need for young students to engage in technological problem solving, the design process, critical thinking and communication[9,10,11,12] the challenge of integration for teachers remains. To this end, an area of student learning where bridging science and engineering problem-solving remains underserved is the development of graphic literacy. This is where student-generated representations can be used during various aspects of the inquiry and problem-solving process to encourage student meaning-making and evidence-based reasoning. In the Grade 5 science curriculum, the state standards list reasoning and the use of models to represent objects, structures and/or phenomenon as unifying concepts[13]. Yet many of the cognitive demands require spatial skills that are not easily acquired without some purposeful pedagogic practice. As such the research team endeavors to try and answer the following research questions:

- What graphic challenges do students face when investigating motion and design?
- How do forms of graphic representation support student meaning-making?
- What symbolic tools could students use to further their scientific and technological understanding?
- What graphic pedagogical strategies should be employed by the teacher?

Problem-solving, scientific thinking and representation

The *Motion and Design STC*[14] kit covers a variety of science and technological concepts that carry into many areas of science and engineering. Many of the concepts (i.e., balanced and unbalanced forces, gravity, friction, and design/build/test scenarios) are covered through a series of problem-solving activities. For instance, students are required to predict the various visible and invisible forces associated with a vehicle attached to a string and washers, the weight is then released from the edge of the table. These along with other problem solving activities (e.g., how load affects vehicle motion) suggest students must begin to build the conceptual foundation of Newtonian physics. The learning of invisible and visible forces can be facilitated by a graphically enhanced mode of learning. By encouraging students to develop rich representational practices along with providing graphic tools (i.e., symbolic conventions, authorized or justified representations) and the ability to achieve classroom consensus through the use of multiple graphical representations[15,16,17].

Science as a discourse is a mix of multi-modal forms of representation—linguistic, numerical, graphical and tabular modes—integrated to represent scientific phenomenon[18]. Students encounter two challenges: a) the integration of multiple modes of representation of a particular phenomena or problem[19], and b) the learning skills necessary to create representations of phenomena in an iterative manner to further their scientific thinking[20]. Teacher understanding of how to support student-generated graphics requires some formal appreciation between the interactions of the graphic signs, the phenomenon and the observer. The understanding of a concept and its representation require the ability to triangulate between the science concept (motion), its representation (vector) and its referent (the phenomenon to which both the concept and sign refer) (Figure 1)[21].

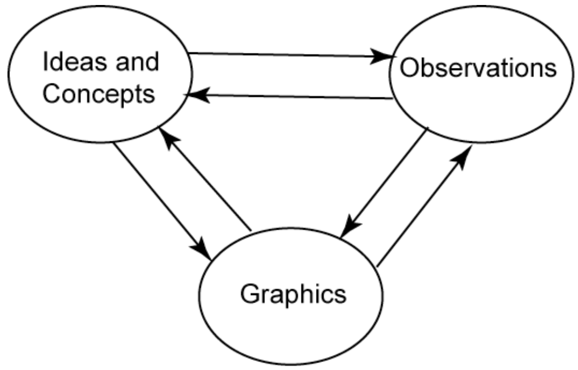

Figure 1. The linkages among observations, graphics, and concepts.

The students' ability to create graphic representations is a means of integrating, interpreting and constructing knowledge that is meaningful[22]. Learners are building on prior ideas to formulate their own understanding of phenomenon[23]. Too often students are instructed to represent ideas that are procedural or observations that are factual (e.g., describe what you see), but in effect do not incorporate the underlying mechanism (e.g., an invisible force) associated with how an object is behaving. Another big challenge is to immerse students in inquiry and problem solving investigation that move beyond human scale drawings that are visible to the naked eye towards representing phenomena that are invisible (e.g., gravity and friction) which informs student understanding of the relationship between motion and design in vehicle performance. The integration of visible and invisible interactions is needed to support increasingly sophisticated understandings of core science and technology concepts[24]. The sophistication from general pictorial graphics, which may or may not be labeled adequately, towards sophisticated abstract representations that attempt to reflect a meaningful understanding of the phenomenon requires a shift in the level of detail and/or simplification. This is where modeling can support refined representation and enhance meaning-making.

A model is a representation of an idea, system, theory or phenomenon that accounts for its known or inferred properties. The model differs from the system—the students definition, rules and parameters used to frame the phenomenon—because modeling can add additional information that is not inherent in the phenomenon[25,26,27,28]. Models cannot interact directly with the ideas they represent; they are intended to be representative of the target phenomenon[29]. Even though social and cultural aspects of an investigation could play a part in understanding the phenomenon, the interest here is in students' modeling as it relates to the cognitive core of the phenomenon[30]. The creation of models provide insight into the fundamental nature of the phenomenon and are powerful descriptive, predictive and explanatory tools, often underutilized in science and problem-solving investigation[31,32, 33,34,35]. When models are conceptualized and communicated as part of mental schemas—knowledge, images and procedures in memory[36]—they can be leveraged as part of an iterative, transformative process necessary to refine student meaning-making. The process of imagining, expressing and negotiating consensus surrounding the purposefulness and meaning represented in the model can transform student reasoning of science and technology. Validation of concepts by agreement with observation and experiment[37] becomes intertwined within the inquiry-problem solving cycle. It continues student development of visual, metaphoric and thematic imagination, necessary in applying science and technology concepts[38,39]. This iterative process supports core skills for engineering students, reinforcing the importance of using graphics in multiple stages of the design process, not just final documentation[40,41,42]. These graphics become an integral part of documenting observations, ideas and solutions.

Methods

Several research components are being accomplished in tandem. Formal teacher professional development training (i.e., kick-off meeting), including a day long session on the use of notebooks and graphics within science inquiry cycle, was conducted with seven area elementary schools. Midway through the year a second round of professional development was completed, with greater emphasis on the role of graphics as a cognitive tool. During the latter session a graphic taxonomy was introduced to help teachers facilitate student graphic use during inquiry and problem solving activities. The taxonomy centered on a class of graphics (i.e., vectors), and master images (i.e., canonical representations) that leverage the graphic taxonomy to support student generated graphics when modeling phenomena. The development of a graphic taxonomy, using both a top-down and bottom-up approach, is based on the elementary science concepts covered in class and symbols used across K-12 science and technology education. This includes research and practitioner literature, state adopted science and technology published curriculum, teacher suggestions based on classroom experience, and observations conducted during science.

Throughout the first year, ongoing science classroom observations utilizing a “science and graphic” protocol was used to analyze a) science classroom interactions throughout instruction, b) the use of teacher-driven and student-driven graphics during the inquiry and problem solving cycle c) informal science discourse between students and the researcher during investigations (e.g., the use of graphics and content understanding), and d) informal interviews with the teacher on the use of graphics and notebooks. The observations were used to support our analysis of student notebooks. Periodically a set of student notebooks were collected, photographed, coded and analyzed to establish the kinds of graphics being used and in what context. A form of graphic analysis, semiotics, was applied to analyze the relationship between the elements (i.e., signs) that make up a graphic, the instructional context in which they were created, and other relevant characteristics of the learner[43]. It provided a framework to categorize graphic types, informing the analysis of how students are thinking with graphics during their investigation. Teacher semi-structured interviews were conducted to inform the researcher on how graphics were used during classroom investigations, what explanations and reflections were the students able to achieve as a result of working with graphical representations, and how student-generated graphics aids teacher formative assessment. Lastly, student interviews were performed to help indentify student scientific thinking and new learning as a result of utilizing graphics as a mode of inquiry.

Results

Based on preliminary findings, a variety of representations were found in student notebooks. Figure 2 illustrates the students’ representation of technological problem solving cycle. Over the course of several weeks students were being asked to design/build/test a standard vehicle under specific conditions related to Newtonian physics, how concepts of force, friction, load, and gravity alter car performance. The student’s use of directional arrows, a type of vector, illustrates their idea of change over time, an important science concept that crosses many areas of science.

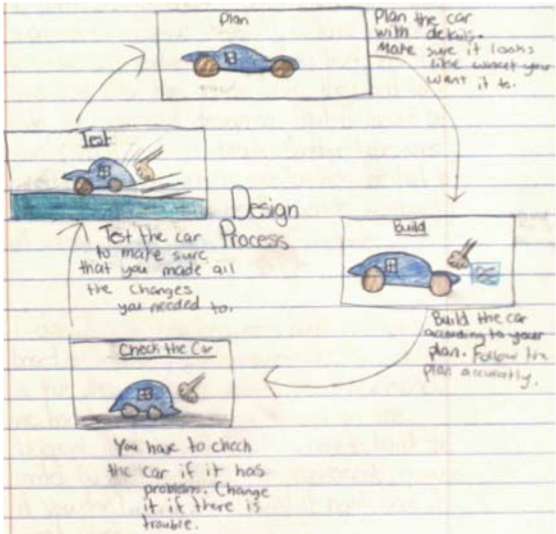

Figure 2: Student generated technological problem solving cycle

Figure 3 is the use of graphics to support student predictions on how force may affect vehicle motion. This prediction requires student elaboration on what invisible forces (e.g., gravity and friction) are interacting with the vehicle.

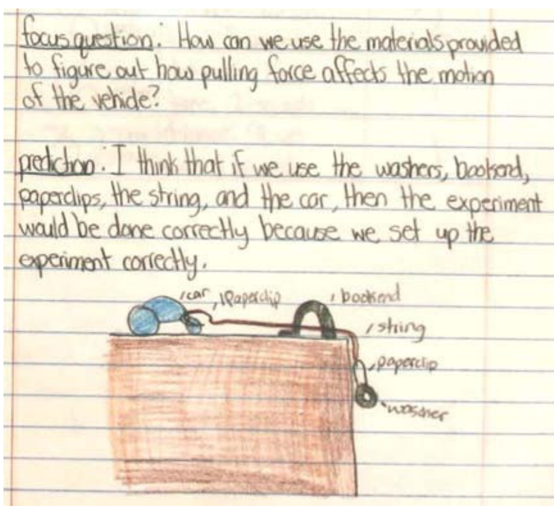

Figure 3 Experimental set up and prediction

The *Motion and Design STC*[44] kit is structured around many key concepts that are covered in a traditional school quarter (8 weeks). As such, graphics have been positioned alongside core science and engineering concepts, creating opportunities to streamline instructional practices, and modifying pedagogy to support inquiry and problem solving process skills. Graphics are also being used as a reasoning tool to support claims and evidence activities. Figure 4 illustrates student use of graphics to help make claims surrounding the amount of force needed to move a vehicle.

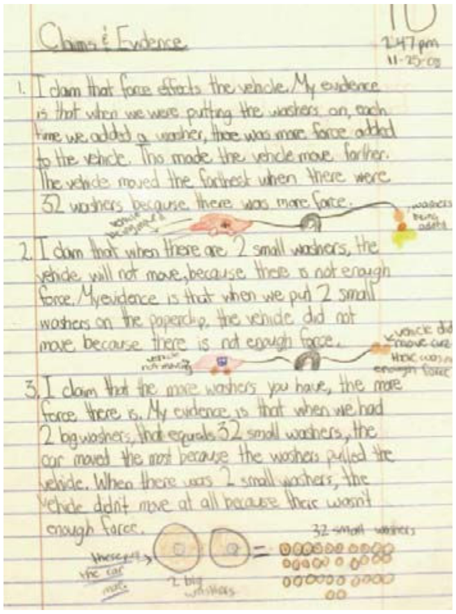

Figure 4 Claims and evidence

Prior to the above investigation (Figure 4) teachers provided students with an explanation of balanced and unbalanced forces. Vectors were used to represent force and direction. Along with teacher driven graphics, the teacher provided gesturing cues and a tug of war game to illustrate the various forces students encounter. The ability for students to represent their visible world with invisible (hard to detect) forces and atomic-scale particles strengthens student understanding of natural and man-made phenomena that may be difficult to achieve with just words.

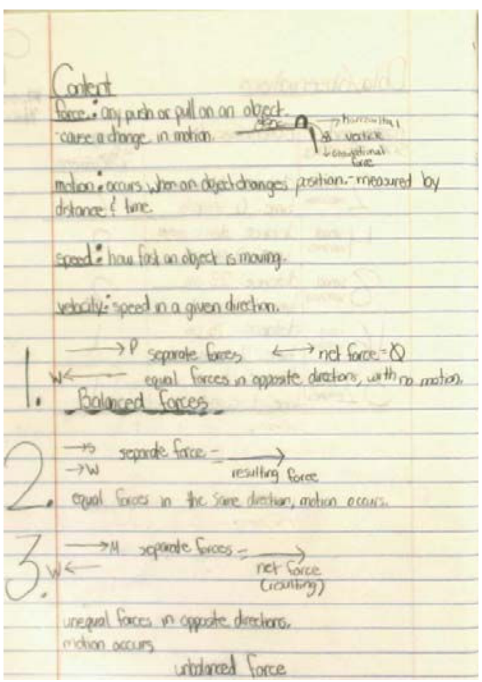

Figure 4 Representing invisible phenomena with vectors

Conclusions

There is a need for systematic graphic training as part of pre and in-service science teacher professional development[45]. Scaffolding techniques that encourage the development of spatially-oriented internal representations during science and technology investigation become explicit when also represented in a physical, graphic form in science notebooks. They also become more accessible to the learner, furthering their understanding, through a process known as representational redescription[46]. This is analogous to a modeling methodology, whereby students move from mental models to expressed models to consensus model building. Mental representations—graphic and otherwise—are continually being constructed as a child is involved in organizing their observations into ideas, thoughts and questions. Students need to develop metacognitive abilities to assess the quality and usefulness of a graphic/graphic type to solve the problem at hand. Since the various graphic types are abstractions of observed phenomena, the teacher and students need to discuss the strengths and weaknesses of their representations[47]. During the lifecycle of the inquiry and problem-solving activity, ongoing formative assessment (e.g., during classroom investigations and notebook assessment) is needed to evaluate student understanding and meaning-making strategies. It is not enough to create representations; students must work through and revisit their graphics in context of the inquiry and problem solving cycle. A "graphic vocabulary wall", synonymous with a word wall (commonly used in elementary classrooms) should be established to support student use of graphics. The facilitation in graphic production will further student spatial abilities by eliminating mental road blocks that hinder their thought processes.

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