Graphicy And Its Role In Elementary Science And Technological Problem Solving Investigations: Implications For Teacher Professional Development

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ABSTRACT - This paper reports on a study designed to provide professional development to elementary teachers on the use of graphically enhanced notebooks. Semiotic theory, along with classroom observations, and student and teacher interviews is being used to analyze student reasoning with graphics. Thus, providing a framework to categorize graphic types, informing the analysis of how students are thinking with graphics during their investigation. Our analyses revealed that the pedagogical power of student-generated graphics is not being harnessed at all stages of the inquiry/problem-solving cycle. We encourage the use of student-generated graphics as a cognitive tool for investigation, explanation and reflection.

I. Introduction

A student’s ability to effectively problem-solve, inquire and explain their understanding of the man-made (designed) world and the natural world is dependent on their ability to interpret their observations, their capacity to construct mental pictures or models, and opportunities to express and test their visualizations through rich explanation (Greca & Moreira, 2000). By testing their explanations, students have the opportunity to revise, explore and generate new meaning. An effective way of developing this recursive style of learning is through the use of graphics—inscriptions to describe and understand natural (and technical) processes that range from atomic bonding (Windschitl et al., 2008) to relationships of force and friction in mechanical devices. As with the terms graphic and inscription, models—representations constructed as conventions within a community to support disciplinary activity—will be used somewhat interchangeably (Windschitl et al., 2008). The community in question is the elementary science classroom where scientific investigation and technological problem solving are often practiced in concert.

Graphicy, or graphic literacy, helps link different representational modes such as written and verbal, important in scientific and technical thinking (Prain & Waldrip, 2006). The importance of graphic literacy and student spatial reasoning is acknowledged by the engineering graphics community (e.g., Ferguson, 1997; Roorda, 1994), science educators (Baker & Piburn, 1997), and other fields of engineering, physics (Pallrand & Seeber, 1984), geosciences (Kali & Orion,
These are all fields of study that rely on student ability to bridge inquiry skills with design process skills, and effectively utilize science and engineering concepts to think technically and creatively to solve problems. The 21st Century learner is tasked with navigating this mental knowledge field that is increasingly abstract and interdisciplinary. Teacher awareness, of student needs in the elementary years, is an important asset for students who are expected to apply science and technical concepts in meaningful ways throughout their academic career. The practice of meaningful learning requires greater student ownership in the meaning making process. Student-generated graphics can facilitate richer student reasoning during science activities, where scientific inquiry and technological problem solving are blended together. An important practice in elementary science education is the use of notebooks, a valued medium among science and engineering educators who acknowledge the power of graphics to reveal student thinking (Lehrer & Schauble, 2002; Wu & Krajcik, 2006). As will be discussed later, more mainstream texts on elementary science instruction with notebooks (Campbell & Fulton, 2003; Harlen, 2001) provide little guidance on how notebooks could be used for this type of learning through graphics or for the design of professional development. Finally, semiotics, the study of symbols and how they convey meaning, will be used to further our analysis of student scientific and technical understanding (Lemke, 1998; Peirce, 1960; Scheiter, et al., in press; Ware, 2004).

This paper reports on a study designed to provide professional development to elementary teachers on the use of graphically enhanced notebooks. The study is set in a U.S. urban/suburban public elementary school with approximately 325 students in grades K-5, with weekly science instruction provided throughout the year. Teachers are expected to use science notebooks as they deliver science instruction via district adopted kit-based materials. While many of these teachers have received district-sponsored professional development on the use of these kit-based materials and/or science notebooks, such training is not mandatory or uniform. Of particular interest is the 5th grade science kit on Motion and Design

II. Graphic Production and Meaning Making

Graphic production as a strong meaning making activity has strong advocates (cf., DiSessa & et al., 1991; Gainer & Child, 1986; Wu & Krajcik, 2006). Several patterns continue to emerge pertaining to the importance of learning technical concepts. To learn science effectively, students must understand different representations of science concepts and processes, be able to translate them into one another, as well as understand their coordinated use in representing scientific knowledge (Prain & Waldrip, 2008 p. 1844). The authors acknowledge that it is not enough to use one graphical mode of learning to solve problems but stress the importance of knowing the strengths and weaknesses in terms of precision, clarity, and associative meaning various representations (graphic or otherwise) offer.

Windschitl et al. (2008) take a slightly different view on the criticality of investigating one’s mental models through the development of conceptual models—expressed representations the classroom community can engage with in order to refine individual and group understanding. The authors advocate for a model-based inquiry method to assist in scientific and technical reasoning. Windschitl et al. (2008) suggest that students need ample opportunities to test their knowledge, in the forms of models by proposing new hypothesis that express possible relationships between events, processes, or properties.
within these models. This provides students with the opportunity to revise and refine their ideas surrounding their proposed model, assisting in the development of evidence-based explanations of the way the natural and (man-made) world works (Windschitl, 2008). As a result, underlying or unobservable processes can be inferred from observations, extending student understanding. This generative iterative process, in the use of models as a cognitive tool, becomes the prime vehicle for new predictions, insights and hypothesis testing. Model-based inquiry, grounded in content, connects empirical data with underlying causes and goes beyond how something happens to why something happens (Windschitl, 2008).

Gilbert (1991) defines science as a process of constructing predictive conceptual models, while Prain & Waldrip (2006) state the nature of learning as re-representation—the re-coding of representations stored in the same and/or different modalities. Engineering education has naturally adopted the language of modeling and problem solving as a major outcome in undergraduate engineering disciplines. If we are going to ask elementary science students to develop richer mental models and representations to problem solve with, then they will require assistance in developing graphical conventions. They must also engage with consensus models or master images that challenge and/or support their mental representations of the scientific or technical phenomena under investigation. This provides students with the opportunity to engage in cognitive apprenticeship—practicing how scientists generate knowledge (Mathewson, 2005).

### III. The Classroom Context

Within the classroom where might the practice and development of graphical fluency, inquiry and problem solving take place? The science notebook is the primary vehicle students have of documenting their thinking, cataloguing their investigations and reflecting on their experience. Science notebooks help students contextualize learning about scientific phenomena from the three key contexts of the imaginary, experienced and investigative worlds (Shepardson & Britsch, 2001). It is a medium for capturing children’s sense making and a resource teachers can use for ongoing formative assessment of the students’ development of science concepts (Alonzo & Aschbacher, 2004; Saul & Reardon, 1996). Success in science and engineering is dependent on "mastery of productive ways of representing ideas, using scientific [and technological] tools, and interacting with peers about science" (Michaels, Shouse, & Schweingruber 2007 pg. 21). Along with how student notebooks are used in the classroom, student-generated graphics are central to our study. Specifically, how students make sense of phenomena through the use of graphics. Figure 1 proposes the bi-directional linkages associated with student-created graphics. Observations and ongoing experiences in the physical world interact with past experience embedded in mental models. Integration of experiences in the “here and now” can be tested, refined and confirmed through graphic representations that comprise conceptual models for use in individual or group sense-making. In the classroom, this process often plays out through the activation of prior classroom learning and newly introduced conceptual content matched with an activity that generates observations of a phenomena recorded in and reflected on in the science notebook.
At present, students’ record phenomena that can be seen in a single, unaided view and happen over a relatively short (i.e., less than a class period) span of time. Teachers should recognize that often a complete understanding of science and engineering concept lies outside of the human scale, as depicted in the center of Figure 2.

Student-generated graphics can be used to investigate phenomena invisible to the naked eye and critical to engineering problem solving. For instance, the Motion and Design kit challenges 5th grade students to investigate science concepts—aerodynamics, air resistance, dynamics, and the laws of motion—while integrating the technological problem solving cycle (NSRC, 2004). The six steps the kit includes are identifying needs, generating designs, building, testing, communicating and evaluating finished ideas. The challenge for 5th graders is to develop graphic skills that assist them in expressing their ideas, hypothesis, creating predictions and documenting observations representative of phenomena they can see (i.e., a weight pulling a model vehicle to test the impact of load), as well as representations of invisible phenomena that impact the cars forward motion (i.e., friction, which requires an understanding of the relationship between surface areas hidden from the students’ naked eye. Lastly, iterative testing, a concept practiced in this kit, is used as a vehicle to impact student reflections and re-representations of their understanding.

IV. Analysis Approach

Semiotic theory, along with classroom observations, and student and teacher interviews is being used to analyze student reasoning with graphics. Semiotics is an approach that can be used to rigorously 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. It provides a framework to categorize graphic types, informing the analysis of how students are thinking with graphics during their investigation. Important characteristics include the scale of the representation (macro being what can be seen in a single, unaided view), the temporal dimension (real-time, faster, or slower), and the text-graphic relationship (Figure 2). Figure 3 is an example of a student-generated representation of a light bulb with its component parts. For example, we labeled the light
bulb as a pictorial, which will then be used as a reference point with the student and teacher during informal and formal interviews, respectively.

Figure 3. A student-generated image of a light bulb's structure.

The teacher semi-structured interviews helps inform the researcher on how graphics were used during student investigations, what explanations and reflections were the student able to achieve as a result of working with graphical representations, and how the student-generated graphic aids teacher formative assessment of student understanding. The aim is to de-emphasize the aesthetic qualities of the graphic representation in favor of its role as a cognitive aid in student reasoning. On the students’ side, the aim of informal interviews is to understand how they reason through or with the graphic within the context of their investigation. As well as how their graphics leverage and/or becomes the vehicle to further other modes of thinking. The use of student-generated graphics requires teacher assistance. Through ongoing professional development the teachers will develop a richer understanding of graphics in the context of multi-modal learning and student meaning making. We are working with teachers to re-imagine the potential and missed opportunities associated with the Motion and Design kit. Specifically, there are inherent connections made between important science content and process skills, and engineering problem solving activities. The overlaps between science and technological problem solving provide opportunities to share with teachers canonical images (master images) that can be used as cognitive tools to assist student thinking. Often, students are engaged in graphic representation, which may or may not include multiviews to document their vehicle prototypes. What was missing was a more meaningful discussion on how multiviews could be used as an investigative tool to learn science. As well, phenomena concerning the impact of gravity or kinetic and potential energy required master imagery to a) deepen teacher cognitions and b) assist student understanding. As stated earlier, students have mental models or mental images that require engagement with other conceptual models produced by their peers, teachers and within the larger body of scientific visualizations.

The discourse that results from comparing, re-representing and re-conceptualizing student ideas is an important contribution to student reasoning. Either via the graphic alone, in conjunction with associated writing, or through personal or whole-class discussion of their graphic, much about what a student knows can be revealed (Lehrer & Schauble, 2002). Assessment of these individual or collective graphics, in turn, can be used as a prescriptive tool for strategically planning next moves on activities surrounding this or related technical topics. Our analyses revealed that the pedagogical power of student-generated graphics is not being harnessed at all stages of the inquiry/problem-
solving cycle. We suspect that such results will inform elementary science teacher professional development efforts which may ultimately impact our ability to produce students who are more proficient in science and engineering (Duschl, Schweingruber, & Shouse, 2007).

We suggest teachers can help student develop conceptual bridges between science investigation and technological problem solving with more effective use of graphics. Due to the nature of science and engineering design, graphic literacy can also enhance teacher cognitions in technical areas where historically they have minimal experience. These new skills can be imparted to students, who require greater freedom to utilize their expressive tendencies to test their ideas using multi-modal learning. The hope is to encourage student-generated graphics as a cognitive tool for investigation, explanation and reflection, suggested hallmarks of the 21st century learner.

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VI. References


