When, What, and How?
A Critical Look at Technology Use in Middle Grades Earth Science

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Introduction

As students are exposed to greater quantities and more complex forms of technology both inside and outside the classroom, the need for educators to determine the most appropriate uses of those technologies becomes evermore critical. Basic understandings of what defines effective teacher practice in specific contexts and of the variability of cognitive development among students discourages a blanket approach to the use of technology for constructing scientific literacy. Furthermore, we acknowledge the potential for technology to either improve or hinder understandings of scientific concepts. As a consequence, this paper examines critical considerations for the use of technology by middle grade students.

The Role of Technology in Science Education Reform

Few would disagree that, “technology has become an important instrument in education” (Bransford, Brown, & Cocking, 1999, p. 217). Agents of reform such as the National Research Council and individual state agencies such as the North Carolina Department of Public Instruction incorporate technology into their documents, defining it in broad terms, including discrete items, techniques, and processes (North Carolina Department of Public Instruction, 1999, Bransford, Brown, & Cocking, 1999, & National Research Council, 1996).

The role that technology does and should play in science education creates much dissention among educators, particularly concerning computer technologies. Opinions range from “computer-based technologies hold great promise both for increasing access to knowledge and as a means of promoting learning” (Bransford, Brown, & Cocking, 1999, p. 217) to a much less favorable view, one where technologies “often undermine what we know about effective teaching and learning” (Olson and Clough, 2001, p.8). Most educators, including those sited above, will readily acknowledge that regardless of whether they believe technologies primarily serve to improve or hinder meaningful learning, appropriately applied technologies can and do work in the classroom.

The use of the word “applied” is both deliberate and significant because the implication is that the teacher is responsible for correctly and effectively using the technology in a given context. This is a crucial point, in that the current role of technology is one of support, rather than functioning as the primary instructor relieving the teacher of all responsibility. Teachers make or break the program (Penick & Bonnstetter, 1993, and Penick, Yager, & Bonnstetter, 1986), not the tools and processes at their disposal. Without "effective questioning, wait time, supportive non-verbals, active listening, responding to students in ways that further their thinking, and structuring activities to keep students mentally engaged" (Olson and Clough, 2001, p.5), children end up playing with or fighting a technology that, along with their teacher, failed them in constructing meaningful learning of the content. A focus on the learning needs of students promotes the inclusion of these and other essential teacher behaviors. Greater attention is given to the teacher's role in making effective use of technologies later in the article.

A wealth of literature documents and speculates on both beneficial and detrimental aspects of technology use in the classroom. Table 1 contains a representative list of some of these aspects. The list is not meant as a comparative piece demonstrating that the advantages outweigh the disadvantages, but rather to provide the reader with an overview of the possibilities inherent through the inclusion of technology in classroom instruction.

Table 1

Advantages	Disadvantages
• *Enhance student achievement* (Bransford, Brown, & Cocking, 1999 and National Research Council, 1997)	• *Extremely poor job of…playing off students/ prior ideas, engendering deep reflection and promoting understanding of complex content* (Olson and Clough, 2001)
• *Aid in visualization of concepts* (Linn, Songer, & Eylon, 1996 and Wu, Krajcik, & Soloway, 2001)	• *Initial time investment* (National Research Council, 1997)
• *Use of real-world problems to facilitate learning* (Bransford, Brown, & Cocking, 1999)	• *Do not promote and hinder deep conceptual understanding* (Olson and Clough, 2001)
• *Provides scaffolded experiences* (Bransford, Brown, & Cocking, 1999 and Roth, 2001)	• *Inappropriate uses can hinder learning* (Bransford, Brown, & Cocking, 1999)
• *Promotes feedback, metacognition, and revisionary practices* (Bransford, Brown, & Cocking, 1999 and Edelson, 2001)	• *Promotes misconceptions* (Olson and Clough, 2001)
• *Increases communication* (Bransford, Brown, & Cocking, 1999)	• *Diminishes the need to… utilize metacognitive strategies* (Olson and Clough, 2001)
• *Increased motivation* (National Research Council, 1997 and Edelson, 2001)	
• *Increased enjoyment* (National Research Council, 1997)	

Table 1 illustrates the enormous potential technology holds for improving or degrading the learning environment; however, without an adequate understanding of and appropriate response to how students learn, any instructional tool becomes impotent.

Concrete to Abstract: What Are They Thinking?

One of the most important considerations a teacher makes when selecting an instructional strategy or tool is first determining how the student learns. Piaget's stages of development serve as a foundation upon which many educators build their lessons, customizing construction as the context necessitates. According to Piaget's theory, most middle school students are deemed concrete operational, "reflecting the child's ability to use operational logic on concrete objects" (Baker & Piblurn, 1997, p. 232). The goal, of course, is to move students from concrete to the cognitively superior, formal operational stage – a stage generally characterized by "abstract thinking and coordination of a number of variables" (Woolfolk, 1995, p. 39). A problem exists however, as Baker and Pilburn (1997, p. 232) articulate below:

> *children cannot move easily from the relatively concrete curriculum of the elementary school to the quite abstract one of the secondary school. We think that the transition from concrete to formal operational thought occupies a much greater time span than envisioned by those who construct curriculum.*
>
> *The period between grades six and ten is critical, and educators could profitably devote most of that period of time to the development of abstract logical thought. The formal teaching of scientific disciplines should be delayed until late in the high school years or in college. There is no point in teaching formal science until students have developed formal reasoning skills.*

The difficulty students have navigating from concrete to formal operations suggests a complexity in the individual stages. Aiding in the development of "formal reasoning skills" (Baker & Pilburn, 1997, p. 232) requires a deep understanding of the different levels within the concrete operational stage. Five major levels (Table 2) have been identified: identity, compensation, reversibility, classification, and seriation.

Table 2
(Woolfolk, 1995)

Levels Within Concrete Operational Stage	Definition
Identity	"principle that a person or object remains the same over time" (p. 36)
compensation	"principle that changes in one dimension can be offset by changes in another" (p. 37)

reversibility	"the ability to think through a series of steps, then mentally reverse the steps and return to the starting point" (p. 37)
classification	"grouping objects into categories" (p. 37)
seriation	"arranging objects in sequential order according to one aspect, such as size, weight, or volume" (p. 39)

These levels are generally thought to occur in a linear fashion from identity to seriation, gradually elevating the individual towards the formal operational stage. As Woolfolk (1995, p. 38) illustrates, however, even with the successful development of all the levels of the concrete operational stage,

> *this system of thinking … is still tied to physical reality. The logic is based on concrete situations that can be organized, classified, or manipulated. Thus, children at this stage [concrete operational] can imagine several different arrangements for the furniture in their rooms before they act. They do not have to solve the problem strictly through trial and error by actually making the arrangements. But the concrete-operational child is not yet able to reason about hypothetical, abstract problems that involve the coordination of many factors at once.*

This becomes a very significant point when considering when, how, and what types of technologies should be introduced. Furthermore, with learner characteristics (e.g. age, stage of development, learning styles) and instructional content (e.g. more concrete vs more abstract concepts) considered, an appropriate instructional vehicle is needed to help transport the student through a transitional period between concrete and formal operational stages. A scaffolding strategy facilitates such a journey.

Matching Technology With Learning Needs

The role the teacher assumes defines the learning possibilities in the classroom. For this reason, teacher choice regarding instructional strategies, goals and objectives, and instructional tools becomes a paramount decision. Reform-minded teachers are more likely to employ instructional strategies like inquiry, problem-based learning, and cooperative learning which, in the absence of supportive structures (scaffolding), are likely to prove insufficient in moving a student from concrete to formal operations. A scaffolded approach, where in teachers facilitate the construction of better understanding by offering students support when and how they need it (Wood, Bruner, & Ross, 1976), is desirable according to research on how children learn (Bransford, Brown, & Cocking, 1999). Some suggest that technology serves as a very useful tool in this regard Bransford, Brown, & Cocking, 1999), strongly implying an ability to enhance student achievement, while others argue that it has a propensity to undermine learning (Olson & Clough, 2001, Postman, 1985 and Postman, 1995). The key to effective scaffolding is to correctly identify and appropriately address students' learning needs within the context of a particular lesson. And context is everything. The divide in attitudes towards technology mentioned above is at least partially rooted in contextual differences and each bares a valid point in a given situation.

Clearly defined lesson goals and objectives help build context by providing a reference for every other aspect of instructional planning. Consideration of technology should in no way influence the development of learning goals, except of course when technologies comprise the content (e.g. learning about a compass). Otherwise, teachers run the risk of their 'lessons' serving as entertainment rather than educational opportunities. This is not to suggest that students should not enjoy learning; they should. It is part of the teacher's responsibilities to motivate students by any ethically sound means, which presumably entails students enjoying the learning process to some degree and at some point. Without the student experiencing some enjoyment, the teacher has failed in producing a positive intrinsic motivation towards learning, which is essential to the development of a scientifically literate individual. The difference between goals and objectives that focus on technologies (e.g. compass) and those that focus on other content (e.g. interpreting maps) are profound and contain inherent differences.

The effective teaching of skills requires instructional strategies that stress repetition and didactic instruction, whereas effective teaching of concepts requires instructional strategies that stress metacognition and inquiry. For example, when teaching students the skill of reading a graduated cylinder, it is generally more effective to tell and/or show the student precisely how to do it and let them practice over and over again. The student's proficiency at reading a graduated cylinder is not diminished because he or she does not understand the 'why' behind the water's action. Most students will, however, want to know why (Bransford, Brown, & Cocking, 1999). So by addressing the 'why' question and teaching students about the concept of the capillary action of water, an inquiry process has already begun that requires the learner to examine his or her own notions about the characteristics of water. The teacher may tell the student over and over again why the water acts the way it does in the cylinder, but that certainly does not ensure that the student will understand the concept. Doing and understanding are separate entities that share a relationship with one another that mirrors the relationship between technology-focused goals and content-focused goals (Table 3).

Table 3

	Focus of Goals and Objectives	
	Technology	Content
Goals and Objectives Require the Teaching of	Skills	Concepts
	Skills/Concepts	Concepts/Skills

Technology-focused goals require teaching either skills or skills/concepts. Skills primarily involve 'knowing how to do' while skills/concepts involve 'knowing how to do' and 'understanding the various why's'. Content-focused goals require teaching either concepts or concepts/skills. Concepts primarily involve 'understanding the various why's' while concepts/skills involve 'understanding the various why's' and 'knowing how to do'. So if both technology and content focused goals require teaching that has the potential to result in the same learning outcomes, assuming appropriate contexts and execution for each, what difference does it make where goals are focused?

Technology-focused goals that are skill-centered, by definition, are not taught to build conceptual understanding. In contrast, the primary purpose of all content-focused goals is to construct conceptual understanding, but what about technology-focused goals that are skills/concepts-centered. These goals, by definition, address conceptual understanding, so again, what's the difference? The difference occurs in technology's role in the development of conceptual understanding. Technology's role in content-focused goals and objectives always remains a secondary consideration even when teaching skills, because those skills are viewed as an extension to conceptual understanding, allowing for application. The exact opposite is noted of technology-focused goals. Skills and the applied nature of technology itself are viewed as the portals through which conceptual understanding may be derived. Teaching for conceptual understanding through technology has important implications that warrant serious consideration.

One implication, for example, involves the notion that a particular technology is an essential component of a concept. Olson and Clough (2001, p. 4) articulate this point nicely.

> *For instance, researchers (Annenberg/CPB, 1997) found that even the brightest students in a high school physics classroom did not understand the basic concept of an electrical circuit despite two months of instruction on electricity. When asked how to make the bulb light, one student thought a bulb holder was a necessary part of a circuit. When trying to light the bulb, the student asks the interviewer, "Can I use the little piece we used in class?" When asked why she needed the bulb holder, she states, "It carries the charge or something…I don't think it will light without it."…Equipment is often used before students have seriously grappled with the concepts under study. As a result, they can perceive the technology to be a necessary part of the concept"*

The student's confusion about the role of technology in this case contributed to her incomplete understanding of the concept of electrical circuits. Other forms of misconceptions may be fostered through the use of technology to teach conceptual understanding. For example, in many instances, technology functions as a 'black box' when students never comprehend the processes implicit in the technology. As a result, when students are asked to apply their 'conceptual understanding' in the absence of the exact technology used in the lesson, their cognitive structures collapse revealing only a partial (at best) framework of understanding (Almy, 1966 and Olson & Clough, 2001).

The complete abandonment of technology is certainly not the answer, however. Students need tools in order to build upon the foundation of their understandings. Most reform efforts in science education such as learning cycles, problem-based learning, and other forms of inquiry demand that student have access to the tools they need to answer their questions. But, the tools must be ones they can comprehend and explain. Without this essential restriction, teachers will contribute to students gaining a false sense of the nature of science. What respectable scientist would think about publishing results of an experiment without an understanding of the technologies used to produce the data? Yet this occurs all too often within the classroom. In order to alleviate this problem, a "low-tech to high-tech" approach may be preferable.

For example, in a unit on topography, students may need to work cooperatively to gather data on beach dune elevations and construct a map based on that data. The fear is that the teacher may give the students GPS (Global Positioning Satellite) units, allow them to collect data, and then download the data into a GIS (Geographic Information System) program that produces a map and assume that students understand technically and conceptually how the data was collected, why it was collected, and what happened to it after they got back to class. This, of course, is a worse case scenario in which the students have little to no idea how their data was produced, what really happened with the data that was collected, and subsequently, what the resulting map spatially represents. In another scenario, the teacher acknowledges that some explanation of the origin and evolution of the data is necessary. The teacher takes the time to explain as well as he or she can (depending on time, knowledge of equipment, etc.) the technical and conceptual aspects of the technologies used during and after the students' data collection. This is, however, a problem which goes right back to the child's Piagetian stage of development (concrete operational) that says that his or her thinking is still heavily tethered to the physical world. Woolfolk (1995, p. 38) illustrates this point:

> *thus, children at this stage [concrete operational] can imagine several different arrangements for the furniture in their rooms before they act. They do not have to solve the problem strictly through trial and error by actually making the arrangements. But the concrete-operational child is not yet able to reason about hypothetical, abstract problems that involve the coordination of many factors at once.*

The simultaneous coordination of numerous factors is exactly what the use of indirect-observational technologies requires. To avoid such complications, the use of 'low-tech' technologies such as meter sticks, string, and line levels can be used to measure elevation changes across a transect that can then be used to construct a hand-drawn map by connecting data points. The important difference is that the students can directly observe and manipulate the physical process of data collection. Once the foundation of the cognitive structure has been laid through concrete experiences, 'higher-tech' tools can be introduced to further build on the conceptual goals, but always with a watchful eye that the technology does not generate a gap in their understanding. Even with the 'low-tech' example given in this paper, if the students do not understand, for instance, how the line level functions in producing the data they collect, the technology is impeding the move towards a more complete understanding of the concept.

Implications for Use

Technologies implemented in classroom learning are either good or bad depending on the context. It is the context (e.g. teacher goals, teacher behaviors and characteristics, student behaviors and characteristics, aspects of the learning environment) that determines when, what, and how technologies should or should not be used. We do not presume to further diminish any vestige of professionalism left teachers by demanding the embracement or abandonment of technology. Rather we want educators to understand that the inclusion of technology into their instruction is a test of their professional competence and excellence and not a fun afterthought. "Making choices about technology for the purposes of K-12 education…should be a serious and thoughtful process guided by the notions of teaching and learning" (Dawkins, 2002, p. 1). Therefore, the idea of blanket inclusion or exclusion of technology in middle grades earth science education is, at best, irresponsible considering our understanding of how these children typically learn.

Before making the choice to include technologies in lessons, educators must understand the benefits and drawbacks inherent to a given technology in a given context. Furthermore, closer monitoring of conceptual understanding is needed based upon the gap that exists between a more concrete, directly observable means of handling data and a more abstract, technology-rich approach, that may in fact hide misconceptions about both the specific content being studied and the nature of science. In the end, the "principles of effective teaching are not changed by the presence or absence of technology" (Olson and Clough, 2001, p. 5). As long as educators adhere to those principles and remain mindful of the advantages and disadvantages inherent to the use of technology, the overarching goals of developing a scientifically literate individual and improving student achievement will be realized more effectively.

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Abstract

As technology's place in the educational landscape continues to grow every year, increasing numbers of teachers and students are affected by its presence and use. Those in decision-making roles regarding the inclusion or exclusion of technology in instruction are responsible for knowing how their decisions affect all populations concerned. This paper provides a model for assisting in the determination of whether technology use is appropriate in a given context based upon the learning goals and objectives.

Biography

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