Defining Technology for Learning: Cognitive and Physical Tools of Inquiry

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Abstract

This essay explores definitions of technology and educational technology. The authors argue the following points: 1. Educational stakeholders, and the public at large, use the term technology as though it has a universally agreed upon definition. It does not, and how technology is defined matters. 2. For technology in schools to support student learning, it must to be defined in a way that describes technology as a tool for problem-solving. 3. Integration of technology, particularly when paired with teacher-centered practices, has the potential of reinforcing and heightening the negative consequences of a conception of learning that positions students as recipients of knowledge instead constructors of knowledge. This article concludes with a call for leaders in the field of educational technology to provide guidance by adopting a definition that encapsulates the third point above.

Introduction

Referencing a ubiquitous morass of communications technology, science fiction writer Ray Bradbury's (1953) protagonist in *The Murderer* declared himself…

> …the vanguard of the small public which is tired of noise and being taken advantage of and pushed around and yelled at, every moment music, every moment in touch with some voice somewhere, do this, do that, quick, quick, now here, now there. You'll see. The revolt begins. My name will go down in history! … It'll take time, of course. It was all so enchanting at first. The very idea of these things, the practical uses, was wonderful. They were almost toys, to be played with, but the people got too involved, went too far, and got wrapped up in a pattern of social behavior and couldn't get out, couldn't admit they were in, even. (p. 4)

Though the technologies referenced by the speaker, Albert Brock, are fanciful versions of the analog devices of the 1950s, wrist radios that functioned like today's cell phones and broadcasting transmitters that were predecessors to current GPS trackers, the sentiment he expresses is all too modern. He could almost be testifying in a *Forbes* article on the impact of social media like Facebook and Twitter on mental health (e.g., Walton, 2017), rather than crying out to a fictional psychiatrist in a short story published more than half a century ago.

Concurrent threads of allure and anxiety have always defined humans' relationships with technology. The realm of education is no exception. As districts across the United States race to adopt new technological enterprises—both hardware and software, experiment with flipped classrooms, and implement one-to-one device initiatives, we add our voices to those urging caution and deliberation when bringing technology into the middle grades to ensure that such integration does not supersede promotion of student voice, developmentally appropriate instruction, and integrative curriculum. We argue the following points:

1. Educational stakeholders, and the public at large, use the term *technology* as though it has a universally agreed upon definition. It does not, and how we define technology matters.
2. For technology in schools to support student learning, it must to be defined in a way that describes technology as a tool for problem-solving.
3. Integration of technology, particularly when paired with teacher-centered practices, has the potential of reinforcing and heightening the negative consequences of a conception of learning that positions students as recipients of knowledge instead

constructors of knowledge.

We conclude the article with a call for leaders in the field of educational technology to provide guidance by adopting a definition that encapsulates the third point above.

Defining Technology

To define technology, we first looked to the International Society for Technology in Education (ISTE) for guidance. We found several documents that referenced technology but only one provided a clear definition (Kolb, 2015; Schrum, 2010; Smith & Throne, 2007). Within the context of an essay about the best research articles from the *Journal of Research on Technology in Education*, Lynne Schrum, former president of ISTE and editor of the *Journal of Research of Technology in Education*, operationally defined technology as "computer-based technologies and includes personal computers, LCD projectors, and Palm Pilots" (Schrum, 2010, p. 60). Palm Pilots slipped into oblivion with the advent of the smartphone, and the last Palm device was actually produced by Hewlett Packer in 2011 (R.I.P. Palm, n.d.). Liquid crystal display (LCD) projectors are in still in use, but must compete with newer projection methods such as digital light processing (DLP), liquid crystal on silicone (LCOS), and laser raster projectors (Hoffman, 2017). Defining technology based upon particular physical objects guarantees that the definition will become obsolete as technologies advance. For example, in 1912, discourse around educational technology was concerned with "instruction by means of motion picture machines, stereopticon lanterns, talking machines, and player pianos, etc.," and in the ways photography could aid education (Ives, 1912, p. 24). Clearly, listing individual technologies will not be a useful way to establish a definition.

Because ISTE, the learned society for technology education, has failed to provide an authoritative definition of technology, we moved on to consider the views of technology put forth by the professional associations for teaching the core curricular areas of English language arts, mathematics, science, and social studies. The definition offered by the National Council of Teachers of Mathematics (NCTM, 2015) is somewhat broader than that implied by the ISTE documents, indicating that technology is made up of "digital and physical tools" (p. 1). Similarly, the National Council of Teachers of English (NCTE, 2013) argues that students should "use technology as a tool for communication, research, and the creation of new works" (para. 3). Though the National Science Teachers Association (NSTA, 2011) does not explicitly define technology, it does argue that science instruction can include "a wide range of technologies [to] serve as tools to engage students with real-world problem solving, conceptual development, and critical thinking" (para. 5). While referencing specific types of digital tools such as online data, mobile devices, and social networking platforms, the National Council for the Social Studies (NCSS, 2013) implies a more nuanced construction of technology by indicating that technology instruction should help "students make sense of all the information, new environments, and ways of being" (para. 1) that characterize technological proliferation.

Defining Technology for Middle School

Though the above implied and explicit definitions of technology from the four professional associations are certainly more useful than the list of individual technologies provided by ISTE, we argue middle school philosophy is best served by a definition of technology as both cognitive and physical tools for solving problems. We believe that technology can only become integral to the middle school curriculum if it centers upon the study and development of tools and processes to solve practical problems. This definition of technology would inherently involve relevant, challenging, integrative, and exploratory curriculum, lend itself to developmentally responsive instruction, and could certainly promote positive relationships for learning and student voice (Jackson & Davis, 2000; National Middle School Association, 2010).

In developing such a construction of technology, we drew upon the fourth definition for technology listed in the Oxford English Dictionary (OED), which includes three components:

> 4. a. The branch of knowledge dealing with the mechanical arts and applied sciences; the study of this…. b. The application of such knowledge for practical purposes, esp. in industry, manufacturing, etc.; the sphere of activity concerned with this; the mechanical arts and applied sciences collectively…. c. The

> product of such application; technological knowledge or know-how; a technological process, method, or technique. Also: machinery, equipment, etc., developed from the practical application of scientific and technical knowledge; an example of this. (Technology, 2018)

Distilling these definitions down, we define technology as a tool, both physical and cognitive, to help solve problems.

We argue that technology in education includes cognitive tools and intellectual procedures such as calculus or the scientific method, as well as physical objects such as books, televisions, computers, and communications networks such as the Internet. Calculus serves as a particularly apt example of what we mean when we call for a recognition of cognitive tools as technologies. Scientists of the 17th century were attempting to solve complex problems of motion and acceleration. Existing mathematical tools were insufficient to solve these particular problems, so a new tool "had to be created [...] the *Calculus,* a general symbolic and systematic method of analytic operations, to be performed by strictly formal rules, independent of geometric meaning" (Rosenthal, 1951, p. 84). This tool, *the Calculus*, as it was referred to by 17th-century practitioners, was not a physical object, but was nevertheless a technology developed to solve particular problems.

However, within the popular discourse, the term technology clearly focuses on digital computing tools, whether in the form of portable devices like smartphones and tablets or hardwired PCs and video gaming systems. Ideological battles about young people's use of technology frequently center on the possible effects of screen time (e.g. Frankel, 2017; Gomez, 2017), and tend to define technology as computers, software, computer peripherals and projectors, and the Internet, which are the most commonly encountered digital technologies in schools (Jones, 2017).

If we define technology as computers, software, computer peripherals and projectors, and the Internet, then the primary strengths of technology are data access, data organization, and data presentation. That these are a computer's strengths are self-evident in the fundamental components that make up a computer—input, output, micro-processor, memory, permanent storage. However, critical thinking, creativity, and purpose must be supplied by the user of the computer. As such, we would argue that technology as popularly defined has the potential to undermine middle school students' learning, while technology as we have defined it above has the potential to promote middle school students' learning.

Educational Technology: History Repeating Itself

Failure to define technology in education is not a new problem, but a persistent one (Saettler, 1969). While many consider technology to be a modern addition to the educational enterprise, it has in fact been part of schooling for centuries. The notion that technology has only recently become part of education may be due to a narrow conceptualization of the word technology in the popular consciousness, a conceptualization that tends to focus on digital computing and telecommunications, and emphasizes physical devices rather than cognitive tools. The earliest recorded usage of the term technology in English, however, dates back to 1612 in the writings of Isaac Casaubon, who used it to refer to academic discussion or debate focused upon the arts. It is not until well into the 18th century that the term technology starts to refer to applied scientific knowledge in the form of tangible objects (Technology, 2018).

Throughout the past few centuries, educational philosophers and reformers, who were possibly ahead of prevailing educational practices of the time, included cognitive tools in discussions of education. A few centuries ago, John Locke (1632-1704), Johann Pestalozzi (1746-1827), Frederick (1782-1852), and Johann Herbart (1776-1841) were writing about education in cognitive and pedagogical terms, and recognized the instructional needs of individual students as being varied. Later, Edward Thorndike (1874-1949) was a proponent of teaching empirical-inductive reasoning, and John Dewey (1859-1952) contributed to educational technology through his conception of instruction in terms of the scientific method.

If we define *education* as the process of learning, and *technology* as tools for problem solving, *education technology*, by extension, is composed of tools that facilitate the process of learning. To test definitions of educational technology, then, we must determine if technology, as defined in particular ways, does indeed facilitate the process of learning; that is, does technology as

we define it, and/or as it has popularly been defined lead to gains in student achievement?

Technology and Student Achievement

While there is little doubt about the value of technology to organize, analyze, locate, and present information, whether technology usage has a positive effect on students learning remains unclear (Odom, Marszalek, Stoddard, & Wrobel, 2011). If technology is narrowly defined as digital computing devices, then empirical scholarship indicates that, at best integration of technology has no impact on student achievement, and, at worst, it has a negative correlation with student academic achievement.

Studies Showing Neutral Effect on Achievement

The studies summarized in this section found no demonstrable impact of technology integration on student academic achievement. For example, Slykhuis and Park (2006) investigated the connection between high school students' achievement and involvement with the online Microcomputer Based Laboratory (MBL) physics curriculum. They found correlations between precursor content knowledge and math ability with physics achievement, but found that online exposure to MBL produced no significant increase in physics achievement.

Similarly, Pihlap (2017) studied ninth-grade students' use of computers while learning quadratic functions. Study subjects included 10 classrooms of students, five in which computers were used alongside traditional methods and five with no computer usage. Pihlap (2017) found that students who used computers had higher motivation for learning but that no significant differences in learning outcomes existed between the two groups.

This might indicate that integration of technological devices could increase student enjoyment of learning. However, Lu, Li, Stevens, and Ye's (2016) research results contradict this claim using the 2012 PISA database to analyze 15-year-old students' evaluations of computer use for academic learning. The majority of participants disagreed with the idea that computers made learning more fun.

Shapley, Sheehan, Maloney, and Caranikas-Walker (2011) studied the effect of a one-to-one laptop initiative by comparing 21 middle schools that adopted the initiative with 21 control schools that did not. The authors found that the initiative had a positive correlation with students' technology proficiency and the frequency of classroom technology-based activities. That is, technology use led to increased technology use and increased skill at using technology. They found no statistically significant effect on student academic achievement.

Studies Showing Negative Effect on Student Achievement

Taken as a whole, the studies summarized in the previous section suggest that technology integration does not correlate with changes in student achievement. However, a worst case scenario exists in which technology use actually decreases student achievement. For example, Cifuentes and Hsieh (2004) found that when computers were used simply as a medium for traditional academic practices such as taking notes or completing worksheets, student academic achievement decreased in comparison to completing such tasks without computers. Likewise, Papanastasiou, Zembylas, and Vrasidas (2003) found in an examination of data from the Trends in International Mathematics and Science Study (TIMSS) that student computer usage in a variety of countries, including the US, was negatively associated with math and science achievement. They also found that frequent student use of spreadsheets and educational software was associated with lower science literacy scores. According to Zhao, Lei, Yan, Lai, and Tan (2005), frequency of student computer usage was negatively associated with grade point average. In addition, the authors argued that extended computer usage was harmful to student achievement, and found that much of the time spent on computers was not linked to activities that would improve achievement.

We advance that these negative effects are likely a result of technology use with emphasis on locating correct answers, given that one of the primary strengths of technology, as discussed previously, is data access. This is a sort of pedagogical version of the phenomenon that has come to be called Maslow's Hammer (Maslow, 1966), in which, to an individual with a hammer, every problem begins to look like a nail. Computers are exceptionally useful for locating information. Therefore, having students locate

information with computers is a tantalizingly easy pedagogical choice. If someone has access to Internet-connected computers, then the solution to every problem may begin to look like a Google search. However, if the learning activity ends with the location of a declarative answer, then likely little or no meaningful learning has occurred. According to Mayer (2002), for meaningful learning to occur, students must "build the knowledge and cognitive processes necessary for problem solving" (Mayer, 2002, p. 227). They cannot simply look up, or look up and memorize, facts.

Studies Showing Possible Positive Effects

Though our review of literature did find some studies indicating positive impacts of technology on middle school students' learning, analysis of these studies indicate that the impact of computer use on middle school student achievement is dependent on how the computer is used, and not whether a computer is used (Pihlap, 2017). For example, in mathematics classes where connective technologies (networked calculators) were used for uptake of students' work as objects of whole class discussion, students' analyses and expressions of mathematical thinking positioned the students as active participants in the construction of knowledge that featured exploration of the mathematical reasoning behind a variety of solution paths (Bell, 2013; Bell & Pape, 2012). As Gee (2003) noted, "Technologies have effects—and different ones—only as they are situated within specific contexts. So we always have to ask how the technology was used and in what context it was being used" (p. 12).

Dynamic computer instruction where students are actively engaged in learning can have a significant positive effect on student achievement according to Turk and Akyuz (2016). They found that computer instruction had a significant effect on students' achievement in geometry compared to traditional instruction. Similarly, integrative white boards reported to be better than lecture at teaching mathematics (Chen, 2013). Additionally, Kposowa and Valdez (2013) found that there was a significant association between generic laptop use and achievement on standardized tests. The more laptops were used, the greater the achievement. What remains unclear is whether actively engaged students without a technology would perform as well as actively engaged students with a technology.

Ercan, Bilen, and Ural (2016) compared web based teaching materials designed for a computer environment to textbook instruction among grade five students. They reported that the computer group out-performed the textbook group on achievement and attitudes measures. Because the control comparison in this study was the use of a textbook, it remains unclear as to whether or not other non-web based teaching materials would have produced similar results in comparison to web based teaching materials. Kocakaya and Gonen (2014) examined computer-assisted Roundhouse Diagrams compared to the Context-Based Learning Approach (non-computer assisted) on the topics of force and motion among grade nine students. The results indicated students who received instruction with computer-assisted Roundhouse Diagrams out-performed Context-Based Learning Approach students. Non-computer assisted Roundhouse diagrams were not used as a control, so we do not know whether the computer was the variable that led to increased performance, or if Roundhouse diagrams are simply a superior pedagogical tool compared to Context-Based Learning Approaches.

Controlling the range of possibilities on experiments with human subjects can be much more limited than investigation in natural sciences. Without controls it can be very difficult to determine the effect of experimental treatment. Each of the research reports above indicated that computer instruction was found to have a positive association with middle school student achievement. But without well controlled comparative experimental designs, it remains difficult to draw conclusions about the value of computers in middle school classrooms.

In their analysis of computers in science classes, Odom and Bell (2012) determined that computer usage could lead to positive effects when used for very specific purposes—"modeling abstract concepts, for demonstrating lab procedures, and for a combination of data collection and lab setup" (p. 78). They concluded their article by offering six recommendations for the use of computers which would allow them to enhance, rather than hinder, the learning process:

1. Use computers as tools for learning, not as the source of learning.
2. Engage small groups of students in both lab activities and computer activities.

3. Let carefully written research questions guide information and data collection during lab activities and when using computers.
4. Use computers to organize and present data and findings and avoid use solely for PowerPoint presentations.
5. Avoid activities that emphasize traditional classroom practices, such as copying notes or looking up answers to lower-level questions.
6. Deemphasize drill and practice and word processing. (Odom & Bell, 2012, p. 78)

Pedagogical Implications of a Broader Definition of Technology

We argue that technology can add significantly to the quality of students' learning experiences if technology is defined broadly as cognitive and physical tools for solving problems. Conversely, adhering to a narrow definition of technology as just digital computing devices is likely to result in negative learning experiences. Adopting a broader definition leads directly to adopting a pedagogical approach compatible with this definition—inquiry learning.

Inquiry learning, as so much else in education, has its roots in the writings of Dewey (1910), who worried that education, particularly science education, focused too heavily on rote memorization of facts, which were, in and of themselves, meaningless. He advocated a student-centered pedagogy in which learners actively engaged in the development of knowledge via application of the scientific method (a technology by our definition), and teachers worked to facilitate that process. By engaging in inquiry learning, students develop procedural knowledge (knowing how), in the process of which they also construct declarative knowledge (knowing that). Epistemologically, inquiry learning locates the source of knowledge within the experience of the learner, rather than within an outside source of expertise, such as a teacher or a search-engine.

The benefits of inquiry learning have been well documented and include increased critical thinking and problem-solving skills as well as deeper conceptual understanding across academic disciplines. For example, Lawson, Abraham, and Renner (1989) found that student development of procedural knowledge through inquiry learning also led to improvement in formal reasoning abilities, including questioning, analyzing data, and drawing conclusions. This is in contrast to the rote learning that so often accompanies teacher-centered recitation or lecture classes, in which students are tested upon their ability to recall information presented to them by their teachers. Ausubel (1968) found that information learned in rote fashion is rarely meaningful, as students tend to be unable to locate this new information within their existing frames of disciplinary knowledge.

Unfortunately, teacher-centered instructional approaches remain commonplace at all levels of education, and when technology is used simply as an extension of traditional pedagogical practices, student learning actually suffers. Odom et al. (2011) found negative associations between both teacher-centered instruction and computer usage and student science achievement. The authors argued that "individual work and acquisition of declarative knowledge with a computer provides little opportunity to make use of procedural knowledge to develop conceptual understanding" (p. 18). We argue that defining technology simply as material devices, and disregarding the cognitive tools that make such devices meaningful, inexorably leads to usage of computers in ways that do not encourage the development of conceptual understanding.

A Call for Action

Given the points made above regarding the serious implications of broad versus narrow definitions of technology, we argue that leaders in the field of education need to step forward and provide direction by clearly establishing a broader definition of technology that includes both cognitive and physical tools for solving problems. We believe that this broader view is particularly important for middle level education where educators are being asked to make the curriculum relevant and applicable to students' lives. Such a curriculum encourages students to identify real problems and then take steps to solve them, thus encouraging critical thinking, decision making, and creativity (NMSA, 2010). With several states (including influential Texas) having already adopted the newly revised ISTE technology standards as requirements for their P-12 curricula, and numerous other states considering adoption (Team ISTE, 2017), we look to ISTE in particular as the body to provide such leadership in the field of educational

technology.

The ever-accelerating push for schools to adopt new technologies and incorporate technological competencies into their curricula is unlikely to slow in the foreseeable future. The Council for the Accreditation of Educator Preparation, the primary accrediting body for educator preparation programs (EPPs), now requires those EPPs to integrate technology as a cross-cutting theme throughout their programs. With lawmakers increasing policy mandates relating to technology, and large educational donors pushing techno-centric agendas in P-12 schools (e.g., Bill & Melinda Gates Foundation, 2018), professional educators are left with a choice—either we increase our influence over the educational technology narrative, and claim our right to define technology in a manner that will best serve our students and our society, or we cede control to those who would define technology in narrower material ways.

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