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Professional development to enhance teachers' practices in using information and communication technologies (ICTs) as cognitive tools: Lessons learned from a design-based research study

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A B S T R A C T

Technology integration in K-12 classrooms is usually overly teacher-centered and has insufficient impact on students' learning, especially in enhancing students' higher-order cognitive skills. The purpose of this project is to facilitate science teachers' use of information and communication technologies (ICTs) as cognitive tools to shift their practices from traditional teacher-centered methods to constructivist, student-centered ones. This paper describes the outcomes and lessons learned from an application of design-based research (DBR) in the implementation and refinement of a teacher professional development (PD) program that is a key component of the overall project. This DBR study involved 25 middle-school science teachers from 24 schools whose implementation of cognitive tools with their students in science classrooms and virtually through a social networking site were observed over four years. A mixed-methodology was utilized to examine the impact of the cognitive tools intervention on teachers' classroom practices and students' development of new literacy skills. Identifying reusable design principles related to technology integration was another focus of the DBR study. The results revealed teachers' positive changes in their classroom practices by gradually allowing students to take control over the use of technology, and positive impact on students' ICT skills and science learning. Design principles for future professional development programs aimed at preparing teachers to adopt a cognitive tools approach are described.

1. Introduction

Teachers' classroom technology integration is usually passive, teacher-centered, and treats technology as a "learn from" tool similar to the way students learn from classroom teachers. This approach has yielded low or no significant impact on students' learning outcomes (Kim & Reeves, 2007). Researchers have been advocating a more constructivist, student-centered technology approach, encouraging students to use technology as a "learn with" tool (Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000). This approach has also been referred to as the "mindtool" or "cognitive tool" model (Jonassen, 2000).

Classroom technology resources have increased and improved in the past decade, giving teachers increased flexibility to allow students to use technology as tools to extend their cognitive skills. However, there is a lack of empirical evidence of the impact of cognitive tools on teachers' classroom practices and students' learning. In this study, we developed an innovative professional development (PD) program for 25 middle-school science teachers, aiming to enhance their knowledge and skills in using technology as cognitive tools to support students' learning. A design-based research approach (DBR) employing mixed methods was utilized over the four years of this study. The purpose of this study is threefold (1) to describe how the PD program changed teachers' practices of using technology as cognitive tools in science

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classrooms, (2) to explore barriers that impede teachers' changes in their technology integration paradigm, and (3) to delineate design principles that guide teachers to use technology as cognitive tools wherein students "learn with" rather than "from" technology.

2. Literature review

2.1. The need to adopt technology as cognitive tools

Traditionally, teachers have taken the "learn from" technology approach and used computers primarily as a different type of media for delivering content to students, in a passive manner similar to how students might learn from textbooks or TV programs. Although technology is widely accessible for teachers and students in schools today (Greenhow, Robelia & Hughes, 2009; Purcell, Heaps, Buchanan, & Friedrich, 2013), research indicates that the majority of teachers still adopt technology passively as a learn-from medium. This approach yields insufficient results in student achievement (Cuban, 2001; Kim & Reeves, 2007; Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). Such disappointing results force educators to reexamine the applications of computers in science classrooms. If learning passively "from" computers (e.g., reviewing information on a web site, or viewing a YouTube video clip about a scientific concept), has failed to enhance student learning, such practices must be changed.

The calls for reformed instructional practices in science teaching to address students' inquiry experience also shed light on implications for technology integration in science teaching (Park, Jang, Chen, & Jung, 2010). Technology integration driven by the cognitive tools approach emphasizes creating a student-centered learning environment that allows students to solve relevant, realistic problems and develop higher-order cognitive skills (Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000).

Cognitive tools refer to "technologies that enhance the cognitive powers of human beings during thinking, problem solving, and learning (Jonassen & Reeves, 1996, p. 693)." The human cognitive system has weaknesses and limited capacity, but can be enhanced through the use of cognitive tools (Jensen, 2011). Using a "cognitive tools" approach is distinctly different from the traditional approach of using technology, in which information is designed by subject experts or instructional designers and then transferred to the students. By using cognitive tools in a constructive framework, learners engage in a variety of critical, creative, and complex thinking opportunities (Campbell, Wang, Hsu, Duffy, & Wolf, 2010; Hsu, Wang, & Runco, 2013; Wang, Hsu, & Campbell, 2009). The reformed technology integration approach extends students' cognitive skills by encouraging them to access multi-modal resources, organize and analyze data, interpret and evaluate information, and communicate the knowledge they have constructed to others (Lajoie & Azevedo, 2000). For example, Inspiration, a popular concept-mapping software, can be used as a cognitive tool to extends student's cognitive capacities in the learning process as they articulate, share, and refine their understandings in science (Martínez, Pérez, Suero & Pardo, 2013). Another example is when students research information about the moons of planets in the Solar System, and then use spreadsheets to visualize and document their research results (Finson & Pederson, 2011). The spreadsheets extend students' ability to visualize complex relationships, think critically, and solve problems, for example, organize and compare multi-modal information to retrieve the answers, or figure out questions such as "how factor X correlates to factor Y?"

It is difficult to develop a universal integration framework because the adoption of cognitive tools is situational (Kim & Reeves, 2007). Assessing students' learning outcomes is also a challenge since the use of cognitive tools involves not only grasping content knowledge, but also critical thinking and problem solving skills. Multifaceted and alternative assessment tools must be in place, requiring more teachers' time (Robertson, Elliot & Washington, 2007). In light of these complexities, advocates of the cognitive tools approach are still searching for strong empirical evidence of the impact of these tools on learning (Herrington & Parker, 2013; Kim & Reeves, 2007).

As the availability of technology in schools has become almost ubiquitous in many countries, Ross, Morrison, and Lowther (2010), among others, have urged educational researchers to focus their studies less on comparing the impact on learning with and without technology, because technology should be deemed as a vehicle for instantiating pedagogical methods. The adoption of a new tool will not have any impact on teaching and learning unless the tool is used to implement pedagogical strategies that help students deploy meaningful cognitive strategies. Previous studies also suggested that the impact of students using technologies is greater when they are used as cognitive tools, compared with technologies being used as simply alternate presentation sources (Schmid et al., 2009; Tamim et al., 2011; White & Frederiksen, 2005). Technology applications that support learners to perform cognitive tasks just out of their reach without them can be categorized as cognitive tools. They have the following characteristics: (1) support students' decision making, (2) support students' metacognitive processes, (3) enable students to organize, evaluate and analyze information, (4) facilitate students' problem solving, and (5) allow them to collaborate and communicate ideas in multi-modal formats (Azevedo, 2005a; Hsu, Wang, & Runco, 2013; Jonassen & Reeves, 1996; Lajoie & Azevedo, 2000).

2.2. Cognitive tools support scientific practices: new literacy framework

We focus on science learning because it promotes learners' multiple cognitive skills, such as inquire, analyze, infer, or evaluate scientific concepts and theories and fosters constructing new knowledge (Kuhn, Black, Keselman, & Kaplan, 2000). Science is a conceptually rich domain that requires students to deploy various metacognitive strategies (Azevedo, 2005b), and technology as a cognitive tool can facilitate students' metacognitive processes in problem solving. In 2013, the National Research Council released the Next Generation Science Standards (2013), encouraging teachers to provide students with the opportunities to practice inquiry using cross-curriculum knowledge such as engineering, math, and technology. The avocation of these core ideas is based on the need to promote inquiry in the classroom and to prepare students' new literacy skills (also known as 21st century skills, digital literacy, or ICT literacy). Technology integration is an important element in the science classroom because it supports the development of students' cognitive skills and nurtures their new literacy skills.

To help teachers envision the value of using technology to support cognitive processes, a framework to align the features of cognitive tools and scientific literacy skills is needed. In this project, we provided professional development opportunities to teachers focused on adopting information and communication technologies (ICTs) as cognitive tools. ICTs refer to hardware and applications that help people to access, retrieve, process, and exchange information. ICTs also enable social networking functions, and thus can be adopted by educators to prepare students' new literacies skills such as collaboration and communication. Most young generation learners are highly motivated when