September 9, 2009

APPLYING TECHNOLOGY TO INQUIRY-BASED LEARNING IN EARLY CHILDHOOD EDUCATION

Feng Wang, Ph.D.

Mount Saint Mary College
330 Powell Avenue
Newburgh, NY 12550
USA

Email: wang.msmc@gmail.com
Tel: 845-569-3543
Fax: 845-569-3464

Mable B. Kinzie, Ph.D.
Patrick McGuire
Edward Pan

The University of Virginia
P.O. Box 400878
Charlottesville, VA 22904-4878
USA

Applying Technology to Inquiry-Based Learning in Early Childhood Education

A major goal of early childhood education is to enhance children's cognitive skills and socialization, prerequisites for future success in schools and as adults (Essa, 2002). To achieve this goal, experts recommend that early childhood programs balance child-driven, embedded, highly-contextualized, and meaningful interactions, and teacher-guided, concentrated, scaffolded, and explicitly-targeted exposures to key concepts (Ginsburg & Golbeck, 2004; Justice & Kaderavek, 2004). In this paper, we recommend inquiry-based learning as a methodology with which this balance can be attained, while engaging students in active and meaningful learning activities.

Inquiry has long been recommended as a basis for student learning, especially in science and mathematics (e.g., American Association for the Advancement of Science [AAAS], 1993; Anderson, 2002; Blumenfeld et al., 1991; Edelson, Gordin, & Pea, 1999; National Research Council [NRC], 1996; National Council of Teachers of Mathematics [NCTM], 2000) but also in the development of language and literacy (Short & Harste, 1996). Children spontaneously inquire, asking questions and exploring, to understand the world; it is an important key to their lifelong development that should be cultivated and nurtured (Lind, 1998; Youngquist & Pataray-Ching, 2004). Adapted to the classroom, inquiry involves a problem-solving process (Lind, 2005; Short & Harste, 1996) during which students answer research questions (Bell, Smetana, & Binns, 2005), construct their own knowledge, and develop their understandings with support of the teacher and peers (Savery & Duffy, 1996). Inquiry helps learners to develop their personal and social understandings of the world by utilizing multiple perspectives and various forms of knowledge, such as mathematics, science, language, and arts (Short & Harste, 1996).

We use the term *technology* interchangeably with *computer technologies* to specifically denote use of computers rather than a broad body of technologies such as TVs, interactive toys, and audio books. Computers are accessible in the vast majority of U.S. classrooms (USDOE, 2003; Rideout, Vandewater, & Wartella, 2003) and have proven effective for various aspects of children's learning, including conceptual and cognitive development, literacy skills, mathematics knowledge and competence, and comprehension monitoring (Clements & Sarama, 2007; Elliott & Hall, 1997; Howard, Watson, Brinkley, & Ingels-Young, 1994; Li & Atkins, 2004; Pange, 2003; Parette, Hourcade, Dinelli, & Boeckmann, 2009). Frequently, technology enables inquiry learning that could not be otherwise accomplished by reducing some of the unnecessary, lower-level procedures involved in these tasks (Quintana et al., 2004; Reiser, 2004). Technology also facilitates learner supports during the inquiry learning process, thereby promoting higher-order thinking and metacognitive skills that are essential to meaningful learning.

Both the National Educational Technology Standards (International Society for Technology in Education [ISTE], 2000) and researchers interested in inquiry-based learning (e.g., Reiser, 2004; Quintana et al. 2004; Edelson et al., 1999) have advocated the application of technology in solving real-world problems and making informed decisions. According to Hoffman and Ritchie (1997), multimedia technology can be used to increase representational richness of problems, offer timely information, individualize problem situations, monitor learning progresses, and improve the efficiency of both creating problem scenarios and solving the problems. Likewise, Blumenfeld et al. (1991) proposed that technology may contribute to inquiry learning by enhancing interests and motivation, offering access to information, structuring the learning process with tactical and strategic support, enabling interactive representations that students may manipulate and explore, diagnosing and correcting errors, aiding production and managing complexity.

Over the past decade, a growing number of interactive games and educational software packages have been implemented in early childhood education and addressed a variety of subjects, including mathematics, science, reading, language, and social studies (e.g., Disney/Pixar, 2005; Riverdeep, 2001, 2006). However, existing products are often designed for drill-and-practice, entertainment, or superficial exploration activities, lacking coherent pedagogy and focused goals to scaffold children's development of concepts and skills (Sarama, 2004). Most software packages have yet to integrate technology into inquiry-based learning for early childhood contexts.

Based on existing theoretical frameworks (e.g., Blumenfeld et al., 1991; Hannafin, Land, & Oliver, 1999; Hoffman & Ritchie, 1997; Quintana et al., 2004; Reiser, 2004), we suggest that instructional technologies should be used in early childhood inquiry education to a) enrich and provide structure for problem contexts, b) facilitate resource utilization, and c) support cognitive and metacognitive processes (see Table 1). Examples of existing and hypothetical early childhood applications are provided as we elaborate on each role. Challenges and future research directions are also identified and discussed.

Insert Table 1 about here

Enriching and Structuring Problem Contexts

Problems that have been planned, created, or selected by teachers are usually more static than those addressed in real-world experience (Hoffman & Ritchie, 1997). To address this issue, technology has been used to present problem contexts pertinent to the inquiry subject matter and guide learners into encountering complex domains that are productive for learning (Reiser, 2004). According to Reiser, domain complexity may initially increase learning difficulties but will eventually positively impact learning. For example, two early childhood educational software packages, *Learning with Nemo* (Disney/Pixar, 2005) and *Reader Rabbit* (Riverdeep, 2001), embed a series of mathematics and language-arts activities (e.g., shape and pattern recognition, counting, letter recognition, vocabulary) in the context of story-based adventures guided by animated characters, which reportedly engage young students in solving newly encountered problems and challenges (Casey, Kersh, & Young, 2004). Similarly, technology can also be used to present problems in contexts relevant to learners' everyday lives (Jonassen & Reeves, 1996; Reiser, 2004). Examples include *Arthur's Math Games* (The Learning Company, 2001), which allows students to learn mathematics concepts (e.g., counting, sorting) by helping computer characters purchase popcorn, lemonade, or brownies from a snack shop, or *Math Missions* (Scholastic, 2003), which situates mathematical problems within the context of concrete and real-world problems such as measuring ingredients to make a drink.

Learning will be facilitated if complex tasks are structured (e.g., setting the scope of learning activities, breaking down complex activities into more manageable ones, specifying activity procedures) and expert guidance is offered regarding how to perform these tasks (Reiser, 2004; Quintana et al., 2004). *Sammy's Science House* (Riverdeep, 2006), for instance, uses visual organizers (e.g., diagrams, picture icons) to confine the learning activities to those in the three distinct (i.e., life, earth, and physical) science centers in the main menu. Guidance can be provided via visual representations and descriptions of complex concepts built on students' intuitive ideas (Quintana et al., 2004). The visual organizers in *Sammy's Science House*, along with thorough descriptions, help children connect abstract science concepts to their prior science experience and understanding. Similarly, *Reader Rabbit* (Riverdeep, 2001) provides a map with picture icons (e.g., flower, train, mountain) that represent different aspects of the overall learning task, and uses verbal reminders (e.g., "let's get moving") and visual clues (e.g., blinking and shiny stars) to assist children in starting and choosing the optimal path of their adventures.

Technology also supports children's development of "expert thinking" in an inquiry problem domain. Novices in a problem domain may not see clear paths for solving a problem, and tend to rely on formulaic solutions based on superficial details of the problem (Bransford, Brown, & Cocking, 2000). Technology can be designed to model expert thinking and processes (Quintana et al., 2004) just as a teacher would for students. *Math Missions*

(Scholastic, 2003), for instance, provides a virtual digital assistant from which children may ask for hints and suggestions when solving mathematics puzzles and problems. Modeling can also be provided by decomposing and sequencing learning tasks. Technology can help decompose complex tasks into smaller ones, making explicit what would otherwise be tacit problem-solving processes (Puntambekar & Hubscher, 2005; Reiser, 2004). For example, mathematics software may decompose the task of identifying a triangle into counting the number of sides and vertices of shapes and prompting children to count and determine whether a given shape is a triangle or not.

Spiro and Jehng (1990) argue that learners need to develop skills to master important “aspects of conceptual complexity” (p. 165) and transfer the knowledge they have learned to new situations. To achieve these goals, technology is used to support multiple, clear, increasingly complex presentations in order to avoid oversimplification; that is, the same learning material can be represented multiple times and in various forms (Spiro & Jehng, 1990). As a result, the “intellectual accessibility” of the learning materials increases because these multiple representations enhance learners’ understandings (Blumenfeld et al., 1991). However, if the multiple representations are redundant rather than complementary, they may place unnecessary burden on a learner’s cognitive load (Sweller, 1988). For instance, computers may be unhelpful for children’s learning if presenting a picture along with a computer narration that simply *repeats* what the children can find out from the picture by themselves. Thus, optimal representations usually allow the learner to revisit different formats of the same learning material and activity and to consider different perspectives, rather than simultaneously focus upon them.

Technology can be used to increase students’ motivation and engagement levels (Hoffman & Ritchie, 1997; Reiser, 2004). Previous research has demonstrated that students who are more motivated tend to engage in learning tasks more actively on behavioral, emotional, and cognitive levels, devote greater concentration, and become more enthusiastic about their learning (Fredricks, Blumenfeld, & Paris, 2004; Jablon & Wilkinson, 2006). The use of technology in both motivating young children and supporting their learning is well-represented in the *Building Blocks* mathematics software (Clements & Sarama, 2004, 2007), which situates students in challenging but authentic mathematics learning activities. For instance, one of the activities requires children to sort and count specific food items (e.g. apples, bagels, cookies) shown on the screen. When a food item is clicked, the computer generates a verbal count of its number among the food items and a biting sound effect, which stimulate learning and help children to establish a one-to-one correspondence between an individual food item and the total number of items on the screen. Empirical research revealed that young children learning with the *Building Blocks* software performed significantly better than the control group on tests of important mathematic skills, including number operations, measurement, and patterning (Clements & Sarama, 2007).

Facilitating Utilization of Resources

With computers and the Internet becoming ubiquitous in U.S. schools and classrooms (USDOE, 2003; Rideout et al., 2003), children have access to multiple resources representing varying perspectives and qualities that would not be available or accessible to them otherwise. Using latest technologies (e.g., digital audio or video conferencing), children may communicate with subject experts (e.g., scientists, historians) or peer learners in other geographic areas with comparatively low or little cost. Similarly, online virtual tours engage children in authentic, real-world experiences by allowing them to closely observe places (e.g., museums, historical sites) that they have never visited or thoroughly examined (Klemm & Tuthill, 2003). Age-appropriate interactive games, videos, music, stories are also available on children's websites such as PBS Kids (http://www.pbskids.org), MaMaMedia (http://www.mamamedia.com), and FunBrain (http://www.funbrain.com). For example, PBS Kids introduces children to the geographic locations of U.S. states through an interactive game in which children choose a state at a time based on a region-specific map (e.g. northwest, southeast, etc.) and clues (e.g., "borders the Atlantic Ocean").

Resources can be static (e.g., book, magazines, CD-ROMs) or dynamic (e.g., websites updated on a regular basis, online databases, people). Dynamic resources can be identified and conveniently annotated in a collection, making the resources reusable for different learning needs (Hill & Hannafin, 2001). For instance, resources can be gathered through popular search engines (e.g., Google®, Yahoo! ®) with the retrieved results published on a website for reuse by children exploring a particular topic. In effect, the implementation of the Web in a learning environment does not limit learner access to a selected pool of resources, but allows learners to utilize resources independent of the resource designer's original intentions (Hannafin et al., 1999).

The availability of multiple resources posits significant potential to support inquiry learning in early childhood.However, learners, particularly younger children, can face challenges when locating, assessing, and utilizing resources for their inquiry learning. According to Quintana, et al. (2004):

> Learners can be overwhelmed by the complexity of options available, making it difficult to direct their investigations, see what steps are relevant and productive, and make effective activity decisions. (p. 359)

If not effectively processed by children, resources may actually hamper inquiry learning because they decrease children's motivation to learn and demand cognitive resources that could otherwise be used for more productive learning tasks.

Various technology tools are designed to help learners search for and process multiple resources in a timely manner (Iiyoshi, Hannafin, & Wang, 2005). For instance, search engines such as Yahoo!Kids and KidsClick.org allow children to identify the most relevant resources from thousands of child-appropriate Web pages using keyword searches. However, these tools are usually targeted at older children and present the search results in text, inappropriate for young children who cannot yet read or read well. Moreover, effective utilization of resources requires children to relate resources to their learning context, determine their relevance and meaning, and apply the relevant ones to their learning (Hill & Hannafin, 2001). These skills are typically undeveloped in young children as they often rely on trial-and-error experimentation rather than comparisons and analyses (Inhelder & Piaget, 1958).

Recent developments in Internet-based software applications have offered new ways for children to utilize resources. For example, KidZui is a browser specifically designed for children, with an animated, child-friendly user interface and access to more than a million websites, videos, and pictures that have been reviewed by teachers and parents trained by KidZui developers. It allows parents and teachers to tightly control the viewable content and monitor the actual visits of their children so assistance may be provided and learning activities planned accordingly. In fact, recent research reports indicate that children learn better with computers when mediated by adults (Clements, 2002; Nir-Gal & Klein, 2004). Researchers have advocated that adults intervene and provide assistance as needed during children's learning with computers (Haugland, 1999; Plowman & Stephen, 2005). For young children to better utilize resources, teachers or designers need to pre-select resources well-matched to the learning goals and assist children with selection. This helps improve the utility of resources for young children or older children less skilled at processing informational resources (Hannafin, et al., 1999). It also helps ensure that children see information resources as a means to the solution rather than the solution itself (Kuiper, Volman, & Terwel, 2005).

Supporting Cognitive and Metacognitive Processes

Technology can be used to automatically handle routine tasks or details (Quintana et al., 2004), to detect errors in their learning processes, and to correct or guide learners in correcting them (Blumenfeld et al., 1991). As a result, technology enables learners to focus on the concepts to be explored and the skills to be learned, rather than being overwhelmed by irrelevant cognitive demands (Blumenfeld et al., 1991; Salomon, 1993). For example, children using *Sammy's Science House* (Riverdeep, 2006) simply select a few key images that identify the scientific process being explored (e.g., plant growth), and the software automatically generates an animated video that fills in the intervening images to present the entire process; similarly, children may build and paint models (of boats or rockets) by clicking and dragging parts from a wallboard to a workbench, while the software automatically assembles the parts or provides feedback on the position of the parts. In the same vein, a game available at PBSKids.org allows children to color five different pictures of an animated character using a mouse pointer (in the shape of a colored pencil) to select colors from a palette; once a region in the character is clicked, the software automatically fills in the region with the color chosen from the palette, enabling children to focus on color patterns and representations without being constrained by their limited dexterity skills.

Researchers have suggested that technology be used for individualizing learning according to a learner's progress, prior knowledge, or ability (Blumenfeld et al., 1991; Hoffman & Ritchie, 1997). Software tools can track learners' learning styles and patterns, providing them with guidance (e.g., expert coaching, hints) and resources when needed (Hoffman & Ritchie, 1997). Using a software application about solar heating of water, for instance, children would need to read a thermometer in order to compare the temperature of water placed in direct sunlight with that of water left under a shade over time. Before starting the inquiry activity, the learner could complete a training game with embedded hints and guidance, to learn to read a thermometer, before being presented with the inquiry challenge.

Learners may better internalize new knowledge if it is represented in multiple perspectives, formats, or modalities (Iiyoshi et al., 2005). They may use technology to explore or modify provided representations, or to create their own representations that help integrate new and prior knowledge (Blumenfeld et al., 1991; Hoffman & Ritchie, 1997). For example, Web-based visual representations such as "virtual manipulatives" (Moyer, Bolyrad, & Spikell, 2002) enable young children to manipulate representations by flipping, turning, or rotating objects (e.g., geometric shapes), helpful for reinforcing critical mathematics skills, such as numbers and operations, algebra, geometry, and measurement. Likewise, Clemens, Moore, and Nelson (2001) implemented an interactive chalkboard tool, the SMART Board, that allowed first grade students to virtually manipulate, identify, and count virtual objects such as coins and dollar bills. The research results indicate that students using SMART Boards in conjunction with mathematics activities outperformed a control group on tests of mathematical concepts and skills, including coin comparison and identification, additions and subtractions, and time measurement.

Technology can facilitate experimentation, wherein children quickly and easily test multiple solutions (Hoffman & Ritchie, 1997) without being penalized by incorrect or ineffective attempts. In a hypothetical science software application, young children may learn the science of gravity and motion by observing and comparing the results of helping a cartoon character drive a car up a ramp and jump it over a river, using different combinations of ramp angle, speed, and acceleration. Technology also enables the creation of views or experimental conditions that would not exist otherwise. Computer-based simulations, for example, allow climate scientists to predict and visualize the impact of global warming on the environment by manipulating relevant variables, such as greenhouse gas emission rates and the percentage of tree coverage on the Earth. In early childhood contexts, Papert (1980) designed a computer software environment that enabled children to conduct a Newtonian physics experiment under ideal conditions: a box in motion continued to move indefinitely until acted upon by an external force.

Technology may encourage children to reflect on, and recognize discrepancies in, their own thinking by allowing them to review their own theories and compare those theories to others. As a result, technology may enable children to become more aware of their own thinking and help them improve their problem solving abilities (Blumenfeld et al., 1991; Iiyoshi et al., 2005; Reiser, 2004). For example, when learning about shadows with a science software application, children may initially record their individual ideas about what makes a shadow (audio recordings can be made for children not yet able to write), and later record their revised thinking after some experimentation and comparisons with peers' ideas. In this process, the software supports children's development of deep understanding of shadows through the process of articulating, comparing, and questioning their own thinking.

Technology also supports the distribution of cognition among learners during inquiry learning. According to theories of distributed cognition, when learning takes place in a group, individual cognition is interwoven with group cognition, grounded in the activities and learning context; learners can collaborate with each other to finish a shared activity, stimulating, guiding, or redirecting others' thinking (Pea, 1993; Salomon, 1993). Technology can be used to facilitate the collaborations, sharing, and negotiating that are part of this process (Reiser, 2004). Technology-enhanced peer support can increase interactivity and provide on-demand guidance during problem solving (Puntambekar & Hubscher, 2005). For instance, Knowledge Forum (Scardamalia, 2004) and its predecessor CSILE (Hewitt & Scardamalia, 1998) provide software tools for communication, searching, recording, and organization with which children collaboratively *produce* knowledge by selecting multimedia notes to be added to a database and linking the new notes to existing ones (Scardamalia, 2004). In a Knowledge Forum study conducted by Pelletier, Reeve, and Halewood (2006), kindergarten students collaboratively created photo journals of their daily experiences by selecting photos and adding limited annotations readable to them and their teachers, who provided support when requested or needed. The results indicated that the technology was successful in motivating and allowing the children to "make entries themselves using whatever strategies they had available, including use of invented spelling" (p. 334). These entries were stored in the software database and used as the basis as peer learners added their own notes, enabling the entire class to collaboratively build their knowledge about the relevant science content.

Challenges and Future Research

Varying Developmental Levels of Young Children

Children face many challenges during inquiry-based learning with technology. One of the key issues is that children vary significantly throughout the early years (from age four in preschool to age seven in the 2nd grade) in aspects of cognitive and physical development, such as reading proficiency, attention span, and fine motor skills (see Hart & Risley, 1995; Lillard, 2005). Children's reading proficiency, for instance, determines the developmental appropriateness of on-screen text or text-based input devices (e.g., keyboards). Their attention span and distractibility are closely related to their developmental age (Ruff & Capozzoli, 2003), creating implications for the amount of time required for completing an activity. Similarly, the design of user interfaces should account for young children's motor skills that affect their computer usage, such as their binocular vision (Moseley & Lane, 1986) and the hand-eye coordination skills needed to select an on-screen object by moving a mouse and clicking a mouse button (Nir-Gal & Klein, 2004). Although considerable research has been done on young children's learning with technology (e.g., Clements & Sarama, 2007; Elliott & Hall, 1997; Pange, 2003), little guidance is available for the design of technology-enhanced learning for children of varying ability levels.

Researchers have reported high variability in children's cognitive abilities and, consequently, academic achievement throughout the school years (Weinert & Helmke, 1998). Considering this, technology applications must be developed for learners of similar developmental levels (i.e., ages or grades) or be customizable otherwise. Children of lower cognitive abilities (Elias & Allen, 1991) or autonomy levels (Grolnick & Ryan, 1987) need more structure and guidance in their learning than their more competent peers. They gradually become prepared to handle complex problems as they develop their own thinking, self-awareness, and autonomy (Lillard, 2005; Rogoff, 2003).

In addition, appropriate levels of scaffolding should be provided in a timely manner (Hoffman & Ritchie, 1997) and individualized to the students (Blumenfeld et al., 1991), acknowledging the intuition that each student brings to the inquiry process (Reiser, 2004). The source of the scaffolding must also be considered, as research indicates that adult scaffolding tends to be of higher quality than peer children's, and older children provide better scaffolding than younger children (Gauvain, 2001). Future research should determine how much structure, scaffolding, and guidance are necessary, and identify the conditions of successful technology-enhanced inquiry learning, for young children at a given age or ability level. This will help designers make informed decisions based upon empirical research rather than their unfounded assumptions.

Teacher Facilitation

Technology cannot stand alone, as it exists as part of a system that also includes students, teachers, and curricula (Quintana et al., 2004; Reiser, 2004; Blumenfeld et al., 1991). Teachers are critical for successful inquiry-based learning across grade levels (Quintana et al., 2004) and particularly important to young children, given the importance of structured and guided inquiry in early childhood education (cf. Ginsburg & Golbeck, 2004). Teachers facilitate student learning in everyday classroom environments, determining whether technology-enhanced inquiry learning applications are implemented in ways that complement current early childhood curricula and other classroom activities. Research indicates that young children use computers most effectively when supported by teachers (Clements, 2002; Haugland, 1999; Nir-Gal & Klein, 2004; Plowman & Stephen, 2005). Teachers need to intervene when children experience problems or frustration during technology-enhanced inquiry learning, scaffolding their learning with prompts, cues, and instructions as needed. The intervention can be both productive and challenging because it requires teachers to fully understand students' thinking and modify the instruction accordingly (Tippons & Kittleson, 2007). Future research should identify and document effective ways of designing and implementing teacher supports for facilitating children's inquiry-based learning with technology, as well as the impact of these supports on children's learning outcomes.

Teacher training is critical for effective classroom implementation of technology-enhanced inquiry learning. Teachers' attitudes, as well as lack of confidence and computer skills, hamper effective integration of computers into classrooms (Chen & Chang, 2006; Ljung-Djärf, Aberg-Bengtsson, & Ottosson, 2005; Ljung-Djärf, 2008; Cuban, 2001). Parette and colleagues (2009) further noted,

> The true issue confronting early childhood professionals…is to develop professional knowledge of and skills in instructional technology…. These education professionals must then systematically integrate the use of that technology in the early childhood curriculum. (p. 361)

Training programs (e.g., workshops, online training) can help teachers learn ways of integrating technology-enhanced inquiry learning into everyday classroom teaching and learning, in addition to prerequisite technical skills, but even simple teacher supports can help. For instance, teacher supports embedded within curricula can purposefully integrate and guide the use of software applications (Chen & Chang, 2006; Haugland, 2000; Reiser, 2004), in a way similar to the *Building Blocks* curriculum and companion software developed by Clements and Sarama (2004, 2007) for Pre-Kindergarten mathematics. This will require the coordination of software developers, curriculum developers, subject experts, and early childhood researchers so that a curriculum and its inquiry-based software applications are complimentary to each other, with adequate instructions provided to teachers for the optimal implementation of both.

Evidence and Empirical Research

Previous research has demonstrated the effectiveness of technology-enhanced inquiry learning for older children (Linn, Clark, & Slotta, 2003; Edelson et al., 1999) and technology itself for various aspects of young children's learning (e.g., Clements & Sarama, 2007; Li & Atkins, 2004). However, limited evidence-based guidelines are available for proper computer uses in early childhood education, and computers are often used merely for play and entertainment (Ljung-Djärf, 2008). It is still unknown whether technology-enhanced inquiry learning is effective for young children's learning, nor the required characteristics to ensure effectiveness. We need to apply the results from previous research to develop and empirically test guidelines for design and use of technology-enhanced inquiry learning in early childhood contexts. In this process, we need to investigate how young children actually learn, and identify the obstacles they often face, during technology-enhanced inquiry learning. Considerable variability has been found regarding older children's use of technology tools (Iiyoshi et al., 2005), but relatively little is known about the patterns in young children's use of these tools. Research on these issues will help address young children's learning needs and design technology applications that are developmentally appropriate and helpful to their overall development.

The measurement of learning outcomes should be consistent with the goals and fundamental principles of inquiry-based learning (see Barrows, 1996; Savery & Duffy, 1996; Wilkerson & Gijselaers, 1996). During this process, attention will need to be paid to isolating learning outcomes from varying elements of the learning experience, for instance the influence of technology, scaffolding strategies, types of inquiry, content, and to a combination of various factors. It may be especially challenging to develop measures of learning for younger children who cannot yet read and who have relatively short attention spans (Ruff & Rothbart, 1996). Collaborative efforts with early childhood experts and psychologists are needed to develop measures that are both valid and feasible.

Conclusion

Inquiry-based learning activities are complex but have substantial potential for encouraging children's knowledge construction; when integrated with technology, this potential is magnified. The roles of technology synthesized in this paper can help guide the design and integration of technology innovations in inquiry-based learning in early childhood. Future research should document both the effectiveness of these kinds of technology use and how young children respond to them during inquiry learning and problem solving.

References

American Association for the Advancement of Science (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education, 13*(1), 1-12.

Barrows, H. S. (1996). Problem-based learning in medicine and beyond: A brief overview. In L. Wilkerson & W. H. Gijselaers (Eds.), *New directions for teaching and learning: Vol. 68. Bringing problem-based learning to higher education: Theory and practice* (pp. 3-12). San Francisco: Jossey-Bass Publishers.

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction: Assessing the inquiry level of classroom activities. *The Science Teacher, 72*(7), 30-33.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3&4), 369-398.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school*. Washington, D.C.: National Academy Press.

Casey, B., Kersh, J., & Young, J., (2004). Storytelling sagas: An effective medium for teaching early childhood mathematics. *Early Childhood Research Quarterly*, *19*(1), 167-172.

Chen, J., & Chang, C. (2006). Using computers in early childhood classrooms: Teachers' attitudes, skills and practices. *Journal of Early Childhood Research*, *4*(2), 169-188.

Clemens, Moore, & Nelson. (2001). Math intervention "SMART" Project: Student mathematical analysis and reasoning with technology. Retrieved September 11, 2008, from SMARTer Kids Foundation website: http://smarterkids.org/research/paper10.asp

Clements, D. H. (2002). Computers in early childhood mathematics. *Contemporary Issues in Early Childhood*, *3*(2), 160-181.

Clements, D. H., & Sarama, J. (2004). *Engaging young children in mathematics: Standards for early childhood mathematics education*. Mahwah, NJ: Lawrence Erlbaum Associates.

Clements, D. H., & Sarama, J. (2007). Effects of a preschool mathematics curriculum: Summative research on the *Building Blocks* project. *Journal of Research in Mathematics Education, 38*(2), 136-163.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Harvard University Press.

Disney/Pixar. (2005). Learning with Nemo [Computer software]. Emeryville, CA: Pixar Animation Studios.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3&4), 391-450.

Elias, M. J., & Allen, G. J. (1991). A comparison of instructional methods for delivering a preventive social competence/social decision making program to at risk, average, and competent students. *School Psychology Quarterly, 6*(4), 251-272.

Elliott, A., & Hall, N. (1997). The impact of self-regulatory teaching strategies on "at-risk" preschoolers' mathematical learning in a computer-mediated environment. *Journal of Computing in Childhood Education, 8*(2), 187-198.

Essa, E. (2002). *Introduction to early childhood education* (4th ed.). Clifton Park, NY: Thomson Delmar Learning.

Fredricks, J., Blumenfeld, P., & Paris, A. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research. 74*(1), 59-109.

Gauvain, M. (2001). *The social context of cognitive development*. New York: Guilford.

Ginsburg, H. P., & Golbeck, S. L. (2004). Thoughts on the future of research on mathematics and science learning and education. *Early Childhood Research Quarterly, 19*(1), 190–200.

Grolnick, W. S., & Ryan, R. M. (1987). Autonomy in children’s learning: An experimental and individual difference investigation. *Journal of Personality and Social Psychology, 52*(5), 890-898.

Hannafin, M. J., Land, S., & Oliver, K. (1999). Student-centered learning environments. In C. M. Reigeluth (Ed.), *Instructional-design theories and models: A new paradigm of instructional theory* (Vol. II, pp. 115-140). Mahwah, NJ: Erlbaum.

Hart, B., & Risley, T. R. (1995). *Meaningful differences in the everyday experiences of young American children*. Baltimore, MD: Paul H. Brookes Publishing.

Haugland, S. W. (1999). What role should technology play in young children’s learning? *Young Children, 54*(6), 26-31.

Haugland, S. W. (2000). What role should technology play in young children's learning? Part 2. *Young Children, 55*(1), 12-18.

Hewitt, J., & Scardamalia, M. (1998). Design principles for distributed knowledge building processes. *Educational Psychology Review, 10*(1), 75-96.

Hill, J. R., & Hannafin, M. J. (2001). Teaching and learning in digital environments: The resurgence of resource-based learning. *Educational Technology Research and Development, 49*(3), 37-52.

Hoffman, B., & Ritchie, D. (1997). Using multimedia to overcome the problems with problem based learning. *Instructional Science, 25*(2), 97-115.

Howard, J. R., Watson, J. A., Brinkley, V. M., & Ingels-Young, G. (1994). Comprehension monitoring, stylistic differences, pre-math knowledge, and transfer: A comprehensive pre-math/spatial development computer-assisted instruction (CAI) and LOGO curriculum designed to test their effects. *Journal of Educational Computing Research, 11*(2), 91-105.

Iiyoshi, T., Hannafin, M. J., & Wang, F. (2005). Cognitive tools and student-centered learning: rethinking tools, functions and applications. *Educational Media International, 42*(4), 281-296.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.

International Society for Technology in Education [ISTE]. (2000). *National educational technology standards for teachers*. Eugene, OR: Author.

Jablon, J. & Wilkinson, M. (2006). Using engagement strategies to facilitate children’s learning and success. *Young Children, 61*(2), 12-16.

Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology: Using computers as cognitive tools. In D. H. Jonassen (Ed.), *Handbook of research on educational communications and technology* (pp. 693-719). New York: Macmillan.

Justice, L. M., & Kaderavek, J. (2004). Embedded-explicit emergent literacy I: Background and description of approach. Language, Speech, and Hearing Services in Schools, 35, 201-211.

Klemm, E. B., & Tuthill, G. (2003). Virtual field trips: Best practices. *International Journal of Instructional Media, 30*(2), 177-193.

Koslowski, B. (1996). *Theory and evidence: The development of scientific reasoning*. Cambridge, MA: MIT Press.

Kuiper, E., Volman, M., & Terwel, J. (2005). The Web as an information resources in K-12 education: Strategies for supporting students in searching and processing information. *Review of Educational Research, 75*(3), 285-328.

Land, S. M., & Hannafin, M. J. (2000). Student-centered learning environments. In D. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 1-23). Mahwah, NJ: Lawrence Erlbaum Associates.

Li, X., & Atkins, M. S. (2004). Early childhood computer experience and cognitive and motor development. *Pediatrics, 113*, 1715-1722.

Lillard, A. S. (2005). *Montessori: The science behind the genius*. New York: Oxford University Press.

Lind, K. K. (1998). *Science in early childhood: Developing and acquiring fundamental concepts and skills*. Paper presented at the Forum on Early Childhood Science, Mathematics, and Technology Education.

Lind, K. K. (2005). *Exploring science in early childhood* (4th ed.). Clifton Park, NY: Thomson Delmar Learning.

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science Education, 87*(4), 517 - 538.

Ljung-Djärf, A. (2008). To play or not to play—that is the question: Computer use within three Swedish preschools. *Early Education and Development, 19*(2), 330-339.

Ljung-Djärf, A., Aberg-Bengtsson, L., & Ottosson, T. (2005). Ways of relating to computer use in pre-school activity. *International Journal of Early Years Education*, *13*(1), 29-41.

Moseley, D., & Lane, D. (1986). Children's binocular efficiency in relation to competence in reading. *Educational and Child Psychology, 3*(2), 90-102.

Moyer, P., Boylard, J., & Spikell, M. (2002). What are virtual manipulatives? *Teaching Children Mathematics. 8*(6), 372-377.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.

Nir-Gal, O., & Klein, P. S. (2004). Computers for cognitive development in early childhood – the teacher's role in the computer learning environment. *Information Technology in Childhood Education Annual*, 97-119.

Pange, J. (2003). Teaching probabilities and statistics to preschool children. *Information Technology in Childhood Education Annual*, 163-172.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York: Basic Books, Inc.

Parette, H. P., Hourcade, J. J., Dinelli, J. M., & Boeckmann, N. M. (2009). Using *Clicker 5* to enhance emergent literacy in young learners. *Early Childhood Education Journal*, *36*, 355-363.

Pea, R. D. (1993). Practice of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47-87). Cambridge, U.K.: Cambridge University Press.

Pelletier, J., Reeve, R., & Halewood, C. (2006). Young children's knowledge building and literacy development through Knowledge Forum®. *Early Education and Development*, *17*(3), 323-346.

Plowman, L., & Stephen, C. (2005). Children, play, and computers in pre-school education. *British Journal of Educational Technology, 36*(2), 145-157.

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist, 40*(1), 1-12.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2004). A scaffolding design framework for software to support science inquiry. *Journal of the Learning Sciences*, *13*(3), 337-386.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *Journal of the Learning Sciences*, *13*(3), 273-304.

Rideout, V. J., Vandewater, E. A., & Wartella, E. A. (2003). *Zero to six: Electronic media in the lives of infants, toddlers and preschoolers*. Menlo Park, CA: The Henry J. Kaiser Family Foundation.

Riverdeep. (2001). Reader Rabbit Preschool: Sparkle Star Rescue [Computer software]. Novata, CA: Riverdeep Inc.

Riverdeep. (2006). Sammy's Science House [Computer software] (Version 4). Novato, CA: Riverdeep Inc.

Rogoff, B. (2003). *The cultural nature of human development*. Oxford: Oxford University Press.

Ruff, H. A., & Capozzoli, M. C. (2003). Development of attention and distractability in the first 4 years of life. *Developmental Psychology, 39*(5), 877-890.

Ruff, H. A., & Rothbart, M. K. (1996). *Attention in early development: Themes and variations.* New York: Oxford University Press.

Salomon, G. (1993). No distribution without individuals' cognition: A dynamic interactional view. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 111-138). Cambridge, United Kingdom: Cambridge University Press.

Sarama, J. (2004). Technology in early childhood mathematics: *Building Blocks* as an innovative technology-based curriculum. In D. H. Clements & J. Sarama (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education.* (pp. 361-375). Mahwah, NJ: Lawrence Erlbaum Associates.

Savery, J. R., & Duffy, T. M. (1996). Problem based learning: An instructional model and its constructivist framework. In B. G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 135-148). Englewood Cliffs, NJ: Educatioal Technology Publications.

Scardamalia, M. (2004). CSILE/Knowledge Forum. In A. Kovalchick & K. Dawson (Eds.), *Education & technology: An encyclopedia* (pp. 183-192). Santa Barbara, CA: ABC-CLIO.

Scholastic. (2003). Math Missions: The Race to Spectacle City Arcade [Computer software]. New York: Scholastic, Inc.

Short, K. G., & Harste, J. C. (1996). *Creating classrooms for authors and inquirers*. Portsmouth, NH: Heinemann.

Spiro, R. J., & Jehng, J.-C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multimensional traversal of complex subject matter. In D. Nix & R. Spiro (Eds.), *Cognition, education, multimedia: Exploring ideas in high technology* (pp. 163-205). Hillsdale, NJ: Lawrence Erlbaum Associates.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257-285.

The Learning Company (2001). Arthur's Math Games [Computer Software]. Freemont, CA: The Learning Company.

Tippons, D.J. & Kittleson, J.M. (2007). Considering young children's production of science: The tensions associated processes, uncertainty, and authority. *Cultural Studies of Science Education, 2,* 816-821.

Vellutino, F. R., & Scanlon, D. M. (1987). Phonological coding, phonological awareness, and reading ability: Evidence from a longitudinal and experimental study. *Merrill-Palmer Quarterly, 33,* 321-363.

Weinert, F. E., & Helmke, A. (1998). The neglected role of individual differences in theoretical models of cognitive development. *Learning and Instruction, 8*(4), 309-323.

Wilkerson, L., & Gijselaers, W. H. (Eds.). (1996). *New directions for teaching and learning: Vol. 68. Bringing problem-based learning to higher education: Theory and practice.* San Francisco: Jossey-Bass Publishers.

Youngquist, J., & Pataray-Ching, J. (2004). Revisiting "play": Analyzing and articulating acts of inquiry. *Early Childhood Education Journal, 31*(3), 171-178.

Table 1

Technology Uses in Supporting Early Childhood Inquiry

Function	Uses of technology	Examples/Citations
Enrich and Structure Problem Contexts	• Enhance representation richness and present problems in contexts relevant to children's everyday lives • Support development of "expert thinking" in an inquiry problem domain • Structure complex tasks by setting learning boundaries, specifying activity procedures, and offering expert guidance • Support multiple, clear, and increasingly complex presentations • Increase motivation and engagement levels	• Learning with Nemo (Disney/Pixar, 2005) • Reader Rabbit (Riverdeep, 2001) • Arthur's Math Games (The Learning Company, 2001) • Math Missions (Scholastic, 2003) • Sammy's Science House (Riverdeep, 2006) • Building Blocks (Clements & Sarama, 2004, 2007)
Facilitate Utilization of Resources	• Enable access to resources of various perspectives and qualities • Help learners search and process multiple resources in a timely manner (e.g., using search engines)	• Online virtual tours (Klemm & Tuthill, 2003) • Children's websites (e.g. PBS Kids, MaMaMedia) • Child-friendly search engines (e.g., KidZui, Yahoo!Kids)
Support Cognitive and Metacognitive Processes	• Automatically handle routine tasks to enable focused attention on more challenging cognitive tasks • Individualize learning according to learning styles, patterns, progress, etc. • Allow children to manipulate existing or create new visual representations • Enable children to conduct experiments to test hypotheses and alternate solutions • Help children become more aware of their own thinking • Enable social learning through peer collaboration	• Sammy's Science House (Riverdeep, 2006) • Physics simulation (Papert, 1980) • Knowledge Forum (Scardamalia, 2004)