

Evidence of Complex Reasoning in Technology and Science: Notes From Inner City Detroit, Michigan, USA

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Abstract: Educational research suggests that children's development of complex reasoning in science involves the simultaneous development of reasoning (e.g. formulating explanations) with scientific knowledge (e.g. interactions between animals in an ecosystem). While scientists utilize technology for the organization, analysis, and presentation of scientific data, children rarely utilize technology for these purposes. This paper presents results demonstrating complex reasoning in science possible among urban 11-13 year old students through the coordinated development of learner-centered technological tools (e.g. customized Internet resources; customized software for hand-held computers), activities that foster complex reasoning, and assessments to evaluate complex reasoning in science and technology.

Introduction

What knowledge, skills and abilities do 11-13 year old children need to be scientifically and technologically literate? How do we document evidence of scientific and technological literacy? This paper outlines a set of comprehensive research studies in science education and learning technologies to promote and evaluate the development of complex reasoning in science and technological literacy among 11-13 year old children in high-poverty urban schools in the USA. This work is funded by two research grants supported by the Interagency Education Research Initiative (IERI), a consortium of three federally funded research organizations (The National Science Foundation, The National Institutes of Health and The Department of Education) joined to collectively supported large-scale educational research¹.

Scientific and Technological Literacy With Customized Resources

Technology can be defined in many ways, but is commonly referred to as “the diverse collection of processes and knowledge that people use to extend human abilities and to satisfy human needs and wants” (International Technology Education Association, 2000, p. 2). Drawing from this definition, technological literacy can be defined as fluency with the processes and knowledge that extend human abilities. The National Science Education Standards (2000) state that becoming scientifically literate involves the development of three kinds of scientific skills and understandings, including: a) principles and concepts of science, b) reasoning and procedural skills of scientists, and c) the nature of science as a particular form of human endeavor. Most learning researchers agree that children's development of complex reasoning in science involves the simultaneous development of knowledge (e.g. interactions between animals in an ecosystem) and reasoning (e.g. formulating explanations) (e.g. Bransford, Brown and Cocking, 2001). Therefore, to develop the ability to perform complex reasoning in science on their

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own, children need learning supports to guide their understanding towards both appropriate science content and reasoning skills (Lee and Songer, 2003; Vygotsky, 1978).

As with the development of complex reasoning in science, the development of sophisticated use of technology by scientists involves complex reasoning skills towards the organization, analysis, and presentation of scientific data. Despite American policy documents (e.g. NRC, 2000) advocating science and technology education that more closely resembles the scientific reasoning and meaningful use of technology of scientists, children's science and technology education seldom exhibits these features of scientist's practice. However, a handful of U.S. science and technology education programs for K-12 students are working towards technological and scientific literacy goals through the creation of specialized learning environments (see Linn, Davis and Bell, 2004 for examples). These environments strive to support the development of scientific knowledge development and reasoning skills through guided use of learner-focused technological tools.

In general, science and technology education researchers have discovered that this work of fostering scientific and technological literacy involves the coordinated research and development of several components of the classroom learning environment, including:

- Learner-centered design of technology (Quintana et al, 2000), e.g. the development of the learning technology for the customized learning purpose (such as scientific concepts and reasoning) and audience (such as 11-13 year olds),
- Learner-centered design of curricular activities (Songer, 2004), to support the development of complex reasoning in particular content areas of science through the use of systems of customized guides or prompts,
- Learner-centered design of assessment instruments (Songer and Gotwals, 2004) for the evaluation of increasing levels of complexity of scientific reasoning and science content development over time and topic.

The following sections outline the research, development and outcomes for each of these components for a particular research project called BioKIDS: Kids' Inquiry of Diverse Species (www.biokids.umich.edu). BioKIDS is a large research project with the specific goal to foster and evaluate 11-13 year old students' learning of complex ideas in science and technology.

Learner-centered design of technology

The learner-centered design of technology requires extensive knowledge of how children learn (e.g. Bransford, Brown and Cocking, 2000) in order to design scientifically based technological tools for fluent use by children. A central component of the design for learning by children is an understanding of the manner in which existing scientific tools that present complex interfaces can be adapted for fluent use by 11-13-year old children.

One technological tool that suggests promise as a classroom-based science tool is Personal Digital Assistants (PDAs). Research demonstrates that data collection on PDAs is a faster and more accurate means of data collection than paper and pencil methods (Spain, Phipps, Rogers and Chapparo, 2001). For our learning environment in the BioKIDS project (www.biokids.umich.edu), we customized existing Windows/Palm OS software for our learning purpose and audience. CyberTracker (www.cybertracker.co.za) is an icon-driven interface designed for African animal trackers to collect

species data on animals in the field. As we needed a technological tool that would support 11-13year old students in the collection of animal data in their schoolyards in Michigan, USA, we customized the CyberTracker interface towards a version that prioritized quick, accurate icon-based recording of local animals in children’s schoolyard. A portion of our version, called The BioKIDS Sequence, is presented in Figure 1 (see also Parr, Jones and Songer, in press).

Learner-centered design of the BioKIDS Sequence resulted in several important design choices. First, we retained the icon-driven interface for efficient data entry, even by very young children. Second, we focused on the linear navigation of screens as compared to branching (Parr, Jones and Songer, in press). Third, we emphasized screens that would result in data collection most useful for our curricular activities that were focused on developing children’s complex reasoning in science. For example, our icon-based screens in the BioKIDS sequence emphasized animal identification and microhabitat data; two data particularly valuable in supporting children’s questions about animal richness (e.g. numbers of species) and abundance (e.g. numbers of animals) in their schoolyards. In other words, our learner-centered design of the BioKIDS sequence prioritized data on animal richness and abundance because, like professional zoologists, our children could use such data to foster complex reasoning around the determination of a biodiversity index for a given region.

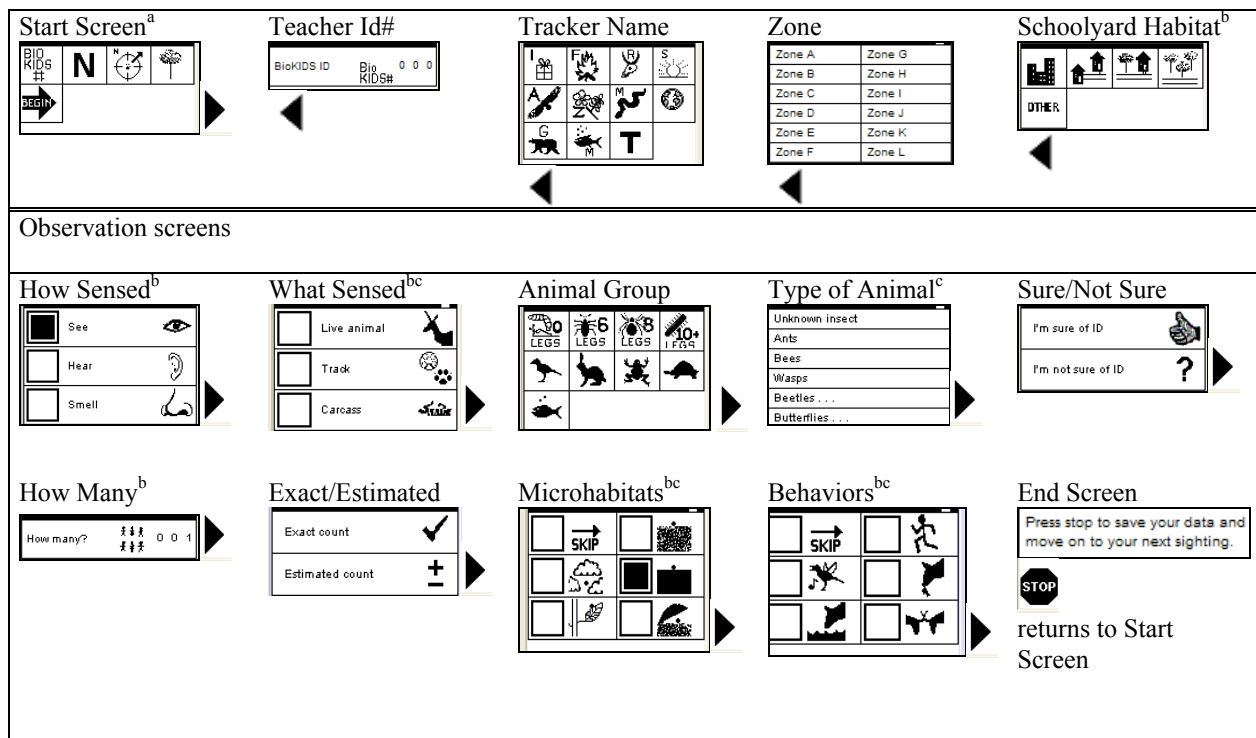


Figure 1 The BioKIDS Sequence.

^a Start screen is a branch point of four “state screens” whose state is retained, unless changed, throughout a session. The “Begin” arrow on Start screen is used to get to *Observation* screens, which are always presented in the same order. After each screen, users press a “next” arrow to proceed; backing up to reenter data is possible until they select “Stop.”

^b Screen can be bypassed without a choice.

^c Screen has more than one page of choices.

Evaluations of our learner-centered design of the BioKIDS sequence revealed high levels of initial usability, improvements in usability with limited use, and high degrees of accuracy of data entry by 11-13 year old students (Parr, Jones and Songer, in press). We speculate that the icon-driven interface and the simple, linear navigation contribute to these positive results.

Learner-centered design of assessment instruments

An important and often underdeveloped area of complexity is the learner-centered design of assessment instruments. Interestingly, while many software and curricular designers have a deep understanding of how children learn and design sophisticated information technologies for educational purposes (e.g. Linn, Davis and Bell, 2004), many of these learning environments remain underutilized without convincing evidence of what children learn with these tools. Without sophisticated feedback on what children learn with these resources, optimization of the learning environment for maximum cognitive benefit and widespread adoption seem unlikely to occur. While testing is a national priority in America and extensive evaluation of student learning is occurring at all levels of K-12 education, nearly all these high-stakes tests are ill-suited to the evaluation of students' complex reasoning, and instead, prioritize the development of declarative knowledge and, if technological literacy is evaluated at all, simple uses of technological tools (Pellegrino, Chudowsky, and Glaser, 2001).

Working in conjunction with a research group titled PADI: Principled Assessment Design for Inquiry and partners from the University of Maryland and SRI International², we have developed a coordinated set of assessment tasks that take into account several dimensions of the student (e.g. prior knowledge, experience with inquiry reasoning), therefore helping to define our criteria for learner-centered assessment (Songer and Gotwals, 2004). Following structural guidelines established by the PADI research team, assessment tasks are reverse and forward-engineered to evaluate simple, moderate, and complex levels of scientific inquiry reasoning within each of several consecutive curricular units. In this work, this battery of assessment tasks can provide sensitive levels of evidence of 11-13 year old students' development of particular inquiry reasoning skills within, and across, several content areas.

Learner-centered design of curricular activities

Many complexities also exist in the design of curricular activities for the development of complex thinking in science. In particular, a major goal of the BioKIDS curricular activities was to foster inquiry reasoning in science; inquiry reasoning is a particular form of complex thinking in science currently advocated by many policy documents (NRC, 1996; NRC 2000). In BioKIDS curricular units (Songer, 2000), inquiry reasoning skills such as the development of scientific explanations from evidence are supported throughout several, sequential science units (Lee and Songer, 2004; Huber, Songer and Lee, 2003).

One characteristic of our curricular activities is the repeated presence of learning supports to help students develop complex reasoning skills. To illustrate the nature of these learning supports, Figure 2 presents one component of learning supports from the biodiversity unit. As discussed earlier, 11-13 year old students collect animal data from their schoolyard using the BioKIDS Sequence. Following animal data collection, activities guide students in the interpretation of their data through the development of a scientific explanation for the question, "Which zone in the schoolyard has the greatest biodiversity?" To address this question, students must analyze the schoolyard data collected using the BioKIDS Sequence,

² The PADI project is under the direction of Dr. Geneva Haertel of SRI International and Dr. Robert Mislevy of the University of Maryland, USA.

then use content and inquiry reasoning prompts as illustrated in Figure 2 to determine what evidence is salient. After evidence is selected, children use the sentence starters and content prompts to craft an explanation based on the salient evidence. Figure 2 presents the format used repeatedly to guide students in the development of the inquiry reasoning skill, formulating scientific explanations from evidence.

Question: Which schoolyard zone has the highest biodiversity?

<p>Claim</p> <p>SENTENCE STARTER→ I think zone _____ has the highest biodiversity because.....</p>
<p>Data or Evidence</p> <ul style="list-style-type: none"> •How many animals and different kinds of animals were found in this zone compared to other zones? • Where were animals found in this zone? • How does this zone support both high abundance and high richness of animals?
<p>CONTENT PROMPTS ^</p>

Figure 2: Activity Supports to Guide Students in Formulating Scientific Explanations from Evidence

Results: Student Learning Outcomes

The following results illustrate examples of student learning outcomes achieved through the coordinated development of learner-center design of technology, assessment, and curricular activities. For more information on this work and the full presentation of learning outcomes, see Songer, 2004. Figure 3 presents student outcome data for control (n=595) versus experimental (n=1329) students on posttest measures (biodiversity unit) by task complexity level. This study constituted a quasi-experimental research design where control students were comprised of students who experienced from 0-30% of curricular activities and experimental students experienced nearly all of the eight weeks of curricular activities (the average was 95% of all activities).

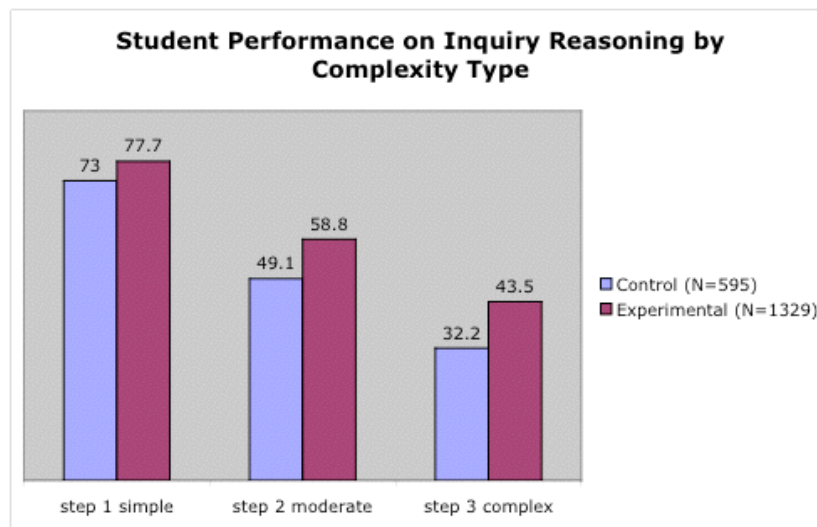


Figure 3: Control and Experimental Performance on Posttest by Complexity Levels

The following trends are apparent in these data. First, while the control and experimental students performed statistically identical on all pretest measures (not presented in this figure; see Songer, 2004), experimental students performed significantly better on inquiry tasks at all three levels of science content and inquiry reasoning complexity (step 1 simple, step 2 moderate, and step 3 complex). These results suggest that the development of complex reasoning and scientific knowledge are intertwined, particularly at the higher complexity levels. In addition, a trend is apparent that the differences between control and experimental populations increase with complexity levels. In other words, as students work with a greater amount of activities that support the development of complex inquiry thinking, their ability to outperform peers becomes more pronounced, particularly on the items of greatest complexity.

Discussion

Educational researchers have long desired learning outcomes that can document the development of complex reasoning in science as students utilize technological tools in ways similar to their uses by professional scientists. While this goal has been evident for a long time, the orchestration of learning environments that can support the development of complex reasoning as well as provide evidence of students' thought processes has not been easy to achieve. The research presented here suggests that the coordination of learning environment components is essential, including coordination of learner-centered design of technology, assessment instruments, and curricular activities.

Scientific and technological literacy require the development of systems that can foster, and evaluate, students' development of knowledge over time, topic, and technological tool. This work outlines the first phase of research to develop and evaluate students' complex reasoning in science over several sequential units and years. Research is ongoing to track students' development of complex reasoning within and across several, sequential curricular units leading to a greater understanding of the careful design of learning environment components, and their interactions, for maximum cognitive benefit.

References

- Bransford, J. D., A. L. Brown, A., and Cocking, R., Eds. (2000). How People Learn: Brain, Mind, Experience and School. Washington D.C., National Academy Press.
- Huber, A., Songer, N.B. and Lee, S.Y. (2003). BioKIDS: A Curricular Approach to Teaching Biodiversity through Inquiry in Technology-Rich Environments. Paper presented at the meeting of the National Association of Research in Science Teaching, Philadelphia, PA.
- International Technology Education Association (2000) Standards for Technological Literacy: Content for the study of technology. Reston, VA: International Technology Education Association.
- Lee, H.S. and Songer, N.B. (2003). Making authentic science accessible to students. The International Journal of Science Education 25(8), 923-948.
- Linn, M.C., Davis, E., and Bell, P. (2004) Internet Environments for Science Education. Lawrence Erlbaum.
- National Research Council (1996). National science education standards. Washington, DC, National Academy Press.
- National Research Council (2000). Inquiry and the National Science Education Standards. Washington, D.C., National Research Council.
- Parr, C., Jones, T., and Songer, N.B. (in press). Evolution of a handheld data collection interface for science learning. Journal of Science Education and Technology.
- Pellegrino, J., Chudowsky, N., Glaser, R. (2001). Knowing what students know: The science and design of educational assessment. Washington, D.C., National Academy Press.

- Quintana, C., Krajcik, J., Soloway, E. (2002) A Case Study to Distill Structural Scaffolding Guidelines for Scaffolded Software Environments. *CHI 2002 Proceedings*, p. 81-88.
- Songer, N. B. and Gotwals. A. (2004). Measuring the Development of Complex Reasoning in Science. Paper presented at the meeting of the American Educational Research Association, San Diego.
- Songer, N.B. (2004) Persistence of Inquiry: Evidence of complex reasoning among inner city middle school students. Paper presented at the meeting of the American Educational Research Association, San Diego.
- Spain, K. A., Phipps, C. A., Rogers, M.E., Chapparo, B.S. (2001) Data collection in the Palm of your hand: A case study. International Journal of Human-Computer Interaction 13: 231-243.
- Vygotsky, L. (1978). Mind in Society: The Development of Higher Psychological Processes. Cambridge, MA, Harvard University Press.