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Abstract

This paper reports an analysis of an interactive technology-supported, problem-based learning (PBL) project in science, technology, engineering and mathematics (STEM) from a Learning Sciences perspective using the Selected Learning Sciences Interest Areas (SLSIA). The SLSIA was adapted from the "What kinds of topics do ISLS [International Society of the Learning Sciences] members study"? (International Society of the Learning Sciences, ISLS, n.d.). The SLSIA is applied to analyze a case study, the interactive technology supported PBL simulation in water quality project the River of Life. This analysis using the SLSIA provides STEM education stakeholders with a reflective framework in designing interactive technology supported environments for PBL in STEM, and a platform for initiating thoughtful discussions on research and development efforts.

Introduction

An analysis of interactive technology supported problem-based learning (PBL) project in science, technology, engineering and mathematics (STEM) education from the view of the Learning Sciences is addressed in this paper. To facilitate this analysis, the Selected Learning Sciences Interest Areas (SLSIA), adapted from the "What kinds of topics do ISLS [International Society of the Learning Sciences] members study?" (International Society of the Learning Sciences, ISLS, n.d.), is applied to analyze an interactive multimedia PBL in STEM project. We live in a world influenced by information explosion, ubiquitous telecommunication technologies, faster intercontinental transportation, and improved health care, due to unprecedented developments in science and its technological applications. Calls for a STEM literate workforce have been made by various sectors of society. As a result education reform in the STEM disciplines is becoming a priority in developed as well as developing nations. According to a report from the Committee on STEM Education of the National Science and Technology Council (2013) "it is essential that the United States enhance U.S. students' engagement in STEM disciplines and inspire and equip many more students to excel in STEM" (p. vi).

In order to "inspire" and "equip" students to "excel" in STEM, it is critical that learning in the STEM disciplines should help students to see the connections between science and technology, and the real world around them. STEM education should enable students to learn by applying their knowledge in real-world contexts to become successful problem solvers (Committee on STEM Education of the National Science and Technology Council, 2013; Meyrick, 2011; Kumar & Chubin, 2000). STEM education has "emerged as one of the most sought after curriculum designs for integrating science, technology, engineering, and mathematics into K-12 education" (Meyrick, 2011, para. 1). When dealing with designing innovative STEM learning environments, one cannot overlook the importance of a more scientific approach to researching and developing learning environments known as the "Learning Sciences."

Relevance of the Learning Sciences

The term "Learning Sciences" refers to an interdisciplinary approach to the scientific study of learning (or learning about learning), designing, developing and researching innovative learning environments in real-world contexts (Pea, 2000; Walsh, 2011; Bransford, Brown, & Cocking, 2002; Kumar, 2015a, 2012). According to the mission statement of the International Society of the Learning Sciences (ISLS, n.d.), investigations in the Learning Sciences "include fundamental inquiries on how people learn alone and in collaborative ways, as well as on how learning may be effectively facilitated by different social and organizational settings and new learning environment designs, particularly those incorporating information and communication technologies (ICT), as in computer-supported collaborative learning (CSCL)" (p. 1). The Learning Sciences is an interdisciplinary field consisting of a variety of stakeholders, for example, educators, psychologists, cognitive scientists, computer scientists, and sociologists all working together towards a common goal of improving our understanding of learning. A variety of empirical approaches to research, including quantitative, qualitative and design-based methods in real-world settings are utilized in the Learning Sciences. According to ISLS (n.d.), Learning Sciences approaches are broad in scope and they include learning modeling, designing, predicting, argumentation, collaborating, apprenticing, teaching, thinking and reflection.

Walsh (2011) views Learning Sciences as a "trend" that "embraces the advances being made in the cognitive sciences and the study of consciousness. It resides in the fast-moving world of changing information technology and social media. It recognizes and builds upon new pedagogies and evolving theories of multiple ways of knowing and learning. It encompasses but transcends the evolution of new and better measures of student learning outcomes" (para. 2). Research and development of innovative computer technology environments are major activities of the Learning Sciences community that fit very well into STEM education.

Over the past several decades, information and computer technologies have been gaining prominence in STEM teaching and learning environments. Calls for interactive technology-based approaches to designing STEM instruction in real-world contexts have come from educators, scientists, business communities, and the President's Council of Advisors on Science and Technology (2010). In thinking about designing interactive technology-supported PBL platforms in STEM disciplines from a Learning Sciences perspective it is worth taking into consideration "What kinds of topics do ISLS members study"? (ISLS, n.d.). The Learning Sciences perspective is important because it provides a scientific base and rigorous research to STEM education and applications in problem based learning with interactive technologies.

The following selection of topics adapted for the purpose of this paper comes from the "What kinds of topics do ISLS members study"? (ISLS, n.d.). According to ISLS, the list of fifteen "prototypical" topics and research questions presented from a broad spectrum of topics is only a sample. Therefore, a note should be made that the seven topics selected are further limited to the scope of this paper dealing with multimedia supported PBL in STEM. The following topics selected and adapted from "What kinds of topics do ISLS members study"? (ISLS, n.d.) may be operationally defined as the Selected Learning Sciences Interest Areas (SLSIA).

1. Guiding inquiry learning in STEM disciplines with technology.
2. Using visually interactive data to facilitate learning in STEM and other disciplines.
3. Creating and applying computational models for integrating physical and social worlds.
4. Teaching for flexible and adaptive understanding towards life skills development.
5. Mediating collaborative learning with technology.
6. Creating teaching and learning environments that support the needs of learners of diverse backgrounds.
7. Designing and evaluating intelligent tutors for STEM.

A brief discussion of the SLSIA items follows. *Guiding inquiry learning in STEM disciplines with technology* involves using technology supported learning environments designed with theoretically grounded pedagogical strategies such as the "STAR Legacy [learning] Cycle" and "Constructing Physics Understanding (CPU)" learning cycle to guide inquiry learning in science, mathematics and related disciplines have shown to promote inquiry learning in science (Schwartz, Brophy, Lin, & Bransford, 1999; Kumar, Thomas, Morris, Tobias, Baker, & Jermanovich, 2011). For example, the Legacy Cycle is developed promote learning by inquiry and it has been successfully used to promote problem based learning in STEM. See Schwartz, Brophy, Lin, and Bransford (1999). In *Using visually interactive data to facilitate learning in STEM and other disciplines*, the visually interactive data may come in many forms, including audio and video formats. For example, the "Jasper" videos developed and tested clearly showed that videos created with an embedded data design tend to help students in problem based learning situations in mathematics (Cognition and Technology Group at Vanderbilt, 1999).

Creating and applying computational models for integrating physical and social worlds demand the use of pedagogical strategies involving computational modeling suitable for helping students see the connection between their social environment and physical environment. For example, students could be asked to graph daily low and high temperatures over a period of one week while reading through Laura Ingalls Wilder's storybooks dealing with winter, and make connections between their social world of surviving the cold temperatures inside their classrooms or homes and the realities of the cold winter outside (Kumar & Voldrich, 1994). Nowadays it is even possible to use temperature probes connected to a laptop to do the recording and graphing, and students can make weather predictions using appropriate software. *Teaching for flexible and* *adaptive understanding towards life skills development* could be achieved through designing a "flexible and adaptive" learning environment that involves problem-solving rooted in real-world decisions. For example, students could be challenged to make an informed consumer choice between a regular sunscreen and a sunscreen containing nano particles in a problem-based learning task implemented through a learning cycle such as the STAR Legacy Learning Cycle which incorporates a "flexible and adaptive" design (Kumar, 2015b; Schwartz et al, 1999).

In the case of *Mediating collaborative learning with technology* it is understood that the technology based learning environment be developed in such a way that students are encouraged to collaborate in mathematics learning through problem solving, as evident in the Jasper Series developed and tested by the Cognition and Technology Group at Vanderbilt (1999). *Creating teaching and learning environments that support the needs of learners of diverse backgrounds* involves careful planning for accommodating diverse learner needs in the architecture of the technology-supported STEM learning environment itself. Often the computer platform of the technology itself is a blessing in disguise, providing more individual learner control over the learning situation, one of the features needed for accommodating slow learners. The SLSIA item *Designing and evaluating intelligent tutors for STEM*, useful in terms of evaluating and adaptively providing feedback to students in real time, has been found to benefit students in problem solving (See Obradovich, Smith, Guerlain, Rudman, & Smith, 2000 for an example with details).

Transforming the Selected Learning Sciences Interest Areas (SLSIA) into Action Items

In order to apply the SLSIA to analyze interactive technology-supported PBL in STEM, it is necessary that the SLSIA form a part of the design architecture of the technology-supported learning environment. Designing interactive technology-supported PBL environments in STEM reflecting the SLSIA will require a move away from traditional teaching and learning practices, and a move towards approaches such as problem-based learning. It should be noted that the feasibility of using the SLSIA as a reflective tool for analyzing STEM educational environments was explored by applying an adapted list of five Learning Sciences interest areas to the problem-based learning with nanotechnology project (Kumar, 2015a). It was found that the Learning Sciences interest areas are potentially useful for gaining a Learning Sciences perspective of multimedia-supported environments in STEM education.

Why Problem Based Learning (PBL)? In PBL, students learn by engaging in problem-solving activities related to real-world contexts (Barrows, 1996; Hur & Kim, 2007; Kumar, 2010). PBL creates self-directed learning, and the teacher's role is that of a facilitator. According to Schmidt (1993), the foundations of PBL are as follows: it enables the activation of prior knowledge that is vital to the processing of new information; as students engage in discussing a case, they are able to make multiple cognitive associations between new and old concepts; and learning takes place in a context similar to real-world situations that help the learner receive cues in accessing prior knowledge. According to the Cognition and Technology Group at Vanderbilt (1999), the role of interactive multimedia technologies for creating real-world situations in PBL should not be underestimated.

Why Interactive Technology? Pea (2000) in his introduction to *The Jossey-Bass Reader on Technology and Learning*, makes a compelling case for why interactive technology does matter for learning designs. "We may distinguish two senses in which technology and leaning are intertwined. The first is thinking with technology, the second is thinking about technology. The second twist of phrase is crucial for technological literacy and technical education and is the topic of recent standards for student learning. But thinking with technology is far more important historically and substantively, for it is in this sense that interactive technology is an instrument of knowing, reason, culture, and humanity itself" (p. xv). Above all the "T" (technology) in STEM is a powerful integrator capable of bringing the component disciplines (science, engineering and mathematics) together for enhanced teaching and learning opportunities (Kumar, 2015a). For example, as Hatch and Brenner (2011) pointed out often "in the U.S. education [system], the "E" in STEM (science, technology, engineering, and math) has been virtually silent" (p. 291). It could be argued that such issues of inadequate integration in designing learning environments be resolved by proper use of interactive technology to integrate the STEM disciplines.

As discussed earlier, one of the most practical ways to promote thinking with interactive technology is rooted in problem solving with technology. Incorporating problem solving in the design of learning environments is critical. According to the Board on Science Education of the National Research Council in the United States, "At the root of all science investigations are complex and compelling problems. In order for problems to be effective for supporting learning, they must be meaningful both from the standpoint of the discipline and from the standpoint of the learner… Students may relate more easily to the curious phenomena they observe in their daily lives, such as what causes an empty juice box to crunch up when you suck continuously through a straw" (Michaels, Shouse, & Schweingruber, 2008, p. 127-128). The authenticity of the learning context is one of the crucial supporting environments for meaningful learning. Often multimedia interactive technology (e.g., video anchors) is used to create authentic contexts in PBL in STEM. Interactive technologies representing authentic learning situations have been developed (e.g., River of Life by Sherwood, 2002; Jasper Series by Cognition and Technology Group at Vanderbilt, 1999) and applied in problem-based learning (Sherwood, 2002; Kumar & Sherwood, 2007). By carefully centering on a problem-based situation, computer systems could be designed to incorporate task-specific, well-defined problem-solving activities in a broader instructional context. The context might contain data and clues to raise societal and economic issues for consideration and discussion in classrooms. Further discussion involves a study of the River of Life project as a case study applying the SLSIA.

Analysis Using SLSIA

Selection of the project River of Life (Sherwood, 2002) for the analysis was based on first-hand information of the project, availability of the software (CD), the availability of published outcome studies (Sherwood, 2002; Kumar & Sherwood, 2007), and the availability of background information. This project has employed problem-based learning in STEM in a real-world context with interactive technologies, and received support from the National Science Foundation and the U.S. National Park Services.

The River of Life (Sherwood, 2002) is an interactive instructional video developed using the STAR Legacy Cycle (Sherwood, 2000; Schwartz et al, 1999). According the Sherwood (2002), the River of Life involves the "Legacy League," "a group of twenty-somethings who have taken on the mission of trying to assist students to develop better attitudes toward learning and to provide them with strategies that might be helpful for the student to use as they tackle problems. The characters are designed to be meaningful to students in the middle grades, and are presented through stop animation with voice over" (p. 151). In the Rive of Life, students take an electronic field trip to analyze a local river ecosystem. The analysis of the river system involves tests for pH, ammonia levels, dissolved oxygen, and macroinvertebrates sampling, based on the Izaac Walton method. (In an online component of the project, using the Internet, data is transmitted to participating classrooms for problem-solving activities and small group discussions.) As Sherwood (2002) pointed out "it would be ideal if students learning to monitor the quality of rivers had easy access to rivers and could learn about them in that context. Often this is not possible. In many areas, schools have to hire a bus for [the] trip and can afford to go to the river only once a year. The realities of schooling would indicate a need to simulate such environments" (p. 148).

The STAR Legacy Cycle used in the River of Life is a "flexibly adaptive" software platform which enables classroom teachers to design pedagogically appropriate science instructional strategies by taking advantage of the flexible nature of anchored instruction to encourage students to solve real-world problems and develop better attitudes toward learning (Sherwood, 2000, 2002; Schwartz et al, 1999). The STAR Legacy Cycle is composed of six steps; a context-based ''Challenge,'' a sequence of instructions to stimulate students to ''Generate Ideas'' (thoughts), and then to listen and view ''Multiple Perspectives and Resources'' of commentaries on their challenge and the underlying principles. This step is followed by ''Research and Revise'' data-collection activities to address the challenge, ''Test Your Mettle'' formative feedback with (assessment), and finally ''Wrap Up'' or ''Going Public'' sharing solutions to problems with others. The simulations represent analyses such as calculating the water quality index based on the number of macro-invertebrates present in water samples as part of the instructional strategies in the problem-solving process. The simulation design also contains videos of students visiting their local water district office to meet the staff engineers and scientists for clarification. Middle school students who participated in this project have shown significant ($p<0.05$) gains in pre- to immediate post-tests, and a delayed post-test in conceptual understanding in areas such as dissolved oxygen and macroinvertebrates, and near transfer tasks to predict outcomes using concepts (Sherwood, 2002). Improved understanding of the importance of macroinvertebrates and dissolved oxygen was attributed to these gains noted among students participating in this project.

Significant ($p<0.05$) pre- to post-test and delayed post-test gains were noticed in the conceptual understanding of students in an elementary and middle school science methods course who used the STAR Legacy Cycle-based River of Life (Kumar & Sherwood, 2007). (This study was part of a project directed by Kumar (2006) with support from the South Florida Caribbean Ecosystem Studies Unit, the National Park Services.) The test (Sherwood, 2002) contained multiple choice and written responses questions dealing with macroinvertebrates, classes of organisms that form a river ecosystem, dissolved oxygen, composition of air and graph reading skills.

The delayed post-test (Vye, Schwartz, Bransford, Barron, Zech, & CTGV, 1998) contained items to measure understanding of basic concepts such as water quality and dissolved oxygen, and near transfer eliciting prospective teachers, for example, to use the process of predicting an outcome rather than recalling an answer. The significant gains in conceptual understanding noticed were in the areas of composition of air, macroinvertebrates, dissolved oxygen, classes of organisms that form a river ecosystem, and graph reading skills. Students were able to successfully complete near transfer problems involving more than one concept. Students were also able to transfer knowledge acquired from the River of Life to plan stand-alone science lessons.

Sample lesson plan topics included Water may appear clean, but still be polluted, Macroinvertebrates are classified into three groups for water quality testing (pollution tolerant, somewhat tolerant and pollution intolerant), pH levels are an indication of water quality, and Water quality must be maintained to sustain all living organisms. The lesson plan behavioral objectives dealt with Identifying Different Types of Macroinvertebrates, Determining the Water Quality of a Sample through Chemical Means (Test Kits), and Calculating Water Quality Using the Isaac Walton Method and Water Quality Index. About 55-70% of the lesson plans complied with the National Science Education Standards (National Research Council, 1996) content standards A (Science as Inquiry), C (Life Science), and F (Science in Personal and Societal Perspectives). About 20-35% of the lesson plans complied with Content Standards E (Science and Technology), B (Physical Science), and G (History and Nature of Science). In an earlier study among fifth grade students, Sherwood (2002) reported a pre-test to post-test gain in their understanding of the significance of macro-invertebrates and dissolved oxygen in water quality measurements. Using the SLSIA design components of the project River of Life were analyzed. The respective STEM components were also identified.

Results

Using the seven item in the Selected Learning Sciences Interest Areas (SLSIA) discussed earlier as a rubric, the PBL STEM project River of Life was analyzed. Table 1 presents a summary of the analysis results.

Guiding Inquiry Learning in STEM Disciplines with Technology

The analysis of the River of Life project using SLSIA showed the utilization of the STAR Legacy Cycle to facilitate guided inquiry through PBL. Students are challenged to make informed decisions on the quality of the river ecosystem. As an example, students were challenged to research and collect more to arrive at an informed decision concerning the relationship between macroinvertebrates and water quality. Students conducted investigations applying the Isaac Walton method by using a computer-based simulation where they classified each macroinvertebrate (e.g., Caddish fly Larva) into pollution tolerant, somewhat pollution tolerant and pollution intolerant. They followed the six step version of the STAR Legacy Cycle in their problem-based learning task. The STEM components involved various aspects of science (e.g., water pollution, pH), technology (e.g., simulation) and mathematics (e.g., counting).

Using Interactively Visible Data to Facilitate Learning in STEM and Other Disciplines

The availability of resources for students to generate and analyze data using the Isaac Walton method was clearly evident. Students generated graphs which included Location vs. Dissolved Oxygen, Location vs. Ammonia, Location vs. pH level, and Location vs. Temperature. Science, technology and mathematics components of STEM were clearly evident.

Creating and Applying Computational Models for Integrating Physical and Social Worlds

The simulation also provided students the ability to plot data by location of the river ecosystem they analyzed in order that they could research science related societal issues as well as the pollution level at particular locations. Relating science to societal issues, one of the goals of science education, is clearly articulated in the “Project Synthesis” and is also a goal in STEM education.

Teaching for Flexible and Adaptive Understanding towards Life Skills Development

The STAR Legacy Cycle used in the River of Life PBL simulation has provided a "flexibly adaptive design" as one of its instructional design features. A flexibly adaptive design would accommodate "methods used by teachers and learners that are constrained enough to be consistent with important principles of learning and instruction, but that are also flexible enough for teachers to be creative in tailoring instruction to their own strengths and learners' and communities' needs" (Schwartz et al, 1999, p. 185). For example, students planning a visit to their local water district office to meet the scientists/engineers to share their findings and to discuss water quality issues affecting their community is an example of the design flexibility for teachers in implementing the project in their STEM classes. In some instances, a physical visit to the water district office may not be possible and instead a videoconference may be the only option. All four components of STEM were evident.

Table 1. Summary of analysis using the selected learning sciences interest areas

Selected Learning Sciences Interest Areas*	Corresponding Design Components of the River of Life**	Corresponding STEM Components
(1) Guiding inquiry learning in STEM disciplines with technology	Problem-based learning, multimedia learning context of river ecosystem and pollution	S, T, M
(2) Using visually interactive data to facilitate learning in STEM and other disciplines	Graphs, data tables for water quality measures and macroinvertebrate identification, calculating water quality index	S, T, M
(3) Creating and applying computational models for integrating physical and social worlds	Connecting pollution tolerant, somewhat tolerant and pollution intolerant macroinvertebrates to water quality and possible sources of pollution (e.g., factories), and societal issues (e.g., lead contamination and public health)	Relating science to societal issues – one of the Goals of STEM education***
(4) Teaching for flexible and adaptive understanding towards life skills development	Problem solving, data-based decision making, critical thinking, understanding river ecosystem and pollution, planning a visit to water district to meet the staff (engineers and scientists) for clarification	S, T, E, M
(5) Mediating collaborative learning with interactive technology	Group work in problem solving, planning to contact local water district staff (engineers and scientists) for clarification	S, T, E, M
(6) Creating teaching and learning environments that support the needs of learners of diverse backgrounds	Helping reluctant learners to aim higher, Challenging and helping students with "just do enough to get by" attitude to achieve better	Personal development of the learner, Relating science to societal issues - Goals of STEM education***
(7) Designing and evaluating intelligent tutors for STEM	NA	NA

NOTE: *ISLS (n.d.); **Sherwood (2002), Kumar & Sherwood (2007); ***Originated from the "Project Synthesis" (Harms, 1980)

Mediating Collaborative Learning with Interactive Technology

Students engaged in collaborative learning in the various steps of the PBL activity incorporating the STAR Legacy Cycle. For example they discussed their predictions and arrived at conclusions involving pH, dissolved oxygen, temperature, and location of the rive ecosystem. Discussions included questions such as which site has the lowest water quality index, and which site has the highest water quality index. Based on the previous year's graphs for sites A and B, what is the trend you see for site A and site B? Collaborative efforts also included problem solving and planning in order to contact local water district staff scientists/engineers for clarification and discussion.

Creating Teaching and Learning Environments that Support the Needs of Learners of Diverse Backgrounds

The PBL STEM project activities created an inclusive environment encouraging reluctant students to aim higher by actively engaging in solving the water quality problems posed by the challenge. The available simulation and resources as well as the student-centered environment helped keep students on task with minimum involvement of the classroom teacher. Students were driven away from the “just do enough to get by” attitude and driven towards achieving better and higher by basing their problem solutions and conclusions on data. Some of the goals of STEM education reform, such as personal development of the learner and relating science to societal issues were clearly evident. However, it should be noted that there was no clear evidence of adaptations for students with any particular disabilities and nor for English language learners.

Designing and Evaluating Intelligent Tutors for STEM

The River of Life simulation did not include intelligent tutors. However, it should be noted that the simulation is potentially adaptable for intelligent tutors. The River of Life project reflected the SLSIA in six out of the seven items. The item “Designing and evaluating intelligent tutors for STEM” was absent. No adaptations for students with any particular disabilities and English language learners were evident. In terms of STEM components (S, T, E, M), out of the six SLSIA items present in the River of Life, four reflected science, technology, and engineering. Mathematics and engineering were missing in two items.

Discussion

The analysis reported here is a pilot in nature and the results should not be generalized. The project River of Life was chosen as a sample case study to practice SLSIA, and therefore the study outcomes should not be construed as an evaluation of the quality of the project. Instead it should be used as a stepping-stone towards conducting more detailed studies to comprehend the place of Learning Sciences in interactive technology-supported PBL in STEM. The inter rater reliability score for the Corresponding Design Components of the River of Live was 87% and for the Corresponding STEM Components 71% respectively. Careful division of SLSIA items into finer items may increase resolution. The SLSIA items were taken on face validity, so additional research is needed to establish their validity. It should be noted that the analysis presented in this paper is an exercise for reflection in designing interactive instructional technology supported PBL in STEM projects.

The SLSIA provides a general framework for reflective analysis of interactive technology-supported PBL projects in STEM. The project analyzed incorporated most of the SLSIA items common to strong interactive technology supported PBL projects in STEM. On the other hand, the absence of “intelligent tutors” might be a reflection of the time period (1990s) the software was developed, when emphasis on integrating intelligent systems in teaching and learning in STEM was minimal and STEM as a field of inquiry was just taking off. Special needs adaptations were not available. No particular special needs adaptations were evident. Most design components reflected in all four for STEM components. In designing interactive instructional environments it may not be always possible to be fully inclusive of all disciplines represented in STEM in sufficient depth due to pedagogical limitations, and curricular and policy implications.

Summary Remarks

This analysis is aimed at initiating discussion on the application of the Selected Learning Sciences Interest Areas in understanding and designing interactive technology supported PBL in STEM. The analysis presented in this paper using the SLSIA provides the stakeholders of STEM education with a reflective framework in terms of developing design strategies for shaping the future of interactive technology-supported environments suitable for designing meaningful PBL experiences in STEM areas, and contributing towards reforming STEM education.

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