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Defining Innovation Literacy: Do Robotics Programs Help Students Develop Innovation Literacy Skills?

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ABSTRACT

There has been an invalidated belief among educators that the robotics activities would improve the innovation capacities of students. The current study addressed the need to conceptualize the innovation literacy idea while the specific purpose of the study was to determine the effectiveness of a robotics program designed for improving the innovation literacy skills of economically disadvantaged students from underrepresented groups. Participants of the study were 11th grade students from an inner city charter school in Texas (N = 31; 15 female, 23 African American, and 8 Hispanic). In this quantitative study, the paired sample t-test showed statistically significant improvement in science literacy skills of Hispanic students and mathematics and science literacy skills of African American students. The findings implied that more controlled learning environments for students from underrepresented groups would be beneficial.

Keywords:
Innovation literacy, robotics, inner city students, integrated curriculum.

Introduction

American political leadership has initiated strategies to foster Science, Technology, Engineering, and Mathematics (STEM) education. The U.S. administrations' Strategy for American Innovation (SAI) has emphasized the importance of graduating every student from high school ready for college and a career in STEM fields (National Economic Council, Council of Economic Advisers, & Office of Science and Technology Policy, 2011). The first goal of SAI was to ensure readiness for college and a career in STEM fields, which could not be achieved without increasing the capacity of students' abilities to apply knowledge and skills to analyze, reason, and communicate effectively (Conley, 2007; Organisation for Economic Cooperation and Development [OECD], 2009). The second goal of SAI was to reach every student, which was contingent on the ability of STEM teachers to capture the minds and inspire the souls of students, including underrepresented groups through technology-rich educational programs (U.S. Department of Education, 2010). American political leadership's vision to ease the access to STEM education has required the success of two major goals.

STEM education considers the unique characteristics of individual STEM disciplines and includes the set of knowledge, skills, and beliefs, which are constructed at the intersection of more than one STEM discipline (Corlu, 2012). STEM education aims "to expand the STEM-capable workforce, and to increase scientific literacy" (National Research Council, 2011, p. 4). STEM education provides students with myriad interdisciplinary opportunities of developing a capacity to innovate (International Technology Education Association [ITEA], 1999).

The purpose of this study was to describe an innovative educational practice that incorporated robotics for STEM education and to determine its effectiveness for improving the innovation literacy skills of

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economically disadvantaged students from underrepresented groups. Specifically, the researchers of this study investigated the relationships of gender, ethnicity, and the scores of students on a measure of innovation literacy.

Theoretical Framework

The Construction of Innovation Literacy

Innovation literacy is a relatively new concept emerging from the innovative envisioning of STEM education (Erdogan & Corlu, 2012). To construct the idea of innovation literacy, there is a need to deconstruct both innovation and literacy so that the foundation within STEM learning can be established. Therefore, the operationalized view of both innovation literacy and STEM education need to be unified.

Innovation. Innovation is a technology-related phenomenon with product and process dimensions (OECD, 1997). Product and process in education are concerned with developing learning environments that help students build 21st century skills to become flexible, self-directed, social, productive, and responsible (Gregory & Kuzmich, 2005; MacDonald, 2003; Partnership For 21st Century Skills, 2009). Innovation in education is concerned with the design of learning environments that foster 21st century skills.

Learning environments that foster 21st century skills are not bound by a single academic division. In the age of innovation, the boundaries of academic divisions are overcome through interdisciplinary approaches so that students can experience the big picture from multiple perspectives (Capraro, 2009; Slough & Milam, 2009). An interdisciplinary understanding of the academic subjects offer multiple methods to analyze, reason and communicate as students pose, solve, and interpret problems in a variety of novel situations (Snyder, 2002). However, an innovative activity cannot occur without the support of subject-matter knowledge. Therefore, the isolated subject-matter knowledge must evolve to include the coordination of various inventive, learning, and implementation skills (Rogers, 1998).

To incorporate innovation in teaching and learning, new pedagogies are needed. New pedagogies are associated with interdisciplinary learning environments that enhance students’ cognitive and social development (Dillenbourg, Jarvela, & Fischer, 2009). These new pedagogies are not only based on the acquisition of knowledge, but also allow students to develop social relationships in order to engage in a shared practice and transform their individual identities in a community (Wenger, 1998). The new pedagogies encourage students to develop their own understanding about innovation and take the ownership of their learning.

Literacy. The idea of literacy extends beyond the common idea within reading; however, the basic tenants remain constant across disciplines. According to the OECD, reading literacy is students’ understanding of and use of written texts or graphs; mathematics literacy is their ability to make well-founded judgments; and scientific literacy is their ability to inquire about phenomenon using multiple methods in a scientific way (OECD, 2009). Thus, students’ capacities in reading, mathematics, and science (RMS) literacy altogether refer to the cognitive process dimension (Mayer, 1992) and can be good indicators of students' innovation literacy levels. Definitions of literacy in RMS are directly related to the innovation literacy idea.

Literacy in RMS has been challenging for the United States. The OECD’s international comparison study, Programme for International Student Assessment (PISA), measured American students’ literacy levels in RMS. According to PISA results, the U.S. ranked at or below the average of other developed countries (U.S. Department of Education, 2010). The mediocre level of American students’ scores on PISA’s RMS literacy levels were not surprising, given research that showed that instruction in public schools was driven by standardized tests, which promoted teaching rote learning over the literacy skills measured by PISA (Haladyna, Nolen, & Haas, 1991; Sklar & Eguchi, 2004). Instructions in US public schools needed to focus on RMS skills, which were among the 12 core subjects in the P21 framework (P21, 2009).

Innovation literacy. Innovation literacy is a combination of the innovative paradigm and strategically paired literacy component in RMS. Reading and mathematics literacy share important fundamental components of comprehension, inference, and fluency (Capraro, Capraro, & Rupley, 2011). The importance of science to innovation literacy includes scientific process and its use as a framework through which students demonstrate innovation literacy. The social product (Filer, 2000) is the other dimension of the innovation literacy model, which emphasizes the collaborative effort to produce a high-quality and original product. Thus, researchers define innovation literacy as the capacity of an individual to understand and use written text and/or graphs to make well-founded judgments and scientific inferences about processes and procedures with the goal of collaboratively constructing a new original product. A synthesis of prior research and current policy on innovation, STEM education, and OECD's RMS literacy definitions culminated the representation of the innovation literacy construct (See Figure 1).

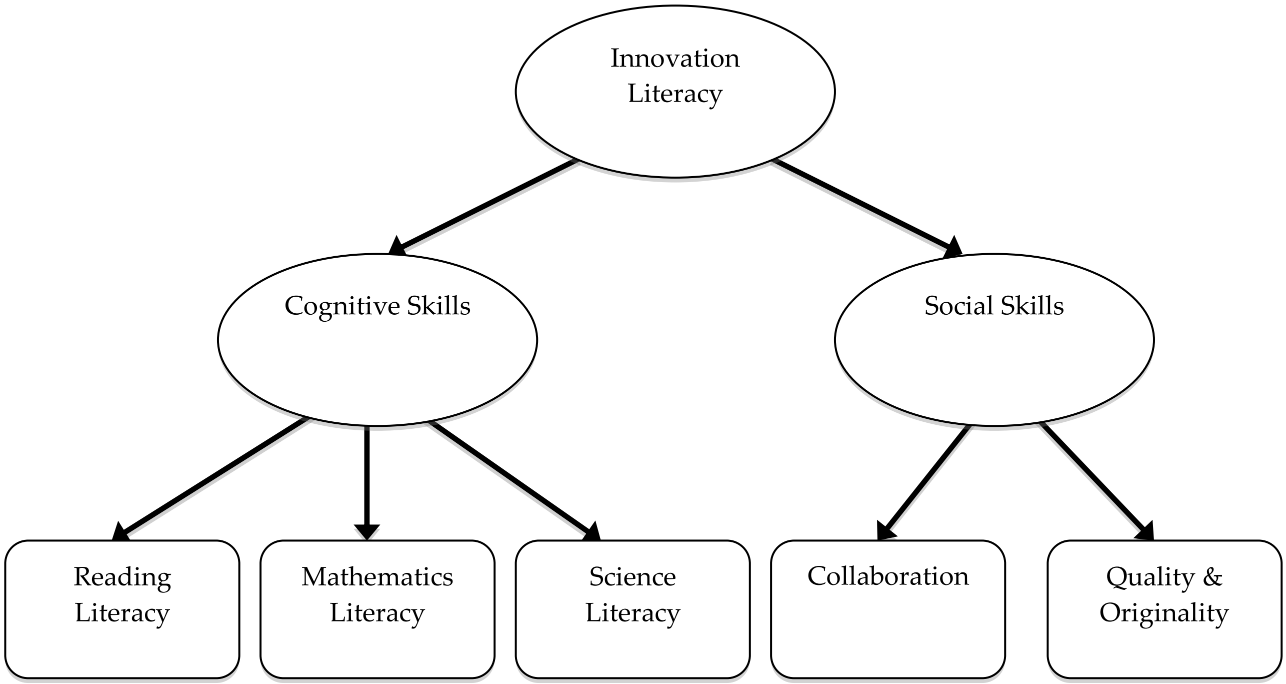

Figure 1. Conceptual model of innovation literacy.

Robotics as Tools of Innovative Education

Innovation-based practices have been utilizing robots for a long time, enhancing the capacity of the production and efficiency of the process in the industrial systems (Edquist, Hommen, & McKelvey, 2001). Robotics systems used in industry were too complex to attract and pass on to students (Lau, Tan, Erwin, & Petrovic, 1999) until a dynamic and physical system with real-time control was developed in 1998, in contrast to previous artificial intelligence systems, such as computer chess (Lund & Pagliarini, 1998). Since then, robotics systems have attracted the attention of educators, some of whom adopted (while some others questioned) the naïve perspective that students learned something worthwhile during their interaction with technology (Sklar, Eguchi, & Johnson, 2003). Robotics systems were initially designed for industry; however, have been quickly adapted by educators despite the lack of research supporting their effectiveness.

Research on robotics-based learning environments was mostly composed of anecdotal conclusions derived from extracurricular activities. Most of these activities were implemented with high ability (i.e., academically selected or gifted students) and possibly already highly motivated students, given that students volunteer for such activities (Silk & Schunn, 2008). Researchers have claimed that robotics systems would help students assimilate concepts that would otherwise be abstract and obscure (Miglino, Lund, & Cardaci. 1999). However, there was little empirical research supporting these claims in terms of learning outcomes (Johnson, 2003). In a study of the robotics competitions, researchers found that the percentage of mentors who evaluated the change in their students' learning as positive was 85% for physics and 80% for mathematics (Sklar, Eguchi, & Johnson, 2003). Other studies showed that robotics systems were effective tools for boosting student and teacher motivation, initially only for boys (Bergen, 2001), in developing social and teamwork skills, encouraging creativity and developing literacy (Johnson, 2003). Though some findings indicated that robotics systems were ineffective for increasing students' attitudes towards learning school subjects (Verner, 1997, 1998). In addition to the motivational benefits, the common theme extracted from educational research literature on robotics was that the researchers agreed on their potential to provide a medium for holistic and interdisciplinary learning, once robotics were successfully integrated into the school curricula with explicit emphasis on core subjects (Johnson, 2003; McRobbie, Norton, & Ginns, 2003; Silk & Schunn, 2008).

Method

In this experimental research, only intervention group was used. Students in the intervention group took the pre-test and post-test that were prepared by researchers. At the end of the intervention, students' products and collaboration were measured with pre-developed rubrics.

Participants

Participants (N = 31; 15 female, 23 African American, 8 Hispanic) were 11th grade students from an inner city charter school in Texas, who participated in robotics summer camp in 2011. The school administrators determined the participants by dividing the entire school population into three strands: A, B, and C groups, determined according to students' scores in Pre-Scholastic Assessment Test (PSAT) 2010 scores. The sample consisted of the students in group B: $PSAT_{mathematics}$ (Mean = 41; SD = 8) and $PSAT_{reading}$ (Mean = 40; SD = 9). The average PSAT scores of the group B participants were below the national average PSAT scores ($Mean_{mathematics}$ = 49; $Mean_{reading}$ = 47, SDs were not reported) (CollegeBoard, 2011). Demographically, two-thirds of the participants were African-American, while the rest were Hispanic. Seventy-five percent of the students in the school were eligible for subsidized lunch, less than 3% had limited English, and around half were reported as at-risk.

Intervention

A two-week long program based on robotics activities was designed and conducted during a summer camp organized by a STEM center at a Research 1 university. Throughout the summer camp, students were engaged in activities that fostered reading, mathematics, and science literacy by utilizing robotics. Expert teachers or professors at the university facilitated the activities. The activities were planned to include approximately twenty-four contact hours of in-class time and over 10 hours of independent study (research, assignments, journal writing, etc.) and exploration time (students worked on their designs on computers). The objective of the investigation unit was to develop a unique robotics model that would conduct a series of science experiments (an analysis of given unknown substances). Students had access to LEGO Mindstorms NXT 2.0®, graphing calculators with data collection capability, and a variety of sensors (e.g., pH, temperature, light, etc.). They were given a modest budget to purchase any other necessary material they would need (glue, glue gun, cardboards, markers, etc.)

Each group, composed of four or five students, built a unique robot that would explore the surface of the planet Mars. Based on their readings of several scientific journal articles and short science fiction stories, in addition to their previous knowledge, imagination and creativity, students had to complete: (1) artistic tasks and (2) consequential tasks. In artistic tasks, students worked collaboratively to design the features that could be on the planet Mars (in addition to geographical bodies, such as mountains and craters, students designed the physical models of colonies that would be populated by humans and a major science laboratory). In consequential tasks, student-designed robots had to locate and move the substances (several rock pieces and liquids) to the test center, where the science laboratory was located. At the laboratory, student-scientists were supposed to develop procedures by using robots to test whether the liquids were drinkable or not, while their robots needed to collect evidence on the type of rock pieces, whether they were igneous or sedimentary. All tasks and the final product were assessed with analytical rubrics.

Data Collection

Two versions of fifteen open-ended questions were written to assess students' RMS literacy through three different rubrics, which were designed in alignment with the PISA framework. Researchers contacted three experienced RMS teachers who were given an initial training on PISA framework, OECD's RMS literacy definitions, and how the released items were assessed by PISA. RMS teachers evaluated the assessment tasks for face and content validities and parallelism between two versions of the test. Two other rubrics were developed, which were used by the students for peer-review to assess the quality and originality of their projects and the individual contributions of group members.

The variables of interest were: *gender* (female = 0, male = 1), *ethnicity* (African American = 0, Hispanic = 1), *collaboration* (collaboration scores of individuals) (range = 0-15), *product* (quality and originality scores of products) (range = 0-15), *preM* (pre-test mathematics scores) and *postM* (post-test mathematics scores) (range = 0-30), *preS* (pre-test science scores) and *postS* (post-test science scores) (range = 0-30), *preR* (pre-test reading scores) and *postR* (post-test reading scores) (range = 0-30).

Data Analysis

The study employed descriptive statistical methods to draw an outline of innovation literacy skills of the participants. The paired sample *t*-tests were conducted to investigate the statistical differences between the RMS literacy skills before and after the intervention and to test the hypothesis that participants' post-test scores would be higher than their pre-test scores.

Effect sizes were estimated in score-world statistics with Cohen's *d*. A post-hoc power analysis was conducted with G*Power 3 (Faul, Erdfelder, Lang, and Buchner 2007).

Results

Analyses focused on the pre- and post-test scores on students' RMS literacy skills. We conducted all the analyses using SPSS 18. Table 1 summarizes the means and *SD*s of the pre- and post-tests.

Table 1. Descriptive statistics for pre- and post-tests of innovation literacy skills

	PreM		PreR		PreS		PostM		PostR		PostS	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
African American	5.05	5.63	18.13	6.67	6.30	5.59	9.51	7.39	19.52	6.43	16.74	6.46
Hispanic	6.41	6.93	13.13	9.00	4.13	5.41	8.28	6.19	18.75	6.32	14.25	4.89
Female	5.17	5.65	16.73	8.28	5.87	5.59	10.17	8.33	18.20	7.44	16.47	6.55
Male	5.63	6.31	16.94	6.99	5.63	5.67	8.28	5.66	20.38	5.04	15.75	5.88
Total	5.40	5.90	16.84	7.51	5.74	5.54	9.19	7.02	19.32	6.31	16.10	6.12

It was evident that the participants were less capable according to the measures in mathematics and science than they were in reading before the summer camp. The paired sample *t*-test showed that there was no statistically significant difference between mathematics and science literacy scores before the summer camp. However, students were statistically significantly better in reading than science ($p < .01$; Cohen's d = 1.71) and mathematics ($p < .01$; Cohen's d = 1.38). At the end of the summer camp, analysis showed that there was a statistically significant difference between mathematics and science literacy ($p < .05$; Cohen's d = 0.62) and mathematics and reading literacy ($p < .05$; Cohen's d = 1.04), although there was no statistically significant difference between science and reading scores. Results indicated that reading supported science learning. Figure 2 delineates the graphical representation of confidence intervals around the estimated means for the sample.

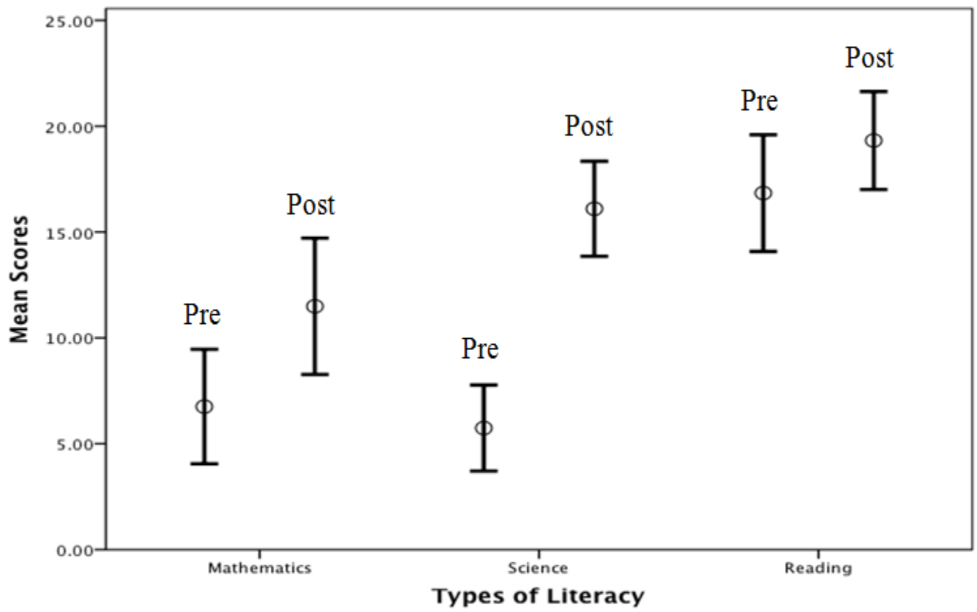

Figure 2. Confidence intervals (95%) for Mathematics, Science, and Reading Scores

Table 2 displays all the correlations between pre- and post-test scores, ethnicity, gender, collaboration scores, and quality and originality scores. Statistically significant correlations between pre and post mathematics (r = .51, p < .01), science (r = .41, p < .05), and reading (r = .65, p < .01) scores showed that people who did well on the pre-test also did well on the post-test. Students, who collaborated effectively, were more likely to have higher scores on the mathematics test at the end of the intervention (r = .44, p < .05). In addition, Hispanic students were more likely to display more original and quality products (r_{bs} = .45, p < .05). The statistically significant correlations between post-test scores of RMS literacy skills ($r_{\text{mathematics and science}}$ = .48, p < .05; $r_{\text{mathematics and reading}}$ = .46, p < .05; $r_{\text{science and reading}}$ = .50, p < .05) were higher than the correlations between pre-test scores ($r_{\text{mathematics and science}}$ = .04, p > .05; $r_{\text{mathematics and reading}}$ = .27, p > .05; $r_{\text{science and reading}}$ = .31, p > .05), indicating that students could recognize the interdisciplinary nature of the cognitive processes after the program.

Table 2. Correlation coefficients in pre- and post- innovation literacy tests and other variables

Variables	Collaboration	Gender	Product	Ethnicity	PreM	PostM	PreS	PostS	PreR	PostR
Collaboration	1	.20	.42*	.26	.32	.54*	.03	.24	.31	.27
Gender		1	.12	.28	.04	-.14	-.02	-.06	.01	.18
Product			1	.36*	.05	.20	-.04	.11	-.26	-.16
Ethnicity				1	.10	-.08	-.18	-.18	-.30	-.05
PreM					1	.59*	.04	.14	.27	.36*
PostM						1	.29	.48*	.42*	.46*
PreS							1	.47*	.31	.19
PostS								1	.53*	.50*
PreR									1	.66*
PostR										1

Note. All correlation coefficients, except those included categorical variables, were Pearson's Product-moment correlation coefficients.

Finally, a paired sample t-test showed statistically significant improvement between pre-post tests based on ethnicity. First, the pre-post difference on science literacy scores was statistically significant for the Hispanic participants: t (7) = 5.70, p < .01, Cohen's d = 2.01. Second, for the African American participants, statistically significant pre-post differences were for mathematics and science literacy scores: $t_{mathematics}$ (22) = 3.25, p < .01, Cohen's d = 0.68; $t_{science}$ (22) = 7.81, p < .01, Cohen's d = 1.63. There was no statistically significant improvement based on gender.

Discussion and Conclusion

The use of robotics was important to learning in both mathematics and science. Science showed the greatest improvement as compared to both reading and mathematics. Mathematics improved as compared to pre-test scores. It is possible that reading was uniformly high across the sample, so given the high reading demand for completion of the activities it is possible that reading facilitated the science gains. That is students relied on their content reading skills to help them make sense of the science and mathematics content. This study showed that, as Miglino, Lund, and Cardaci (1999) claimed, robotics systems helped students assimilate science concepts that were abstract and obscure.

Ethnicity was an important factor. The results indicated that African Americans experienced the most gain across both mathematics and science. They obtained grater gains than the Hispanic students on mathematics. Hispanic students displayed a greater degree of creativity. There were no statistically significant effects based on gender whether comparing students as a whole or within ethnic group. If one considers ethnicity as an important variable, it could likely show that minority students (African American and Hispanic) are very likely to benefit from the contextualized learning of mathematics and science within robotics. However, two important caveats are warranted. First, there was an absence of White or Asian students who may offer competition during learning. There are no studies that show that during integrated instruction with White and Asian students that African Americans and Hispanics do not opt for smaller less involved roles in group learning than do White and Asian Americans. In fact, there is no clear understanding what effect integrated group learning has on African Americans or Hispanics. It is possible that just as females who learned mathematics in single sex classrooms had greater mathematics achievement (Lee, Marks, & Byrd, 1994; Baker & Jacobs, 1999). The findings from this study are a precursor to an important understanding that more controlled learning environments for African American and Hispanic students would be beneficial. In fact, early work shows that perhaps one answer to closing the achievement gap may lie in providing ethnic support structures during mathematics and science instruction (Baker, 2002).

The current study contributes to the knowledge based on innovation through operationally defining the construct of innovation literacy in terms of measurable variables. The study also promotes teaching school subjects with an innovation literacy theme and broadens the participation of underrepresented groups by investigating the factors contributing to their innovation literacy. Studies with larger sample sizes are required to test a causal (i.e., SEM) model of innovation literacy.

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