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Robotics in K-12 Formal and Informal Learning Environments: A Review of Literature

Mr. Nicholas Alexander Bascou, University of Pittsburgh

Graduated from the University of Pittsburgh in 2016 with a B.A. in Anthropology and a B.S. in Biology and Chemistry. Research experience includes the use of robotics in K-12 education at the University of Pittsburgh's Learning Research and Development Center and research into neural pathways involved in the onset and treatment of Schizophrenia at the Anthony Grace Lab at the University of Pittsburgh. Future plans include the pursuit of an M.D. and PhD in biological psychiatry.

Dr. Muhsin Menekse, Purdue University

Muhsin Menekse is an assistant professor at the School of Engineering Education at Purdue University, with a joint appointment at the Department of Curriculum & Instruction. Dr. Menekse's primary research investigates how classroom activities affect conceptual understanding in engineering and science for all students. His second research focus is on verbal interactions that can enhance productive discussions in collaborative learning settings. And his third research focus is on metacognition and its implications for learning. Much of this research focuses on learning processes in classroom settings. Dr. Menekse is the recipient of the 2014 William Elgin Wickenden Award by the American Society for Engineering Education.

Introduction

In the past fifteen years, researchers have taken great initiative in publishing vast quantities of articles that have demonstrated robotics' ability to stimulate enhanced comprehension and interest, namely in fields of science, technology, engineering, and mathematics (STEM) (Hussain et al., 2006; Williams et al., 2007; Nugent, 2010). Although earlier studies generally pondered the question of whether educational robots was a mere fad rather than a truly valuable educational tool, more recent publications have often presupposed their effectiveness, and instead considered strategies for optimizing the possible benefits of educational platforms. But despite the large and rapidly growing body of literature pertaining to robotics' usage in K-12 education, there remains a need to connect the theoretical basis of their usage to how they are functionally implemented in practice.

With that said, the goal of this study was to conduct a review of relevant literature published between 2000 and 2015 in which researchers' main interests were centered on the implementation of robotics in K-12 STEM education. Specifically, in this review, we worked to identify common themes encountered throughout the literature and attempted to systematically classify and describe 119 relevant studies based on how well their theoretical frames and subsequent results exemplified and conformed to each theme. Whereas similar syntheses, such as that performed by Benitti (2012), mainly considered the mundane functionality of robotic platforms (i.e. what subjects/topics were taught; was robotics an instrument or the educational focal point; are robotics truly effective educational tools; etc.), the current review has proffered a more conceptual approach in our attempt to summarize the 119 studies.

In short, the purpose of conducting our review was to: a) organize the studies investigating K-12 robotics implementation under various themes in order to present a fluent and comprehensible picture of the current state of research; b) present a synthesis of empirical evidence suggesting the benefits of introducing robotics-based pedagogies that integrate certain cognitive, social/cultural, or aesthetic elements as means for enhancing learning, interest and motivation; c) define research perspectives that concern educational robotics in order to aid in developing and improving STEM pedagogies and providing potential guidance for future studies.

Data Sources and Research Methods

The Literature Review Process

To begin our review of the relevant literature, we first conducted a search in the research databases—ACM, IEEE Xplore, and ASEE Annual Exposition and Conference Proceedings—exploiting the advanced search option in order to narrow the pool of articles down to only those that contained all of the following keywords: robotics (or robots), education, and K-12. The three databases yielded 229, 14, and 73 studies, respectively, giving a total of 316. Of the initial 316, we were able to eliminate 161 based on a preliminary read through. After scrutinizing the remaining 155 in more detail, we further refined our subset of included articles to a final total of 119. Summaries for these 119 were compiled based on seven features (experimental vs. non-experimental, formal vs. informal, learning data, aspects of programming and what platform, sample properties, goals/purpose, and results/findings). Once the summaries were completed, we identified commonalities in their research methodologies, results, and subsequent findings. Each article was then systematically classified in accordance with the six most prevalent themes encountered throughout the literature. The six themes are 1) substantiating the general benefits of educational robotics, 2) learning by design and knowledge transfer, 3) social/cultural based motivation, 4) creativity based motivation, 5) increasing diversity in STEM, and 6) professional, curricular, and pedagogical development. Articles containing characteristics of multiple themes were, however, not uncommon. In such cases, the theme that appeared most prominently was chosen as means for classification. After assigning each article to a theme, we selected representative studies for each theme and proceeded to summarize and discuss the selected studies under their corresponding headings. Table 1 depicts the number of studies categorized under each of the six themes, and appendix A provides the complete list of the 119 included studies and places the citation for each article underneath the proper thematic heading.

Table 1

Thematic Classification Distribution

Theme	Number of Articles
General benefits of educational robotics	17
Learning by design and knowledge transfer	24
Social/cultural based motivation	20
Creativity based motivation	13
Increasing diversity in STEM	17
Professional, curricular and pedagogical development	28
Total	119

Exclusion principles. Of the 316 articles uncovered in our search, we abstained from including 197 studies for various reasons. Although the specific conditions for the exclusion of each study were not entirely congruent, it was feasible to develop a generalized mode of categorization based on discrepancies/issues in the following areas: sample properties, primary versus secondary/tertiary sources, publication date/abstract only/repetition, and format. Note that although secondary sources were excluded because they did not present case studies, such studies were sometimes useful in uncovering nuances and contributed to developing a fuller understanding of the current state of research. Concepts and ideas from these informative studies can be found throughout the discussion and are cited in the reference list.

Certain trends emerged in the excluded articles. For example, articles that were excluded because of their relevance often involved engineering or computing but were not focused on education. In addition, others that were excluded based on relevance used educational robots but with the intention of facilitating language acquisition or improving education for individuals with disabilities and thus were unrelated to STEM. Articles that did not present case studies were most often syntheses that compared and contrasted work of multiple researchers, attempted to extrapolate findings from primary studies in order to develop theories of their own, or described

Table 2

Criteria for exclusion of articles

Exclusion Principle	Description	Number of Excluded Articles
Sample Properties	Articles in this category did not contain the desired age group (i.e. undergraduates, professionals, or any other cohort not at the K-12 level), have N < 10, or failed to disclose essential information regarding the participants.	49
Secondary or Tertiary Source	Articles in this category did not present a primary study. Most were syntheses that compared and contrasted work of various researchers or attempted to extrapolate findings from primary studies in order to develop theories of their own.	51
Format	Articles in this category did not exhibit the desired format. Most of them were expert interviews, editor's notes, or summaries of a person's work or theory.	45
Relevance	Articles in this category showed no direct relevance. They often involved innovations in computing or robotic engineering but failed to address education.	26
Publication Date/ Abstract only/ Repetition	Articles in this category were published prior to 2000, only made available the abstract in the database, or were repetitions of other articles seen previously.	26
Total		197

the history of a particular educational platform (i.e. LEGO, Alice, etc). Repeated articles generally occurred when the study was first presented at a conference and later accepted to a journal. Although minor differences in the manuscripts were occasionally present, changes were insignificant and abstracts, goals, and conclusions were always analogous (look to Nugent et al. 2009 and Nugent et al. 2010 for an example). Detailed descriptions for each exclusion principle can be found in table 2.

Inclusion principles. The properties of a study meeting the criteria for inclusion were essentially derived from the same logic used in developing the exclusion principles: From the most basic perspective, the study must have pertained to STEM education, along with having involved a cohort of K-12 students or teachers. Studies should have also presented a case study of a program or experiment that referenced robotics or similar technologies in some fashion. Robots were either virtual or physical in form and could have implemented as a tool for education or as the curricular focal point.

Additionally, the studies must have presented a sample size of no less than 10 participants. Because of the greater statistical validity characteristic of studies that utilized larger samples sizes, slightly more emphasis was placed on studies with more than 20 participants. In regards to data retrieval and evaluation methods: authors must have referenced quantitative data, questionnaires, surveys, interviews or direct observations when drawing conclusions and presenting their findings

As one last inclusion principle, prior to 2000, the use of educational robots was construed as somewhat ‘ground-breaking,’ and due to insufficient former research, studies conducted prior to this date often lacked well-defined goals. Therefore, our review only considered articles published after 2000.

Results of Search

Basic Data Gleaned from Surveying the Literature

The following statistics relate the 119 included articles based on mundane features about the setting, research design, and publication type. As can be gleaned, a substantial majority of studies failed to implement a true experimental design; slightly more studies were conducted in an informal setting as compared to formal setting; and the distribution in respect to publication type marginally favored conference papers over journal articles

-Setting: Formal- 46.3% (55 articles) vs. Informal- 53.7% (64 articles)
-Design: Experimental- 12.2% (15 articles) vs. Non experimental- 87.8% (104 articles)
-Publication Type: Journal- 41.5% (50 articles) vs. Conference-58.5% (69 articles)

Classifying and Conceptualizing the Literature

After surveying the databases and acquiring the 119 articles—which composed the foundation of our literature review—we conducted an analysis of the studies based on commonalities found in their research methodologies, results, and subsequent findings. While every article meeting the requirements specified by the inclusion principle represents a study that attempted to evaluate the impact of robots on student learning in K-12—through the consideration of demographic features, tools used for student motivation, and pedagogical approaches—it was possible to further classify the 119 studies into numerous thematic headings: 1) substantiating the general benefits of robotics as an educational tool, 2) learning by design and knowledge transfer, 3) social/cultural based motivation, 4) creativity based motivation, 5) increasing diversity in STEM, and 6) professional, curricular, and pedagogical development.

Developing the Thematic Classification System

When initially undertaking the project to conduct a literature review, our goals were loosely defined and based on the work conducted by Benitti (2012). Nevertheless, after surveying a considerable number of articles during a month long period, it gradually became apparent that Benitti's review lacked in certain aspects. For one, while the author thoroughly described how educational robots have been implemented from a practical stance and from a teacher's perspective, she did not satisfactorily account for the underlying theoretical foundations that made certain forms of robot-based pedagogies more effective in augmenting students' learning than others. In addition, Benitti included only ten studies in her review. Despite her claim that including more would give a convoluted view of the literature, by neglecting to do so, she ran the risk of proffering a limited conception of the literature, driven by anecdotal examples that may have failed to encompass more nuanced patterns within the extensive body of literature. Acknowledging these two deficits—in the current review—we reasoned that it was imperative to provide a more holistic portrayal of the respective research in a manner that not only captured how and in what subjects teachers and researchers have attempted to use robotics but, more importantly, highlighted the complex sociological, psychological, organizational, and cultural mechanisms that influence the capacity for robotics to increase students' motivation to learn and, more generally, better K-12 STEM education as a whole. However, our goals demanded that we developed a systematic manner in which to organize the studies. It was with respect to this notion that the six themes were derived.

In order to develop a systematic mode in which to organize the studies, we began dividing the studies up based on their seeming similarities to one another. Once all the databases were exhausted of relevant primary studies, we ascribed each grouping with a brief description depicting common trends found throughout the studies contained within that grouping. To refine the rationale behind the groupings, we read up on a number of secondary and tertiary sources. These sources provided insight into the nuances that marked how certain types of studies evaluating robotic implementation in K-12 education differed from one another in relation to their goals, theoretical frameworks, and findings. With a more grounded conceptualization of the literature, we began to reread the 119 articles, imposing a coding scheme that assigned studies to a generalized theme based on their overall goals, participant demographics, features of the learning environment, nature of the learning activity, and the manner in which researchers indexed their findings. After one last read-through, we further refined the thematic headings to most accurately reflect their respective studies, in addition to combining redundant themes—ultimately leading to the maturation and finalization of the six themes that constitute the basis of our review.

(The forthcoming subsections present specific exemplary studies that are representative of their respective theme. For summaries of the cited articles and additional exemplary studies, refer to Appendix B).

Theme 1: Substantiating the General Benefits of Educational Robots (N=17)

To understand research pertaining to educational robots, it is beneficial to first have a decent grasp on the history of their usage. Ever since LOGO was first introduced in 1967, robotic implementation has assumed an increasingly integral role in STEM education; however, their frequency of usage has exploded most significantly within the past fifteen years. The reason for their increased prevalence presumably coincides with the need to garner a larger number of individuals entering the respective industries. While the release of LEGO Mindstorm in 1996—with its inclusion of modular sensors and motors—succeeded LOGO in the evolution of hands-on educational robotics, the next real pivotal innovation came in the form of virtual robotics and programming platforms such as that associated with Alice, Greenfoot, and Scratch (Utting et al. 2010). The easy to use nature of these virtual platforms provides, even those with little to no experience, an opportunity for exposure to the world of programming via robotics.

Although most studies in the review posed research questions with greater specificity, 17 of the 119 studies merely attempted to validate/invalidate the appropriateness of robotic usage in K-12 education. The main concern in these studies was simply providing support (or undermining support) for the hypothesis that there is an advantage to using robotics-based activities over more traditional methods. Results from the 17 studies almost unanimously argued that active learning based pedagogies, which were made possible through educational robots, were considerably more effective than pedagogies that passively transmitted information from teacher to student.

For evidence substantiating the effectiveness of robotics (specifically LEGO) look to the study described in Williams et al. (2007). The overall purpose of the study was to evaluate the impact of a robotics summer camp on students' physics content knowledge and scientific inquiry skills and to explore various factors that might have contributed to the impact of the program. Specifically, the author's research questions were: 1) do student participants exit the summer robotics program with increased content knowledge; and 2) do student participants exit the summer robotics program with better scientific inquiry skills. In completing challenges, students worked in small groups. Statistical analysis indicated a significant difference on the physics content knowledge measure from pretest to posttest (M pre=8.40; post=9.75; p=0.004). That is, the summer camp was a success in regards to the first research question. Facilitators reported that students generally showed less interest in passive lessons and tutorials in comparison to robotics building and programming tasks. However, no statistically significant differences were found when comparing pretest and posttest scores from the scientific inquiry measure, plausibly explained by the fact that students predominantly used the trial and error method to solve problems. The authors surmised that it may take years for students to acquire inquiry skills and they suggested that longitudinal studies may be needed tin order to investigate how learners develop such skills for advanced scientific inquiry.

While the non-experimental set-up of the Williams et al. (2007) study did not provide conclusive evidence—due to the possibility of numerous confounding factors—the experimental design utilized in Ortiz (2011) represents an experimental study complete with both a control and treatment group. Students were divided into two groups: one who engaged in passive, textbook based reading and another that engaged in active learning via LEGO robotics. In summary, the research described in this study explored the impact of utilizing a LEGO robotics integrated engineering and mathematics program as a tool for supporting fifth grade students learning of ratios and proportion in an extracurricular program. The main research question was "How do students test results compare for students learning ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program versus when using a non-engineering textbook-based mathematics program?" (Ortiz, 2011). Results from the study indicated that students in both conditions were able to make significant progress in learning new concepts of ratio and proportion as a result of participating in the intervention program learning experiences. However, experimental students' performance on the engineering context assessments was significantly higher than that of the control students ($p=0.005$), indicating that students who learned about ratio and proportion in an engineering related context increased their understanding to a greater extent. In addition, students in the experimental group retained their learning for a longer period of time, demonstrated by the fact that a test administered 10 weeks after participating in the learning activity recorded a mean score of 65.3% for the experimental group and a mean of 44.7% for the control group.

Although we have described only two of the eighteen studies classified under the theme 'substantiating the general benefits of educational robots,' the given examples shall suffice in providing support for the claim that educational robots are indeed effective tools for increasing student interest and learning. Results from the remaining studies posited mostly similar if not entirely congruent findings.

With that said, the goal for the remaining themes was to describe methods for optimizing the potential benefits of educational robots. First, we summarize research investigating cognitive, environmental, social, and cultural factors that may enhance the benefits of robotic implementation, before finally considering the practical use of robotics for increasing the degree of demographic diversity in STEM and ways to effectively educate K-12 teachers about methodologies regarding the successful curricular integration of robotic teaching platforms.

Theme 2: Learning by Design and Knowledge Transfer (N=24)

A prominent obstacle encountered by students of STEM is transforming knowledge of abstract concepts into techniques and information applicable in solving real problems. Based on educational research in physics and engineering, learning by design via robots has proven successful because students are able to visualize and actively investigate/explore concepts introduced in the classroom. In computer science education, researchers have also demonstrated robotics ability to enhance student learning by providing a programmable interface that enables students to draw connections between the physical world of robots/virtual reality and the abstract world of scientific concepts and mathematical models.

Ultimately, when used in education, robots function as tools for constructivist forms of learning, where students actively engage in the learning process, constructing new knowledge through inquiry, exploring, and making cognitive associations with prior experience. While 24 of the studies exhibited direct relevance to the constructivist theory in their goals and results, three prototypical examples were selected that either explicitly concerned: a) the benefits of using robots to promote students' ability to transfer knowledge learned through experiences in a certain setting or problem to a novel setting or problem; or b) how the hands-on learning experience provided by robots allows students to better understand abstract concepts.

The first presented study, conducted by Williams et al. (2012), assessed the effectiveness of an afterschool program in implementing hands-on robotics activities as a tool for facilitating elementary school children's understanding of the applicability of mathematical concepts outside of a traditional classroom setting. The authors orchestrated three interactive LEGO-based activities that promoted team-oriented and research-like environments in which students operated a robot in order to first ascertain the length of a line, then to empirically derive the value for pi, and finally to learn how to collect and analyze empirical data from spring-mass oscillations using statistical quantities (such as the mean, mode, and median). Specifically, the authors' research question was whether active engagement with LEGO-based activities increases students' understandings of mathematic concepts and of their applicability outside of the classroom. Based on data collected from pre and post-activity surveys, evaluations of all three lessons demonstrated that students improved their conceptual understanding of the lesson content after participating in the activity to varying degrees. In the first activity, variations between pre and posttest showed significant differences in students' conceptions about the applicability of mathematics ($p<0.001$) and their ability to give an accurate description of a machine ($p<0.0025$). Pre and post-tests for the second activity showed a significant increase in students' ability to recite the number for pi ($p<0.001$), understanding of the relationship between circumference and diameter ($p<0.001$), assessing how robots can help in learning math ($p<0.001$), and the real-life applicability of math ($p<0.025$). As for activity three, students' significantly benefitted in terms of their ability to find mean ($p<0.05$) and increased their understanding for how robots can help in learning math ($p<0.001$). Additionally, students showed an increase in interest and motivation to learn math through team activities. Moreover, these activities exposed students to real-world applications of mathematics outside of classrooms.

An earlier study by Sanchez-Ruiz & Jamba (2008) evaluated the success of an extracurricular program—whose goals were to help 4th and 5th graders students establish connections between acquired mathematical skills and computer programming, to help them understand how computers work, and to help them build computer programs using Squeak—over a two week period. Their general research question was whether the program effectively accomplished its goals based on student performance and feedback. While Sanchez-Ruiz & Jamba collected formal and informal qualitative data, they did not have a sufficient amount of quantitative data to fully assess whether robotics contributed a significant advantage in accomplishing the aforementioned goals. Nevertheless, based on surveys and student feedback, the authors strongly advocated the benefits of using educational robots to facilitate students' ability to apply mathematical skills in programming.

In a yet another study, conducted by Okita (2014), 4th and 5th graders learned to program robots using abstract concepts such as speed, distance, and direction. In this quasi-experimental approach, researchers divided 41 students into a high-transparency and low-transparency group.

Students in high-transparency environments learned visual programming to control robots (e.g., organizing visual icons), and students in low-transparency environments learned syntactic programming to control robots (e.g., text-based coding). The overarching research question guiding the study was concerned with whether or not there would emerge differences between the two groups regarding students' ability to transfer and apply learned knowledge to novel settings. Midway through, assessments in both conditions suggested that students learned equally well when solving problems using familiar visually-based programming materials, with the high-transparency group exhibiting a mean score of 75% and the low-transparency exhibiting a score of 74% ($p=0.84$). However, a difference emerged when students were asked to solve new problems, using unfamiliar visually-based programming materials. The low-transparency group was more successful in adapting and repurposing their knowledge to solve novel problems that required the use of unfamiliar high-transparency materials, scoring an average of 75%. Students in the high-transparency group were less successful in adapting their knowledge when solving new problems using unfamiliar low-transparency materials, scoring an average of 62%. The difference between groups is significant with a $p<0.05$. The posttest revealed the benefits of initial learning in low-transparency environments, as students performed better than the high-transparency group on repeated and new inferential problems across virtual and physical platforms. Despite the better performance for the low-transparency group from pre to post test when comparing them to the high-transparency group, differences were only significant in respect to virtual platforms ($p<0.05$) but not physical platforms ($p=0.09$). Overall, results from Okita (2014) suggested that the deeper the interaction a student has with a robotic platform, the greater the increase in the student's ability to transfer and apply knowledge learned in one setting to solving a novel problem in a disparate setting.

Linking empirical research to theory: with all social, cultural, and affective aspects aside—at its bare essence—mastery of computational thinking requires a "deep" and "abstract" understanding of fundamental computing concepts. In this sense, "deep" implies the ability to recognize fundamental concepts applied in the appropriate programming context; and "abstract" implies the ability to separate the essence of a mechanism from the syntactical details (Touretsky et al. 2013). Effective pedagogies commonly utilized in successfully instilling students with such deep levels of understanding often feature a programmable interface that brings abstract computing to the physical world. Virtual reality is particularly suitable for this form of education owing to its ability to bridge the gap between the concrete world of nature and the abstract world of concepts and models (Adamo-Villani & Wright, 2007). However, virtual reality is outside of the budget for many school districts, thereby making it unattainable for most K-12 students and school districts. Still with its cost, yet considerably cheaper, are tangible platforms like LEGO, which allow students to use programing as a conduit for controlling the actions of a robot. In conclusion, the majority of the 24 respective studies supported the notion that when students are able to observe a program realized in robotic behavior, they are provided with the opportunity for a fascinating experiment in which ideas, scientific theories, and computer code merge with the real world—thus engendering the deep and abstract understanding required for knowledge transfer and critical thinking in STEM (Nugent et al., 2010).

Theme 3: Social/Cultural Based Motivation (N=20)

Programming does not happen in a vacuum—personal, social, and cultural forces constantly influence it. Despite the apparent truth intrinsic to this statement, conventional robotic-based pedagogies implemented in computing courses frequently fail in drawing connections between the curricular materials and the applicability it has to students' daily lives, thereby causing students to view programming skills as irrelevant to their future careers. More recently, researchers and educators have recognized the flaw in their teaching methodologies and—as indicated by the growing number of studies regarding social/cultural aspects in STEM education—have taken strides towards integrating social trends and student culture in hopes of enhancing student interest and motivation (hence why 20 of the 119 studies included in our review directly consider either social or cultural trends as means for enhancing interest). Their research was often driven by the question: How do everyday moments—experienced across settings, pursuits, social groups, and time—result in scientific learning, expertise development, and personal identification (Bricker & Bell, 2013)?

In terms of conforming to the evolution of modern social trends, one fashion in which researchers have experienced success in terms of student motivation is via the use of smartphones, as demonstrated by Tewolde & Kwon (2014). In their paper, Twolde & Kwon described their analysis of a pre-college summer program in robotics and smartphone programming that was developed for high school students with the goal of attracting them to the field of engineering. The research question guiding the assessment of the camp was—does the integration of robotics with smartphones present a fun way to introduce students to STEM in way that significantly enhances student interest while simultaneously improving a range of programming skills. The analysis argued that the program offered great opportunities for the participants to appreciate the practical value of their academic curriculum and at the same time develop their creativity, problem solving, communication, and team skills. Although results were based solely on surveys, results suggested that through this summer program, robots and smartphones were shown to be effective, fun and engaging tools for motivating and attracting students to STEM. 91% of students responded positively in terms of satisfaction; 95% claimed to have a fun during the entirety of the program; 86% stated that they would like to continue learning about topics on their own; 95% stated that they liked and felt confortable in the learning environment; and 86% said they would recommend the camp to other. Overall, the authors concluded that it gave students great satisfaction when they were able to build their robots, program them to perform specific tasks, give their robots capabilities to sense the environment in order to detect and avoid obstacles, or navigate in a maze. Also, the practical activities the students performed with robots, sensors, programming, and the smartphone apps they developed gave them excellent exposure into the fields of Computer Engineering, Electrical Engineering, Computer Science, and other related STEM fields.

Ultimately, as more aspects of their lives become centered around cyber interactions, the youth of today are progressing more and more towards a technologically dominated social sphere and, subsequently, are becoming personally intertwined and proficient in the use of their smartphones. With countless apps being designed as mediums for constant communication, the days of creating programs for individual and small-scale use is coming to an abrupt end. Therefore, it can do well to frame computing education in a manner that reflects the evolution of the industry (and society) at large. As suggested by Tewolde & Kwon (2014) and a similar study conducted by Wagner (2012), smartphones, in combination with robotics platforms, provide means for capitalizing on current social trends in order to introduce programming concepts via media that students are extensively familiar with on multiple levels.

For student bodies exhibiting an inordinately strong aversion towards STEM or for those whom are without regular access/contact with advanced technology or fall outside of "mainstream" society, research has also shown that in order to attract, motivate, and sustain student interest, educators should design and implement robotic activities that are contextualized within the culture of the respective population. E-textiles (which include sewable microcontrollers and animated technologies that can be connected to sensors and actuators by stitching circuits with conductive thread to create wearable, interactive toys, home furnishings, and soft toys) represent one approach that has been used in achieving such a feat. In a study performed by Kafai et al. (2014), the researchers described a robotic approach to ethnocomputing that combined the teaching of computation with aspects of local culture. The researchers were interested in the question of whether the use of the e-textiles would promote the children in a Native American community to acquire a better appreciation for computing in order to increase overall diversity in the industry. They investigated their research question by introducing electronic textiles to a group of 41 8th grade students in the Native American community. The textiles connected crafting practices that have a long history in many indigenous communities to computing and engineering practices. In this context, the programmable robotic flower—known as LilyPad Arduino—functioned to promote the 'design agency' of computer science learners in culturally responsive ways via the construction physical artifacts that facilitated the translation of students' ideas into a technical realization. The students were given a LilyPad Arduino e-textile construction kit and were expected to program Lilypad to sensors and actuators in order to give it the capabilities of illumination and small movements in response to the environment. Overall, students unanimously proclaimed a heightened appreciation for computer programming and an increased desire to pursue further education in the subject matter. The authors concluded that working with LilyPad Arduino was a productive methodology for students in a Native Arts class to develop design agency though the extent of student development varied with different degrees of success depending on the content/context of the activity.

In sum, people tend to be drawn towards learning activities and educational opportunities that appear relevant to everyday facets of their lives. By considering cultural and social tendencies of a student body, educators have tried to capitalize on the opportunity to individualize robotic learning experiences and garner more interest from the targeted student body. Research has shown that robotics can be utilized as a motivational tool in that robotic platforms provide educators with an efficient means of creating social/culturally relevant curriculum. The studies described above and the remainder of the 20 articles classified under the social/cultural based motivation heading suggested that to optimize motivation and learning, educators should be knowledgeable about the background and dispositions of their students. By considering demographic, cultural, and social tendencies of a student body, educators may be able to capitalize on the opportunity to individualize learning experiences and garner more interest from the targeted student body. In summary, the literature provides evidence that robotics can be utilized as a motivational tool in that robotic platforms provide educators with an efficient means of creating social/culturally relevant curriculum.

Theme 4: Creativity Based Motivation (N=13)

Numerous STEM fields have notorious reputations for their dullness and lack of opportunity for self-expression; therefore, it not surprising that—in addition to utilizing social and cultural tendencies as means for supplementing robotic-based pedagogies—student motivation can also be enhanced by incorporating creative outlets in combination with robotic platforms. Before delving into exemplary studies, it is important to note that, in general, results obtained from the 13 studies classified under 'creativity based motivation' strongly suggested that robotics programs, which found ways to integrate creative and aesthetic values into their pedagogies, typically managed to increase student learning and interest more effectively than their more restrictive counterparts. Additionally, through a meta-analysis of the findings ascertained from various studies, it became clear that by integrating creativity into beginner computing education, students become intrigued by the potential of Computer Science, while further application of computer models and simulations better suit them for mathematical and scientific investigations.

Shanahan & Marghitu (2013) depicted a study advocating the potential benefits of using creativity-based activities in their analysis of a middle school program known as Project Expression, where Project Expression was a course designed to attract students into the field of computing. In short, the course focused on a film project where participants were challenged with creating a movie that expressed an idea, opinion, or belief relative to society. The film project was a landscape for learning cloud-computer-programming and reached across the computer spectrum with engaging activities that stimulate creative design. The research question was if this creative challenge would incite participants interest in computing, and if it was an effective method for teaching cloud computing. During the program, participants were trained in Java programming and the art of multimedia production. Students were instructed in the use of physical LEGO robotic platforms and virtual Alice platforms as potential tools for their movie-making project. By implementing a wide range of apps, students learned cloud communication techniques in a software environment. The study under consideration examined the curriculum's approach and measured its effectiveness to teach the cloud-computing mentality. Based on 71 student surveys, the results were favorable: 95% enjoyed the camp, 86% thought that the content was interesting, 91% believed the instructors to be knowledgeable in teaching, 76% said they learned a lot about using computers, 63% believed the material would be useful for their future career, and 80% said that they would recommend RoboCamp (the name of the camp orchestrating Project Expression) to others. From these results, the authors concluded that the Project Expression represents a valuable example for a multimedia-based learning experience that draws students into the field of computer science and software engineering. It is also important to note that students preferred Alice to LEGO.

In another paper, written by Werner et al. (2009), a study was conducted in order to assess the effectiveness of a 2-week summer course for middle-school students in game programming using Storytelling Alice (SA). Essentially, SA is an innovative unrestrictive, free-form modeling 3D programming environment that makes it easy to create an animation used for telling a story. Although virtual in form, by convention, ALICE is considered to be a robotic platform —for the logic behind the design of Alice traces back to the tradition originated by Papert's Turtle Graphics and Pattis' Karel the Robot—and is frequently compared against more traditional physical robotic platforms like LOGO and LEGO (Utting et al. 2010). The authors chose SA because they believed the participating age group could easily learn it, because it is fun to use, and because it can be used to create 'games.' Werner and collogues were interested in the research question of whether unrestricted programming environments such as SA were effective at facilitating programming skills in middle-school cohorts. The findings argued that middle-school students can use SA to make games, and that this activity could be used to build information technology fluency. At the end of the course, the 23 student-created games were coded for six different aspects of algorithmic thinking, programming, modeling, and abstraction: events, alternation, iteration, parallelism, methods, and variables/parameters. It was ultimately found that 30% of the games had four or more aspects and 74% had two or more. A surprising number (52%) included parallelism, a concept that is difficult for novice programmers to learn but is clearly more accessible when using 3-D tools such as SA.

Through consideration of the 13 studies classified under the respective heading, it was apparent that the incorporation of creativity into the early stages of computing and engineering education functioned as a catalyst that simultaneously diminished the learning curve and increased interest amongst neophytes—explaining why in such cohorts Alice was nearly unanimously preferred over more restrictive platforms like LEGO. However, despite the benefits of incorporating creativity in early STEM education, the same positive results have not been obtained at more advanced levels, lending way to the argument that, while useful for beginners, the benefits of creativity decrease as students progress down the STEM pipeline.

Theme 5: Increasing Diversity in STEM (N=17)

The overwhelming majority of individuals composing the populations of physics, engineering, and programming professionals are males of Caucasian or Asian descent. Attributable to a myriad of reasons, minorities such as Latinos, African Americans, women, and citizens of low socioeconomic status are highly underrepresented in these fields. Much recent research has focused, however, on developing afterschool programs and summer camps intended to increase diversity. Aside from fulfilling a moral obligation to provide equal opportunity to all genders and ethnicities by encouraging the youth of minorities to pursue careers in STEM, one can generate a larger number of young professionals entering and thus expanding these fields. A larger pool of prospects yields a greater number of college applicants declaring majors related to engineering, computer science, and physics. In order to increase minority retention rates and interest in STEM, educational programs geared towards underrepresented groups often utilize motivational techniques that have strong cultural/social or creativity based relevance. For this reason, of the 17 articles falling under the heading 'increasing diversity in STEM, seven were also included under another heading. Overall, research shows that robotic platforms are generally effective at increasing the interest of underrepresented populations.

Illustrating a typical model of a computer science summer camp committed to recruiting students from underrepresented groups is the camp named Generation Innovation—where instructors implemented robots with LEGO NXT as a low-cost means for exposing African American students to a breadth of topics in computer science. Through this program, its creators aimed to dispel the myth that computer science is an industry focused only on programming and also hoped that by providing students with instructors who "looked like them," students would better be able to envisage themselves in the professional role, and thus increase students' interest in pursuing a career in computer science. In one evaluation of Generation Innovation, Stone & Brown (2014) utilized pre- and post-surveys in order to answer their research question of whether or not there were any significant changes in students' attitudes towards computer science prior to the time they started the Generation Innovation until the time they completed the camp. On most survey questions, responses indicated that after participating in the camp, students acquired a better appreciation for computer science and exhibited a better understanding regarding the breadth of opportunities available in the industry. Interestingly, however, a portion of the questions on the survey indicated marked differences in respect to gender. For example, *t*-test analysis revealed that the female participants reported a significant improvement in their feelings that computers were easy to use after their participation in GI ($p<0.05$), while the male scores did not significantly change ($p>0.05$). Other questions asked also revealed a significant change for females but not males, in short, suggesting that females benefitted from the camp to more of a degree than males. For example, when asked, "If I get stuck on the computer, I can get it working again," male participants did not exhibit a difference in their pre ($M=4.73$, $SD=2.01$) and post ($M=4.73$, $SD=1.86$) survey responses, while the female participants exhibited a statistically significant ($p<0.05$) increase pre ($M=3.25$, $SD=2.12$) to post ($M=4.56$, $SD=1.42$) survey responses indicating an increase in their perceived ability to use computers. Given the analogous lesson plans for males and females, the disparity in responses is an interesting conundrum that demands more rigorous investigation.

Whereas the work done by Stone & Brown (2014) asserted that Generation Innovation instills new perspectives of computer science upon underrepresented students via basic exposure and instruction on the use of a physical robotic platform, the authors of Searle et al. (2014) took a more holistic approach in their efforts to incite interest in African American, Latinos, and Pacific Islanders demographics. Similar to Kafai et al. (2014), Searle and colleagues turned to the question of epistemological pluralism and its potential to broaden participation in computing through a new intervention in computer science: the tangible and expressive use of electronic textiles. The program's pedagogy was designed in accordance with recent research where educational psychologists define an epistemological standpoint as having two components: (1) an individual's views/attitudes about the discipline and (2) an individual's conceptualization of the nature of knowledge production within the discipline. While the authors acknowledge that both components are important to developing a successful computer science program, the goals of this study revolve around the first component. Specifically, the researchers explored and questioned how students' attitudes and perspectives toward computing are shaped by engagement with robotic materials and how these relate (or fail to relate) to computational thinking. Ultimately, comparative analysis of pre/post-surveys and interviews indicated that upon completion of the program, students were better able to articulate a range of perspectives on computing, which could be linked to professional practice. 23 out of 24 students noted that the initial hands-on, low-tech nature of making an e-textile artifact and the ability to literally see one's progress (e.g., number of stitches sewn, number of lights), made it more accessible. A smaller (18 students) but still significant number of students appreciated the creativity and variability in learning computing through engagement of robotics. One overarching theme arising from analyses of the pre-interviews was the understanding of computer science as narrow and limited (limited to the screen, a solitary activity) versus a broader sense of its relevance in everyday contexts. The authors interpreted the change in attitudes seen throughout analyses of post interviews as a first step in developing students' epistemological stances towards computing as a discipline. Taken together, Searle et al. (2014) provided a concrete example—complete with both qualitative and quantitative data—substantiating the benefits of integrating aesthetic, cultural, and sociological factors with robotics in order to encourage underrepresented minorities to pursue educational and professional opportunities within the computing industry.

Summing up the 17 articles representing research with the goal of increasing diversity in STEM, numerous robotics summer camps and after school programs have been designed in hopes of sparking interest in underrepresented groups. Educators and researchers who focused on maintaining and improving such programs advocate the notion that exposing students to STEM in their nascent years of education will stimulate motivation and interest in the subject later in life. While studies such as Stone & Brown (2012), which considered simple exposure to STEM via Robotics, have shown robotically-based curriculum to be successful in inciting interest, studies such as Searle et al. (2014), Terry et al. (2011), and Doerschuk et al. (2011) demonstrated the relatively greater success achieved by programs that integrate robotics with other forms of social, cultural, and creativity based motivation. Overall, multicultural STEM-focused developmental frameworks facilitate knowledge and awareness of STEM education and career options and delineate considerations for practice aimed at increasing the attainment and achievement of diverse groups in STEM industries (Byars-Winston, 2014).

Theme 6: Professional, Curricular and Pedagogical Development (N=28)

Of all the articles reviewed from the databases, the largest proportion (28/119) concentrated on elucidating a solution to one of the most pressing issues plaguing STEM education—instructor quality. Brophy et al. (2008) states that while the introduction of robotics engineering education into K-12 classrooms presents a number of opportunities for STEM learning, it also raises issues regarding teacher knowledge and their professional knowledge, along with institutional challenges such as funding and high-stakes assessments. In a similar vein, according to Goode (2008), the commonly addressed predicament stems from the fact that many teachers exhibit major knowledge, skill, and pedagogy gaps, which consequently inhibit efficient conveyance of the curriculum. To improve teacher efficacy and thus mitigate the problem, many school districts now offer professional workshops with the goal of educating teachers on how to effectively integrate robotics as a tool for bettering the quality of their computing courses. Most research on teacher development focused on evaluating the success of various workshops. Since in many states teachers of computer science are not required to obtain a certificate in the subject prior to teaching, and because they often come from disparate academic backgrounds, aligning teacher knowledge and pedagogy has proven difficult. In order to close knowledge, skill, and pedagogy gaps, K-12 educators are encouraged to enroll in and attend professional development workshops. While earlier workshops focusing only on the subject matter experienced nominal success, more recent developmental programs introducing new pedagogical techniques have reported better results. Turning directly to studies that present evaluations of individual workshops, we concentrate on those that fall into the latter category—namely workshops which promoted improving teacher pedagogies as a whole.

In a study conducted by Alimisis (2012), the author's research highlighted the role of constructivist pedagogy and consequent educational methodologies, both while using robotics in school education and while training teachers to use robotics for instructional purposes. In this framework, constructivist methodologies for integrating robotics in school physics and informatics education and in professional teacher training were evaluated. The research question under investigation pondered whether or not the workshop was effective at educating teachers in pedagogical techniques by assessing how their students performed in robotic design competitions following the workshop. Exemplary projects from each case were reported to illustrate the learning potential of the proposed educational methodologies involving teachers and students while using robotics to study kinematics and programming concepts in physics and informatics. In the two case studies (involving the construction of a miniature automated vehicle), the respective teachers attended a workshop that instructed them on behaving as experienced advisors towards students, assisting pupils only when necessary. By doing so, researchers intended to maximize the educational benefits provided to the children. In order to evaluate the workshops effectiveness, the teachers followed up the workshop by instructing students in a robotics competition. Alimisis argued that because groups were pitted against one another, competition between them provided motivation to optimize the vehicular designs. The teacher—playing the role of experienced advisor—intervened minimally, allowing students to make most of the decisions. Through trial and error, the mechanized vehicles gradually performed better and better. In respect to teaching methodologies employed by teachers before attending the workshop to that after, the new constructivist pedagogy enhanced student knowledge and academic performance—as demonstrated by the significant improvement seen in test scores for students who participated in vehicular construction activities that were led by teachers who attended the workshop (although the exact differences in test scores were not reported). As succinctly put by one interviewed teacher, “the robotics-based teaching method followed in this project had effectively helped students to achieve cognitive goals in physics and technology, to acquire skills and competencies and solving problems.” Finally, “the students had appreciated the value of teamwork and cooperation.”

While face-to-face workshops such as that considered in Alimisis (2012) are currently the most popular way to educate K-12 instructors regarding ways in which to effectively educate their students, the amount of time that workshops require may function as an inconvenience for teachers, thus discouraging them from attending. A less common alternative to face-to-face workshops comes in the form of online courses that operate with a similar goal of improving pedagogical approaches adopted by teachers. Illustrating a specific example is Massive Open Online Courses (MOOCs). As of now, few school districts have used MOOCs to train their teachers in computer programming concepts. Essentially, the goal of MOOCs is to offer a high-quality education to massive audiences using open access educational resources at a low cost. In a paper looking at the use of a MOOC’s, Spradling et al. (2014) briefly reviewed the history of MOOCs, reasons for offering MOOCs to K-12 teachers, shared their experiences teaching three Google-funded MOOCs to K-12 teachers, described incentives utilized to motivate the K-12 teachers and survey results of certain K-12 communities reactions to the MOOCs. The main goal of the evaluated MOOC was to increase the effectiveness of teaching pedagogies that implement Scratch based programmable robotics kits. The research question posited by Spradling and collogues was whether teacher responses coincided with the aforementioned goals of the program based on teacher perception. In the surveys, researchers asked what type of MOOCs material was most beneficial. 23 responded that instructional projects containing directions in the use of Scratch robotics were most beneficial, with videos a close second with 19 responses; 9 thought that the virtual meetings were most beneficial; and 5 thought that the online forum were most beneficial. In addition, when asked how likely they would be to incorporate the course materials into their own courses, 18 (72%) of the 25 respondents indicated they would very likely incorporate MOOC course materials. For various personal and professional reasons, when the survey respondents were asked to rate their current MOOC experience, the authors found that the largest portion (45.8%) thought that the MOOC experience was better than a face-to-face workshop—although some of the respondents (29.1%) would have preferred a blended course. Overall, the study conducted by Spradling et al. (2014) offers preliminary evidence supporting the use of online courses as a means for enhancing the quality of teachers on grand scale.

In summary, because of their mediatory position between educational theories and the implementation of theory in practice, it is critically important to ensure that K-12 teachers are competent in their ability to effectively convey information and concepts to students in a relevant and comprehensible manner. Although controlled studies focused on delineating the cognitive and motivational benefits of using robotic platforms in K-12 STEM education are vital for developing and refining theories of learning, without knowledgeable teachers and effective pedagogies, these theories represent a mere pipedream, only useful for educating the small groups of students whom participate in the studies and pilot programs. In order to achieve large-scale success, we must find a way to educate teachers in the most effective methodologies for fostering student learning via physical and virtual platforms—whether it be in the form of face-to-face workshops or online courses such as MOOCs.

Conclusion

This systematic and conceptual review has considered the use of robotics in educating elementary, middle, and high school students. Unlike an earlier study conducted by Benitti (2012) (presumably the first real attempt at compiling a literature review pertaining to the use of robotics in K-12 education, whose author attempted a synthesis of empirical evidence in pertains to the overall effectiveness of implementing robotics in STEM education) we presupposed the general benefits provided by robotics and, instead, desired to synthesize—based on empirical research—appropriate uses for such technologies and methodologies.

After reading each study and formulating detailed summaries, it was evident that research into educational robotics occurs at different levels and with various scopes. For example, in the 24 studies classified as 'learning by design and knowledge transfer,' research questions were predominately formed based on a desire to demonstrate/improve robots' capacity to enhance students' abilities to actively construct knowledge and to apply knowledge learned in one environment/problem to novel environments/problems. To phrase it in terms of Touretsky et al. (2013), robotics can aid students in acquiring a deep and abstract conceptual understanding. In sum, these studies evaluated cognitive factors involved in teaching STEM education via robotic platforms. Due to the ability to divide participants up into control (non robotic curriculum) and treatment (robotic based curriculum) groups, a multitude of short-term experimental studies whose research practices quantitatively evaluated the capacity of educational robots to increase students' ability for knowledge transfer have been conducted. Such studies have been informative and have demonstrated the promising future of robotics in STEM education. However, the short-term nature of many of these studies has limited the range of plausible conclusions that can be drawn. In order to discern improvements in content knowledge from improvements in overall scientific inquiry skills, long-term follow up studies are necessary.

A substantial portion of the 119 studies also took a step back, focusing less on the direct benefits of educational robots and, instead, concentrated on elucidating ways in which to motivate students via the integration of social, cultural, or aesthetic elements. While a majority of the 33 studies attempting to enhance interest or motivation in STEM via social, cultural, or creative avenues reported success, some cases did not. The success of such pedagogical approaches was often contingent upon the ethnic background or gender of the targeted student body, knowledge of their proclivities, and students' degree of prior exposure to STEM. Practices, which integrated enthocomputing (i.e. Kafai 2014), often demonstrated marked success in stimulating student interest and motivation. Future studies that utilize more rigorous forms of assessment will be useful in substantiating the benefits of ethnocomputing and uncovering more efficient methods for capitalizing on student cultural propensities in the context of a robotic curriculum. In terms of creativity, studies that continue to evaluate differences in Alice, Scratch, and LEGO throughout various settings will be useful in helping educators decide what platform is most appropriate under particular circumstances.

Acknowledging the lack of ethnic, socioeconomic, and gender diversity in STEM, 17 studies took a sociological stance and operated with the goal of increasing the proportion of women, lower class and ethnic minorities in STEM professions. However, because many individuals that identify with underrepresented minorities are also disposed towards having a strong aversion for STEM (due to misconceptions regarding the nature and relevance of the fields), researchers and educators are finding it beneficial to incorporate certain cultural, social, and aesthetic elements into their studies and, in some cases have demonstrated extrapolation and formal applications of findings obtained from the 33 studies classified as either social/cultural or creativity-based motivation. In addition, programs that practice hiring teachers and role models whom are of the same ethnicity as the students have been successful. Since research practices typically only survey students immediately after the camp/program, longitudinal studies tracking the future decisions and selected career paths of individual participants would allow researchers to evaluate whether or not they had long lasting positive effects. Giving participants time to reflect on the camp/program would also permit participants to provide opinions and feedback about what specific components of the camp/program had an enduring influence on their perception of STEM.

Bringing it all together, studies classified under 'professional, curricular, and pedagogical development' took the broadest approach in their attempts to formulate the findings of micro-level research into fluid methodologies practical for teacher use. Studies of this theme typically evaluated teacher workshops that were purposed towards instilling K-12 teachers with the skills and pedagogical approaches thought to be most effective in maximizing student-learning efficiency on a large-scale and in formal classroom settings. Whereas face-to-face workshops have been investigated more thoroughly, the benefits of online courses are less explored, although open communication between those taking the course appears to be a requisite for success. In spite of the large number of studies dedicated to educating teachers about effective pedagogies, most abstained from using quantitatively rigorous methods of analysis, instead framing their results/findings based on teacher feedback and surveys. Moreover, although many of the claims made regarding the improvement of teacher quality seem reasonable, some are invalid in a strictly statistical sense. In order to achieve substantiation, researchers will once again need to utilize more rigorous methods of analysis, similar to that seen in Alimisis (2012). Additionally, because teacher surveys from previous workshop assessments suggested that teachers continue to improve over an extended timeframe, longitudinal studies tracking the performance of an individual teacher's classes throughout the years would aid in determining practices that make a workshop effective. Such research would be tremendously useful in terms of developing professionals whom are adequately prepared to teach STEM.

In conclusion, this study has shown that educational robotics have an enormous potential as a learning tool, including supporting the education of students who do not display immediate interest in academic disciplines related to science or technology. Our analysis suggested educational robots allow for an integrated, multi-disciplinary approach that involves a synthesis of many technical and social topics which encourage students to make mental connections and associations between a breadth of engineering, physics, and mechanistic concepts. In order to motivate students and optimize the learning process, it is imperative that researchers and K-12 teachers incorporate—in combination with robotic platforms—a wide range of sociological, cognitive, and affective methodologies. It is hoped that the study will provide useful guidance for educators, practitioners and researchers in areas of educational robotics and STEM education.

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Appendix A. Classification of All 119 Included Studies based on Themes

Social/Cultural	Increasing Diversity	Creativity	General Benefits	Professional Development	Design/Knowledge Transfer
Jordan & McDaniel 2014	Terry et al. 2011	Hamner & Cross 2013	Okita 2014	Harris & Hofer 2011	Kapila & Faisal 2012
*Terry et al. 2011	Mason et al. 2011	Werner et al. 2009	Rursch et al. 2010	Alimisis 2012	Garcia et al. 2014
Tewolde and Kwon 2014	Rieksts & Bank 2008	Smith et al. 2014	Altun et al. 2013	Stubbs & Yanco 2009	Park & Howard 2013
Tatsumi et al. 2009	Doerschuk et al. 2011	Sentence & Schwiderski-Groscher 2012	Osborne et al. 2010	Yilmaz et al. 2013	Nugent et al. 2009
Russak and Lim 2014	Zimmerman et al. 2011	Shanahan & Marghitu 2013	Sivilotti & Laugel 2008	Goode & Margolis 2011	Rieksts and Banks 2008
Kafai et al. 2014	Husley et al. 2014	Giannakos et al. 2013	Lakanen et al. 2012	Dodds & Karp 2006	Park and Howard 2013
*Doerschuk et al. 2011	Siraj et al. 2012	Van Delden & Yang 2014	Williams et al. 2007	Desjardins & Martin 2013	Phalke et al. 2009
Starett et al. 2015	Yilmaz et al. 2012	Wyfells et al.2014	Hussain et al. 2006	Kay et al. 2014	Feaster et al. 2011
Wagner et al. 2013	Steckel et al. 2014	Ruf et al. 2014	Morishita & Yabuta 2007	Imberman et al. 2014	Taub et al. 2012
*Siraj et al. 202	Modekurty et al. 2014	DeMichele et al. 2008	Williams et al. 2008	Spralding et al. 2015	He et al. 2008
Searle et al. 2014	Velda et al. 2011	*Yilmaz et al. 2012	Stansbury 2012	Seiter & Foreman 2013	Sanchez-Ruiz & Jambda 2008
Liu et al. 2014	Rosen et al. 2014	Eguchi and Uribe 2012	Chalmers 2012	Pitti et al. 2013	Touretzky et al. 2013
Robinson 2005	Muldoon et al. 2013	Liu et al. 2012	Ortiz 2011	Guzdial et al. 2014	Koh et al. 2013
Sullivan & Wilson 2013	Takaghaj et al. 2011		Corbett et al. 2011	Sabin et al. 2005	Oliveira et al. 2014

Cueller et al. 2014	Mcdonald and Howell 2012		Talley et al. 2009	Myketiak et al. 2012	Crawford 2012
Barco et al. 2014	Cadad and Jawaharlal 2012		Chin et al. 2014	Cooper et al. 2010	Sullivan 2008
Mcdonald & Howell 2012	Stone and Brown 2014		Zahn et al. 2010	Curzon et al. 2014	Galvan 2006
Bernstein & Crowley 2009				Kay & Mcklin 2014	Nugent et al. 2010
Del-solar 2004				Feaster et al. 2013	Williams 2012
Powers et al. 2008	TOTAL=17	TOTAL=14	TOTAL=17	Doerachuk et al. 2007	Barker & Ansorge 2007
				Dunn et al. 2011	Ayer et al. 2013
				Taban et al. 2006	Igel et al. 2011
TOTAL=20				Cejka et al. 2006	Muldoon et al. 2013
				McGrath & Lowes 2011	Howard and Dorsey 2011
				Saygin et al. 2012	Casad & Jawaharlal 2012
				Espana et al. 2013	
				Tims et al. 2011	
				Alemdar & Rosen 2011	TOTAL=24
				TOTAL=27	

*Studies with an asterisk were classified as ‘increasing diversity in STEM’ in addition to a secondary theme.

Appendix B. Summaries of Exemplary Studies

Article	Age	Sample Size	Heading /Topic	Study Type	Goals	Results/Findings
Nugent 2010	Average age of 12	N=176	General Benefits of Educational Robots: Robot programming and construction	Experimental study conducted in informal summer camp	This study examined the impact of robotics and geospatial technologies interventions on youth's learning of and attitudes STEM. Two interventions were tested. The first was a 40-hour intensive robotics summer camp; the second was a 3-hour event modeled on the camps experience and intended to provide introduction to respective technologies.	Results showed that the longer intervention led to significantly greater learning than a control group not receiving the instruction, whereas the short-term intervention primarily impacted youth attitude and motivation. Although the short-term intervention did not have the learning advantages of a more intensive robotics camp, it can serve a key role in getting youth excited about technology and encouraging them to seek out additional opportunities to explore topics in greater detail, which can result in improved learning.
Hussain et al. 2007	5th-9th graders	N=696	General Benefits of Educational Robots: Benefits of robotics in mathematic and programming knowledge	Experimental	The purpose of this study is to investigate the effect of one year of regular "LEGO" training on pupils' performances in schools; Formulating a proper model, interpreting the parameters and quantitative assessment will be attempted. Testes hypothesis: By using	When looking at achievements in mathematics for pupils in grade 9 before and after the training, we did not find any significant shifts in the mean with regards to mathematics. For the problem solving, there is no significant improvement either. This seems to be true for both grade 5 and 9.An interesting

					LEGO construction kits, sensors and programming tools, pupils will 1) develop better knowledge in mathematics than pupils that do not work with the material and 2) develop better problem solving ability than pupils that do not work with the material.	result of the study is, that pupils with higher ability in mathematics tend to be more engaged. They have also found that pupils learn the material in different ways; boys and girls learn equally as well; learning context plays crucial role.
Ortiz 2011	5th graders	N=30	General Benefits of Educational Robots: Benefits of robotics in mathematics	Experimental	The research described in this study explores the impact of utilizing a LEGO-robotics integrated engineering and mathematics program to support fifth grade students" learning of ratios and proportion in an extracurricular program. One of the research questions guiding this research study was "how do students" test results compare for students learning ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program versus when using a non-engineering textbook-based mathematics	The results indicated that all students were able to make significant progress in learning new concepts of ratio and proportion as a result of participating in the intervention program learning experiences. However, experimental students" performance on the engineering context assessments was significantly higher than that of the control students, indicating that students that learn about ratio and proportion in an engineering related context improve in their understanding significantly and retain their learning for a longer period of time when they encounter these situations in an extra-mathematical versus in an

					program?"	intra-mathematical context.
Stone and Brown, 2014	Middle and high school	N=30	Increasing Diversity In STEM: Increasing access to educational tools for underprivileged students	Non-experimental; informal summer camp; evaluated via pre and post test and survey	Expose students to the breadth topics within computer science via robotics; Provide a low-cost summer program; Expose students to role models who "look like them; Provide students with technical skills.	t-test analysis revealed that the female participants reported a significant improvement in their feelings that computers were easy to use ($p<0.05$) after their participation in GI while the male scores did not significantly change ($p>0.05$). Other questions asked also revealed a significant change for females but not males, suggesting that females benefitted to more of a degree than males.

Doerschunk et al., 2007	7th to 9th grade	N=23	Increasing Diversity in STEM: Increasing girls' confidence and ability in computing	Informal summer camp; Assessed via pre and post assessments and surveys	This paper describes experiences in conducting pilot robotic summer camps in computing for middle school girls. It covers the whole process, from conception through assessment, including how the authors worked with local schools to organize and devise the content of the camps, and how the camps were funded, conducted, advertised and assessed.	A significant increase in Cumulative Knowledge was reported ($t = 6.595$, $p<.00$). The Cumulative Knowledge scores reported by the students on the pre-program assessment ranged from 5 to 18 out of a possible 25. On the post-program assessment the range was from 12 to 25 with 36.4% of students rating their Cumulative Knowledge 20 or over. Knowledge increases most in computer programming. In addition, there was a significant increase in confidence in succeeding in Computer Science ($t=2.321$, $p<.025$).
Searle et al., 2014	16-18 years;	N=24	Using creativity to increase diversity in STEM: Using creativity to enhance interest in minorities	Informal after school program; Evaluated via pre and post survey	In this paper, the authors turn to the question of epistemological pluralism and its potential to broaden participation in computing through a new intervention in computer science: the tangible and expressive use of electronic textiles. Research questions: How does taking a hands-on, crafts-oriented approach to computing in an elective computer science course influence how students engage with	Students more clearly articulated a range of perspectives on computing, which could be linked to professional practice. 23/24 students noted that the initial hands-on, low tech nature of making an e-textile artifact and the ability to literally see one’s progress (e.g., number of stitches sewn, number of lights), made it more accessible. A smaller (18/24) but still significant number of students appreciated the creativity and variability in learning computing using e-

					learning computational concepts and practices? How might this shift their conceptions about computing culture at-large and their place within it?	textiles.
Williams, 2012	Elementary, middle, and high school	N=226	Learning by Design	Non-experimental; formal setting; assessed via pre and post questionnaire	Students lose motivation in the face of having to comprehend material that appears to be unrelated to their everyday experiences. To overcome such obstacles, many mathematics concepts can be viewed as inherent to explaining simple tasks performed by a robot. The lessons were designed to engage students in K-12 math classrooms and allow them to explore abstract math concepts using LEGO-based, hands-on activities	This paper presented three illustrative examples of hands-on lessons that proved useful in enhancing students' comprehension of the underlying math concepts and boosting their interest in the subject matter. The evaluations of all three lessons showed that students improved their conceptual understanding of the lesson content after conducting the activity.

Okita, 2014	9-11 year olds	N=41	Knowledge Transfer to real world: computing	Experimental study comparing effectiveness of low and high transparency activities	To examine whether (1) initial knowledge building in specific environments (ie, high or low transparency) matters, when students' actions (eg, programming and formalizing rules) bear very little resemblance to the output carried out by an external source (ie, robot or another human); (2) whether benefits of initial learning in specific environments continue to influence performance, even after students are exposed to alternative learning environments; and (3) if the benefit extends across different computing platforms, specifically virtual platforms (computer generated) and physical platforms (real world).	The data show that individuals originally exposed to low-transparency scenarios performed significantly better in the majority of cases. In addition, students whom were initially assigned to high-transparency groups, but then, following the midterm test, were reassigned to low-transparency learning situation, ubiquitously earned higher scored on the posttest.

Feaster et al., 2013	6-8th graders	N=118	Learning by design: fundamentals of networks, protocols, and algorithms	Non-experimental —evaluated via pre and post survey and content quizzes	Observing the importance of networking concepts in computing, the authors have developed a LEGO based curriculum module designed to introduce middle and high school students to the fundamentals of networks, protocols, and algorithms in interesting manner, and to have a positive impact on students' perception of CS as a discipline. The approach combines lecture, physical demonstrations, and hands-on activities.	Figures 3a and 3b show that the module did have a positive impact on student attitudes for the majority of the groups. Overall, 88% (37 out of 42) of the content understanding statements showed a statistically significant increase. In regards to the quiz, with the exception of group 6A, all increases were statistically significant.
Shanahan and Marghitu, 2013	Middle school	N=72	Creativity Based Motivation: Using Social and emotional issues to motivate students in computing by creative means	Non-experimental; camp; evaluated via surveys	Project Expression is a course designed to attract students into the field of computing. By implementing a wide range of apps they learn cloud communication software environment. The course focuses on a digital film project and participants are challenged with creating a movie that expresses an idea, opinion, or belief relative to society. It emphasizes the importance of empathy in	The results were favorable: 95% enjoyed the camp, 86% thought the content was interesting, 91% believed the instructors to be knowledgeable in teaching, 76% said they learned a lot about using computers, 63% believed the material would be useful for their future career, and 80% said they would recommend RoboCamp to others. In addition, Alice was preferred over LEGO

					a technology based society. Furthermore, it investigates whether or not such a course is an effective method for attracting students into the field of computing.	
Kaifai et al., 2014	Middle school	N=41	Culture: Using Interesting cultural topics and computing to increase student interest and skill	Non-experimental; camp and class (informal); evaluated via student performance and decision-making	In this paper, we proposed an approach to ethnocomputing that focused on culturally responsive open design and investigated how learning with electronic textiles about circuitry and computation in two different contexts, a class and a summer camp, situated students' understanding as members of an indigenous community. By culturally responsive open computing, we refer to practices that connect community funds of knowledge and computing in culturally	The authors found that working with e-textiles was a productive context for students in the Native Arts class and the summer camp to develop design agency. Students exercised their design agency by choosing to make projects connected to youth media culture and by focusing on honing their programming skills. Students benefitted from an increased level of design constraint, at least insofar as their knowledge of computational concepts and practices was concerned. When their designs were constrained, students moved more quickly beyond the initial design

					relevant ways but with fewer design constraints than those imposed when students work with culturally situated design tools.	phase and were able to devote more of their time to circuitry and programming.
Kapilla and Faisal, 2012	Kindergarten	N=19	Affective Based Motivation: Enhancing memory and geospatial cognition through emotional arousal	Non-experimental conducted in formal setting; results based on performance.	To elucidate a plausible correlation regarding emotional arousal and geometric thinking. Through interacting with a robotic companion, the authors hoped to augment participants rate if spatial development. Results were quantitatively analyzed via the equation presented in the article.	By arousing the emotions of the students, the subjects became better apt to solve problems related to spatial arrangement. Remembering location of particular buttons on the robot was done with ease compared to the baseline state taken at the beginning of the survey.

Werner et al., 2009	Average age of 11.5 years	N=22	Creativity Based Motivation: Using creative game design to enhance programming skills mentioned in results section	Non-experimental conducted in informal setting; evaluated via pre and post survey; qualitative methods were also used.	This paper shares experiences from two 2-week summer courses for middle-school students in game programming using Storytelling Alice (SA). The students spent 20 hours learning SA and creating their own 'games' alone and in pairs. We discuss problems and preliminary findings regarding game programming by middle-school students.	From the post-course survey, 90% of the student responders said using the computer was fun and 62% said it is easy to make a game in SA. The percentages of games containing these fundamental concept aspects are: events – 100%, alternation – 26%, iteration – 17%, parallelism – 52%, additional methods – 48%, and parameters, local and global variables -- 39%.
Van Delden and Yang, 2014	Middle school	N=37	Autonomy is design and programming of robotic arm	Non-experomenal conducted in informal summer camp	The camp evaluated the students on academic/technical content and on their level of STEM interest, and also on their likelihood of attending Southeastern Louisiana University. The primary content of the camp was to build a two degree of freedom robotic arm using a LEGO Mindstorm NXT which could move a metal washer exactly one foot, the distance of a square tile, on the floor. The students had complete freedom on how to construct the robotic.	Results show that there was a significant improvement in all questions, except, curiously, for question nine (depicted in table 9). In regards to attitudes, the largest gain in interest was for the Occupational Safety degree. Average numerical scores for all these questions were very high, indicating that students were impressed with the camp.

Adamo-Villani and Wright, 2007	Ages 5-10	N=21	Using emotional engagement to facilitate scientific and mathematic skills	Non-experimental; evaluated via pre and post survey and in game performance	This paper describes the implementation and evaluation of the second iteration of SMILE (*S*cience and *M*ath in an *I*mmersive *L*earning *E*nvironment), an immersive learning game that employs a fantasy 3D virtual environment to engage deaf and hearing children in math and science-based educational tasks. The objectives of the SMILE project are: (1) the development of an effective and enjoyable immersive game in which deaf and hearing children interact with fantasy 3D characters and objects and learn standards-based math and science concepts, and (2) the investigation of its educational benefits.	In summary, the program should be (1) an intriguing story context that establishes and supports challenging tasks with variable difficulty level, (2) an emotionally appealing fantasy world designed to evoke curiosity, and (3) a well defined advancement and reward system centered on curriculum-based activities are all key elements that allow children to perceive their participation as meaningful and engaging and, thus, motivate them to continue to play and learn. As far as engagement, the majority of the subjects appeared to be very focused on the tasks. The mean learning time, i.e., the meantime necessary to perform a sequence of basic operations (pick up an object, move it and place it inside another object, and then put it on top of another object) was 58 seconds. Students had fun and indicated that the program exceeded expectations.