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Robotics in the classroom: The effectiveness of robotics based curriculum in STEM education

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Abstract
Students learn best when they are engaged and are able to interact with their environment. They can build their own definition of concepts and themes, which are more meaningful because they are related to their own experiences and memories (Kolb, 1984). Simply put it all comes down to constructivism, which means a person builds knowledge and meaning from interactions between their experiences and ideas (the environment they work/play in and the people and objects they interact with). The purpose of this study is to find out how a middle school and high school constructivist robotics curriculum impacts students' conceptual understanding of electrical circuit concepts.

ROBOTICS IN THE CLASSROOM:

THE EFFECTIVENESS OF ROBOTICS BASED CURRICULUM IN STEM EDUCATION

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Chapter 1: Introduction & Framework

Introduction

In a global market, we, as teachers, are failing. Our students rank behind eleven other countries in our country's average math score in understanding of mathematics concepts by the fourth grade level according to the Trends in International Mathematics and Science Study (TIMSS), which compares the statistics for the forty-six countries that participate in the study (Gonzales, 2003). We are also behind in both math literacy and science literacy by age 15 according to statistical results from the Program for International Student Assessment (PISA) in comparison to a majority of countries that participate in the Organization for Economic Cooperation and Development (OECD, an inter-governmental association of industrialized countries) (Lemke, 2004). With a growing demand for a skilled technological labor force, the U.S. must improve its interest and skills one develops and gains by taking STEM (Science, Technology, Engineering and Mathematics) courses and by improving the delivery of STEM courses by adding more trained teachers to this field if we want to buck the trend of declining numbers of Physical Science degrees. The next big market for jobs will not be pipe layers, farmers, or cops but in skilled technicians to the tune of half of the U.S.'s economic growth. While a recent and small resurgence of manufacturing jobs have come back to the United States, most manufacturing jobs will progress to semi-automated and eventually fully automated systems. In contrast, the number of individuals trained in STEM fields, like physical scientists and engineers, has dropped (Bonvillian, 2002).

The Next Generation Science Standards (NGSS) is a set of national science education goals that while being interdisciplinary contain both a practical (common practices of professionals) component, a theoretical (main science concept) component, and minimum performance expectations of students. The new NGSS contain an engineering component that will be required of science classes (NGSS, 2013). Iowa has adopted the NGSS and has incorporated them into the Iowa Core. In addition to this, numerous schools in different states (including Iowa) are looking to incorporate more technology into their curriculum because of state mandated technology standards (Iowa Dept. of Ed., 2010). In order to do this, the Physical Sciences (Physics and Chemistry) need to secure more federal research funding in order to thrive. From 1970-1999, the Biological Sciences tripled their federal research funding from $5 billion to $15 billion. During this same period in which Biological Science research spending soared, Physical Science spending stagnated and even declined somewhat. The number of life science undergraduates and graduates has increased while the number of physical science undergraduate and graduates have flat-lined or declined (Bonvillian, 2002).

Many teachers across the country are looking for more effective ways to help students create a better understanding of physics and math concepts, which build the basis for a learning and understanding of engineering and technology. Robotics could be a way to help teachers help their students achieve success in understanding science, technology, engineering, and mathematics (STEM) concepts. The Iowa Governor's STEM Advisory Council seems to agree with this position as it has had FIRST Technology Challenge's (FTC) robotics program as a part of its STEM scale-up programs four of the past five years and FIRST Lego League's program as a scale-up in the 2012-13 school year (Linn, 2012; Linn, 2014). Robotics as a way to teach STEM concepts is not a new idea. Robotics as a means for education and promoting STEM interest and growth had been around since the 1970's (Papert, 1980). One has to only look at the insurgence of computers in the classroom to see that robotics is not far behind. Where we once thought of programming as theoretical, not only can we program a computer model, but also an actual robot to complete a series of tasks.

Lego Mindstorms robotics is relatively new to science. Its creation has been credited to the University of Colorado in the year 1994 when it created the first visual programming environment called "LEGOsheets (Gindling, Ioannidou, Loh, Lokkebo, & Repenning, 1995)." Since LEGO Mindstorms is rather new, not many studies have been completed about using it in the classroom setting. The studies that have been completed about it have been performed in a variety of areas (Fagin & Merkle, 2003; Barker, 2007; Barnes, 2002), however, few have specifically looked at how LEGO Mindstorm robotics affects student learning of Physics concepts. Robotics has been shown through many of the aforementioned studies to increase learning, motivation (Fagin & Merkle, 2003; Moundridou & Kalinoglou, 2008) and promote interest in STEM areas (Barnes, 2002; Robinson, 2005; Rogers & Portsmore, 2004). Rogers & Portsmore (2004) and Moundridou & Kalinoglou (2008), in particular, found that robotics increased scientific and math principle comprehension. In addition to this, they also found that the use of robots increased the reading and writing skills of elementary students.

All of the previously mentioned studies show that instruction in robotics helps to improve many student abilities, but none of the studies are specific to working with high school students in a Physics/Physical Science classroom. Some of the studies use high school students, but the individual sample sizes are small. Fagin & Merkle (2002) used a larger number of students, but they used college/military academy students in a computer programming class that emphasized computer-programming concepts, which is not an emphasis in a Physics/Physical Science curriculum.

Students learn best when they are engaged and are able to interact with their environment. They can build their own definition of concepts and themes, which are more meaningful because they are related to their own experiences and memories (Kolb, 1984). Simply put it all comes down to constructivism, which means a person builds knowledge and meaning from interactions between their experiences and ideas (the environment they work/play in and the people and objects they interact with). The purpose of this study is to find out how a middle school and high school constructivist robotics curriculum impacts students' conceptual understanding of electrical circuit concepts.

Theoretical Framework

The Iowa Core is the standards and expectations of the K-12 education system in the state of Iowa. Its “Characteristics of Effective Instruction” are known by the acronym “START” (Iowa Department of Education, 2010). This acronym stands for “Student-centered classrooms, Teaching for understanding, Assessment for learning, Rigorous and relevant classroom conversations, and Teaching for learner differences.” Assessment for learning with the emphasis on formative assessments means that you find out what students know before and during the teaching of the concept. You collect data on what they know in order to formulate your instruction so that you can focus on teaching the understanding of the concept. One can do this by giving pretests on concepts so that they can find out what students know and what they do not know. Teaching can then be focused on the concepts that the majority of students missed in the pretests. This can help create for more time to teach on those concepts that the majority doesn’t understand as the pretest data will allow you to determine which concepts the majority of students already know so that you do not need to spend as much time teaching them. When one focuses on teaching for understanding, the classroom discussion focuses on making students think about the concept on a higher level while connecting it to things that happen everyday in the real world. The data you collect from formative assessments (which are mostly not graded) helps one figure out how to design the learning to take place so that the teacher can design lessons, which reach to different student ability levels and ranges. All of these attributes connect to one another to create a classroom that is centered on student achievement.

The Iowa Core has made a big push for school science classrooms to convert from traditional paper and pen settings with the teacher as the center of attention into student-centered classrooms with hands-on activities where students can explore ideas, manipulate objects, test many different variables, ask questions, make observations, collect data and form hypotheses about what they are working with. Robotics over the years has continued to develop and become an integral part of the classroom since it has become more advanced and user friendly and has become a more popular tool of choice in helping students learn in the classroom. Robotics has been used in the science classrooms to help learn many science, engineering and technology concepts (Barker & Ansorge, 2007). Robotics-based curriculum allows students to explore ideas, manipulate objects, test many different variables, ask questions, makes observations, collect data and form hypotheses about what they are working with. One of the advantages to using robotics in the classroom is that it gives instant feedback because students can see right away whether or not something works and go back to figure out what they could've done wrong in order to see their mistakes. Constructivism supports all of the aforementioned behaviors. Wadsworth (1996) discusses how constructivism is based on children "constructing" their knowledge through their actions on their environment and those actions can either be physical or mental (wonder/curiosity). Constructivism has a phase known as "disequilibrium" or "cognitive conflict". This is where a person expects one thing to happen and something else does. They become unsure of what they currently know and go about trying to figure out how this situation is different in one of two ways; 1) "Assimilate" ideas into their current understanding of a concept. 2) "Accommodate" by tearing down their understanding of that concept and rebuilding it through this new situation and new information/situations. Students gain meaning through social interaction with others in order to develop their schema about an idea.

In fact, the instant feedback mentioned earlier can come from two areas: 1) The success (or failure) of the robot to do what the student wants it to do; 2) The social interaction with the other students working in a group, the interaction with an instructor, and interaction with others on different teams via competitions or forums on FTC websites or through email. Students working with robots have the opportunity to figure out things for themselves and then can discuss these ideas with the teacher for clarification. They get confused, go through a process of thinking about ideas, researching new ideas, watching other new phenomena, and figuring out whether or not this information can fit with their existing schema or tearing down old schema and rebuilding new schema with what they've learned. Ultimately, constructivism explains why this is a good form of learning. The teacher in turn can help shape and mold these ideas into concepts for the students to understand and hold onto for basic understanding. This allows the student to build larger ideas on the basis of smaller ideas where they can continue to work with the robots to gain and develop their own understanding that is meaningful to the student because it is the student's own authentic experience which is driving their learning.

Chapter 2: Relevance and Literature Review

Review of Related Literature: Constructivism and Robotics in the current Science Curriculum

Constructivism as a theory is all about engagement and self developed learning. Stolkin (2007) had students build underwater robots and found that student teams arrive at their own creative solutions when given a problem. Their design process involved lots of testing and modification where the students were highly engaged in their work and took pride in their creations and enjoyed the challenges. Lastly, the students were forced to experiment and discover the concepts on their own rather than being given a set of prescribed instructions. Even though it's not mentioned in Stolkin's work, it's as if he discovered that the ultimate learning theory behind robotics is constructivism!

The toy company, LEGO®, creates the most popular form of classroom robots; this allows students to think of these items as toys and make the learning experience more fun. In addition to this, it teaches the students hands-on and written problem solving skills and gives them immediate feedback (Mauch, 2001). Sullivan (2008) found that students who participate in a robotics curriculum build and develop their thinking and science processing skills. This allows them to scientifically attack and solve any problem. She also found that students understanding of science and technology skills improve because they have to use thinking and processing skills (observing, evaluating solutions, testing/experimenting, generating hypotheses, controlling variables, manipulating variables, estimating). In addition to this, Nourbakhsh et al. (2005) discovered that a curriculum centered around robotics provides concrete items for children to observe and experiment with, helping the students understand abstract concepts better and gain more functional understanding. It helped students understand that there are often multiple correct answers and creative solutions to a problem not just the one memorized answer (Beer et al, 1999). Flowers & Gossett's (2002) results show that the robot helped students visualize solutions and apply their problem solving skills in order to analyze the problem, come up with a solution and implement that solution in order to test to see if that solution is indeed the correct one.

As Barker & Ansorge (2007) mention in their work, there is a major lack of quantitative research on how robotics can increase STEM achievement in students. Even though the research involving robotics in the classroom has been conducted with high school students, the results have been reported as student and/or teacher perceptions rather than from measures of student achievement.

Fagin & Merkle (2002) did a large-scale study looking at teaching robotics to 938 college freshmen in an entry level computing course and how it would affect the conceptual understanding of students. They were not successful in showing gains or losses in conceptual understanding of computer programming. They felt that since students could not take the robots home to work on programming on their own time and instructors lacked experience teaching in this style, these factors negatively affected scores, which leaves the door open to more studies about robotics positively impacting achievement. Barker & Ansorge (2007) did a similar study with a much smaller (32 students) and younger (ages 9-11) group and got significant results and greater interest in their curriculum. Their results showed that students participating in robotics saw a significant increase in pretest to posttest scores in regards to learning achievement in science, engineering, and technology concepts (SET) compared to their control group. Moundridou & Kalinoglou (2008) looked at 16-18 year olds in a technical/vocational school in Greece and their conceptual understanding and enjoyment of robotics concepts. The lesson plan was put together and executed with the study in mind, but did not include a control group. The two researchers found that after the students had concluded with their unit on learning how to put together and operate a LEGO Mindstorms robot, students better understood the robotics/mechanical engineering concepts and enjoyed the class activities involved with the robot. Barnes (2002) found that using Lego Mindstorms was successful in teaching his students introductory Java programming. Mauch (2001) taught a select small group of middle school students about robotics and found that it helped increase their science problem-solving skills and their enthusiasm and interest in science. Rogers & Portsmore (2004) found LEGO Mindstorms to be a successful resource to teach engineering, math, science, and reading. Nourbakhsh, Crowley, Bhave, Hamner, Hsiu, Perez-Bergquist and Wilkinson (2005) found the program to be successful in teaching computer programming to high school seniors. Stolkin (2007) found his study to be successful in showing that student design techniques, experimenting, and modifying abilities (along with their altogether scientific abilities) improve through the use of a robotics program. Sullivan (2007) found that science skills and problem solving abilities improved in terms of science literacy through the use of Lego Robotics. Flowers & Gossett (2002) found that their study with military cadets improved the problem solving and computing abilities of their students.

Five studies (Barnes, 2002; Mauch, 2001; Nourbaksh, Crowley, Bhave, Hamner, Hsiu, Perez-Bergquist, & Wilkinson 2005; Robinson, 2005; Rogers & Portsmore, 2004) found positive results with problem solving skills. "Problem-based learning" (PBL) is the process in which students learn about a subject by solving open-ended problems and learn how to solve those problems through learning new thinking strategies. The study by Hmelo, Gotterer, & Bransford (1997) found that students who have done PBL compared to those who have not, tend to do better in terms of knowledge, reasoning, and learning strategies. Norman & Schmidt (1992) support this further showing that PBL increases knowledge retention, enhances transfer of concepts to new problems and integrates science concepts into new clinical problems, increases interest in subject matter, and enhances one's own learning skills. Beer (1999) and Nourbakhsh et al. (2005) found that robotics encouraged cooperative learning and teamwork, a key concept in constructivism. All of these studies were qualitative in nature, and as such reported results that were localized and with smaller sample sizes (10-15 students).

STEM Interest and Growth

Robots help students become interested in more than just robotics (Papert, 1980; Rogers & Portsmore, 2004). Because of the interdisciplinary nature of robotics building, student interest has grown in programming, construction, engineering, mechanics and even medicine. Moore (1999) used robotics as a hook to teach geometry concepts, as characters for literature studies, and to show the differences and similarities between the human body and a technical system. Nourbakhsh et al. (2005) found that girls in particular appreciated learning with robots over traditional methods and that their confidence in learning with robots increased more than boys by the end of the study. Rogers and Portsmore (2004) had success in teaching decimals. Papert (1980) and Moore (1999) used robots to teach geometry concepts. Robots helped students see the relationships between programming, mathematics, and movement of the robot. Educators have used robots as a tool to assist in the teaching of computer programming languages (Barnes, 2002; Fagin & Merkle, 2003).

Most of the research done showed positive results from qualitative studies on the high school and college level. However, relatively fewer quantitative studies have been published.

Recent Quantitative Studies

Fagin and Merkle's (2003) study on using a robotics curriculum to teach computer programming at the college level saw inconclusive results (no measurable increase or decrease in conceptual understanding) that the authors attributed to poor planning and execution of the robotics curriculum. Barker & Ansorge's (2005) study on a 4-H robotics afterschool program saw positive results when they compared pre-test to post-test scores in regards to learning science, engineering and technology concepts with a smaller sample size of 9-11 year olds. Both studies illustrate that proper time must be given to the curriculum or else students will not learn what you would like them to learn. Even though Barker & Ansorge based their research on the idea that a robotics-based curriculum will positively affect youths' understanding of science, engineering, and technology topics in a quantitative manner, they left the door open for future work on testing the effectiveness of a robotics curriculum in learning physics concepts. They also wanted to prove that the assessment developed for the experiment was valid and reliable. Barker's study included 32 students (20 boys, 12 girls) in the 9-11 year old age range from a small community in rural Nebraska. The independent variable in Barker's study was conditional (after school robotics program, robotics kits, computers vs. no after school robotics program, no robotics kits, and no computers). His dependent variable were the scores on a pre-test vs. scores on a post-test) in regards to the learning of science, engineering, and technology concepts.

In Barker's study, he broke the students into groups of 4-5 with each containing one adult volunteer/after-school teacher. Students were introduced to robotics by building a basic "tankbot." Students programmed the tankbot by using ROBOLAB software and learned progressively harder programming tasks. They first learned how to "move" the robot. Lastly, students fitted the robots with touch and light sensors and programmed them to react to changes that were registered by the sensors.

Barker's results included the following:

- The pre-test and post-test results from control group showed no significant difference in scores.
- There was a significant difference between the pre-test and post-test scores for the experimental group ($p < .000$).
- Overall percent change from pre-test to post-test was 128% for experimental group.
- Assessment was proved to be reliable and valid.

From this research, Barker was able to conclude that a robotics curriculum is one successful method in helping students to understand concepts in science, engineering, and technology, but he indicated that future work done in this area should be directed by the following questions:

- Does generalized classroom instruction help students do better on some items rather than others?

- Does the robotics program foster positive attitudes toward science, engineering, and technology in school and as a career?

Fagin & Merkle (2003) wanted to prove that the use of Lego Mindstorms in laboratory instruction would significantly improve the test performance of their students who take the required core-computing course. In addition to this, they wanted to prove that learning through the use of robots encourages the selection of computer science or computer engineering as a field of study. Fagin & Merkle's study included many more subjects than Barker's study; Fagin & Merkle had 938 students in 48 sections of a required computing course in the Air Force Academy where each course contains 15-20 students each. The students' tasks were to go through six laboratory exercises where they learned about the following concepts: Variables, constants, sequential control flow, procedures without parameters, procedures with input parameters, condition-controlled iteration, selection, count-controlled iteration, procedures with output parameters, and arrays. The non-robotics section also learned about packages because Mindstorms did not support the concept files.

Fagin & Merkle discovered that the control group had SIGNIFICANTLY better scores for the final total and course total ($p = .01$, $p < .005$) for the complete academic year and that there were no significant results for either the fall or spring semester for students declaring a computer science or computer engineering major.

From this study, Fagin & Merkle were able to draw the following conclusions:

- A goal for robots in the classroom is to improve student learning and attract people to the discipline.
- The goal for this experiment was not met.
- Instructor experience may play a part in student achievement.

Current Curriculum Used

"Capacitor-Aided System for Teaching and Learning Electricity (CASTLE)" (Steinberg, 1999) is a curriculum that is geared towards teaching students the basic concepts about how an electrical circuit works using basic terminology, drawings, and equipment. The situations, drawings, and equipment start out basic and simple and as one continues to gain understanding of how the circuit works, more objects are added to the system and drawings so that one can learn how another variable can affect the system. More description of how this curriculum (and how the other two curricula) works can be found in chapter 3 in the "Methodology" section.

Modeling (AMTA, 2015) curriculum in electricity and magnetism is consistent with the constructivist approach in that it utilizes the 5E learning cycle process of engage, explore, explain, elaborate, and evaluate to help students learn the theory behind how electricity and magnetism work the way they do. This process is consistent with the constructivist approach because both processes start out with simple ideas and questions, which then continually build upon one another. The situations become more complex and ask students to explain and expand their thinking. All the while, students work in groups to discuss ideas and phenomena and get the opportunity manipulate objects (which relate to the concept) in order to gain more meaning of the phenomena. In other words, the 5E learning cycle is a teaching method that one can use to achieve the constructivist approach to teaching. Simply put, CASTLE explains the "how" it works and Modeling explains the "why" it works the way it does when learning about electricity and magnetism.

Lab View robotics and RobotC robotics act as bridging components between the how and the why. Lab View utilizes pictures where one can click and drag on icons in order to program an FLL robot and the final picture looks and acts similarly to an electrical circuit. In other words, what the diagram on the computer is to the running robot, the drawing is to whether or not the objects receive electricity and operate. RobotC utilizes coding where one learns basic computer programming language (C-based) in order to get the robot to do what one would like the FTC robot to do, instead of the pictograph method featured in Lab View. The same principles still operate in how the robot works or doesn't work and students can go back and figure out why it doesn't work the way they would like it to.

In summary, multiple experts agree that constructivism is a key theory in education and as demonstrated by Stolkin (2007) and Nourbakhsh et al's (2005) research, a key instrument in science education. Nourbakhsh et al's (2005) research about a robotics based curriculum shows this. In addition, a robotics-based curriculum has shown in the studies mentioned in this literature review to develop problem-solving skills including multiple answer and increased creativity, developing a deeper understanding of abstract concepts and developing the basic science skills. Robotics develops a deeper understanding because students are able to relate an actual experience to the concept rather than rote memorization or a strict theory only review of content. Robotics has been useful in developing thinking and processing skills across multiple subject disciplines including computer sciences and mathematics. While these studies provide a wonderful framework of recent robotics curriculum research, they leave still a few lingering questions. The goal of this paper is to add to the breadth and depth of this existing research in so much as to focus the impact of robotics curriculum on specific physical science lessons.

Chapter 3: Project

Research Questions

Based on a constructivist theoretical framework and previous studies, can we find particular areas that are best affected by robotics in the classroom, if any? By using this study that will contain different population sizes and different test populations, can we discover if there are significant results (positive or negative) between physics, physical science, and robotics students on adapted conceptual assessments? Even though a direct comparison may not be possible since different curricula and different assessments are used, will I observe that robotics students will have marked increases in scores as Barker & Ansorge (2007) did with their students in Nebraska?

My questions are:

1. Will the implementation of a robotics curriculum impact student understanding of the physics concepts of electricity and circuits?
2. Will the implementation of a research-based Physics curriculum significantly impact the student understanding of the physics concepts of electricity and circuits?

Methodology

This project took place during the 2014-15 school year at a rural community school district in eastern Iowa. Four groups of students were tested in the study: 1) Physics students (11^{th} and 12^{th} graders); 2) Physical Science students (9^{th} graders); 3) Students in the high school FIRST Tech Challenge (FTC) robotics club; 4) Students in the middle school FIRST Lego League (FLL) robotics club.

Physics students worked through “Modeling Electricity and Magnetism” (Modeling Instruction, 2012) curriculum to learn electrical concepts. The teacher acted as a guide by giving the students equipment for specific labs along with questions to answer while manipulating the objects. The students had specific challenges to achieve with the equipment. Following the lab, the teacher would conduct a whiteboard session where students presented their findings to the questions and explained what they saw happening, along with what they had to do to get the results they achieved. The curriculum starts with students learning about what an electrical charge is, how it can be generated, electric force, what an electric field is, how charge flows, Coulomb's Law, and conductors and insulators which is all included in the first unit titled "Charge and Field." The second unit deals with electric potential in which students learned about electrical potential, electric field lines, and electric equipotential lines. In essence, this class learned about the background information behind how we know what we know about electricity without actually learning about circuits. If the students would've actually gotten to unit 3, they would've learned about circuits, but time ran out on the project. This group was chosen to be the control group since they received no instruction or training on electric circuits. The circuits unit was skipped with the Physics class since students who take this class are looking for skills and knowledge in Newtonian Physics for college and with the amount of time left in the school year, these units needed to be started then in order to dedicate enough time to them.

Physical Science students worked through CASTLE (Steinberg, 1999) curriculum and the teacher guided student learning of electrical concepts in the same fashion as the Physics students. Unit 1 (Closed Loop Model) had students focusing on identifying situations where bulbs would light and wouldn't light, differentiating between conductors and insulators, tracing the continuous conducting path through the wires and light bulb, analyzing which direction electricity flows in a circuit based on the evidence of compass deflection, and applying and identifying the definition of conventional current. Unit 2 (Charge Flow and Sources of Charge) had the students drawing schematic diagrams to represent simple circuits, identifying the parts and structure of a capacitor, indicating the direction of charge flow in a circuit when a capacitor is charging and when its discharging, identifying the source of a mobile charge in the circuit, indicating where conventional charge flow in a complete circuit originates, and comparing the amount of charge stored in different capacitors. Unit 3 (Resistance Model) had students figuring out what parts of a circuit resist charge flow, using indicators such as bulb brightness and compass deflection to compare flow rates in circuits, differentiating between flow rate and speed, using tools that show/represent the flow rate and bulb brightness on circuit diagrams, explaining how adding series vs. parallel bulbs will either raise or lower overall resistance, and using evidence to explain how connecting wires have less resistance than bulbs. Unit 4 (Compressible Fluid Model) has students using evidence to explain how the mobile charge in a capacitor plate can be compressed, explaining high and low electric pressure in relation to compression and depletion of charge, citing evidence that a battery creates a high and low pressure in its terminals, explaining how electric pressure is uniform in any wire and connected wires, explaining how a battery and wires create a pressure difference that lights a bulb, and analyzing simple circuits through color-coding conducting parts to represent electric pressure. Unit 5 (What determines pressure in a wire?) has students comparing pressure differences between a long bulb and round bulb in series, explaining how steady-state pressure values arise in wires that are not connected to a battery, why the steady-state flow rate is the same through all resistors in a series circuit, describing the process by which steady-state conditions arise from initial conditions, comparing the flow rate through a round and long bulb in parallel, analyzing more complex circuits which contain a combination of series and parallel bulbs, describing the effect of a battery's internal resistance on a circuit, and explaining what happens when a wire is placed in parallel with a bulb.

FLL and FTC students worked through a curriculum developed by Tetrix Robotics where the FLL students learned about LabView programming and FTC students learned about RobotC programming. Both groups worked out of the "Tetrix Getting Started Guide" (Pitsco Inc, 2011) (HS at a faster pace, MS at a slower pace) in which the first three lessons respectively were: basic chassis, ranger bot movement, and ranger bot sensors. In lessons 2 and 3, since the two groups are working with different programs, the groups diverged and the HS group would work in the section on RobotC programming and the MS group would work in the section on LabView programming. The first lesson, basic chassis consisted of simply building the basic frame of the robot. It was in lessons 2 and 3 where both groups learned how to program the robot to move and how to use the robot's sensors to guide its actions and movements. Direct instruction occurred in the programming of the robot. Demonstrations of electrical circuits occurred along with discussions about how the robot programming was similar to an electrical circuit (LabView is a graphical programming environment where users drag virtual "wires" to make connections between the elements of the program in order to command the robot to do something) so that students could understand the idea of how the two related to one another.

All four groups of students were presented with two multiple-choice concept tests. The tests given to them were the "Electrical Circuits Concept Evaluation (ECCE)" (Thornton & Sokoloff) and the "Directing and Interpreting Resistive Electric Circuits Concept Test (DIRECT)" (Engelhardt & Beichner, 2004) which are also both typically given to Physics and Physical Science students at the beginning and end of the electricity curricula in both classes. All four groups took the pre-tests at the beginning of the school year. Physical Science students took the post-tests in November at the end of the first trimester of school. Middle school FLL students took the post-tests in the beginning of December after their season concluded. Physics students took the post-tests in December right before Christmas break. FTC students took the post-tests in February after the conclusion of their season. Whether students were taking the pre-tests or post-tests, students were asked to answer the assessment to the best of their ability as it DID NOT count as part of their grade in the academic course. Since the robotics club is an after school group, there would naturally be no grade associated with the survey and their decision to not take the survey would not affect their status as a club member.

Pre-test and post-test means and standard deviations were calculated for each population. From the population average for those questions, percent gains were calculated. Using a method frequently employed by the physics education community, the average question percent gain was calculated using the following formula: $\frac{post-pre}{Max-pre}$ (where *Max* represents the maximum score, *post* the post-test score and *pre* the pre-test score). If the student saw a drop from their pre-test to their post-test score, the following formula was used to calculate % loss: $\frac{post-pre}{pre}$. The second equation was developed by Marx & Cummings (2007) and is used to calculate % loss so that it more fairly and accurately describes the drop in the student score. Below, you will find Tables 1-8, which contain findings from the data analysis performed on the test scores of the test populations. Complete test scores are appended.

Findings

Table 1: Gains on DIRECT for four populations

	Pretest Score (max 29)	**Posttest Score (max 29)**	**Gain (Loss)**	**Gain (Loss) %**
Physical Science (n=42)	**7.88** ±2.63	**9.95** ±2.80	**2.07**	**6.14%**
Physics (n=5)	**11.40** ± 2.30	**9.00** ± 2.74	**(2.40)**	**(22.63)%**
FTC (n=8)	**8.88** ± 2.85	**9.75** ± 3.20	**0.88**	**2.17%**
FLL (n=5)	**8.6** ± 5.94	**8.6** ± 2.70	**0**	**(5.95)%**

Table 2: Gains (Losses) on ECCE

	Pretest Score (max 29)	Posttest Score (max 29)	Gain (Loss)	Gain (Loss)
Physical Science (n=42)	**8.05** ± 2.37	**9.64** ± 3.73	**1.60**	**(2.46)%**
Physics (n=5)	**9.2** ± 1.79	**9.00** ± 3.08	**(0.20)**	**(10.90)%**
FTC (n=8)	**7.38** ± 2.45	**10.75 ± 3.73**	**3.38**	**13.59%**
FLL (n=5)	**5.8** ± 4.76	**6.6** ± 2.41	**0.80**	**(4.43)%**

The raw number gain (or loss) is the gain (or loss) of the average scores from the post-tests when compared to the pre-tests for each respective group. The gain (loss) percent is the average of the individual gains (or losses). This explains the discrepancy in some cases when there was an average percentage loss while the average gain in questions was either positive or zero.

The FTC and FLL robotics groups were combined into one group to be compared to the physical science class since neither the FTC nor FLL robotics group had many members. Their combined total (13) was still only about 1/3 that of the physical science class (42). Since the FTC and FLL groups were combined into one group, they could more reasonably be compared to the physical science group to: 1) see if each group had significant gains in their pre-test to post-test scores; 2) see what their effect size was for each test.

The effect size statistical test was developed by Cohen (1992) and determines the significance of the group gains for the size of the group population. An effect size is a statistical calculation that helps the researcher figure out if the independent variable tested had a small, medium, or large affect on the population being tested. It helps to eliminate bias in data that could be caused due to small population sizes (e.g. such as major increases in test scores but only 6 people were part of that population group). The effect size was calculated using the following equation: $\frac{(Post\ Test\ Avg.) - (Pre\ Test\ Avg)}{Average\ of\ Post\ Test\ and\ Pre\ Test\ Std.Deviations}$

An effect size of 0.20 is considered small, 0.50 or greater is medium, and 0.80 or greater is large.

After these tests were run, a type 2 t-test was run to compare the gains of physical science to the gain of the robotics group to see if there was a significant difference in the gains of the two groups.

Table 3: Statistical Significance of Gains within Physical Science & Robotics Populations

	DIRECT Gains T-Test (Type 1)	DIRECT Gains Effect Size	ECCE Gains T-Test (Type 1)	ECCE Gains (Effect Size)
Physical Science	**0.0004**	**0.7621**	**0.0172**	**0.5229**
Robotics	**0.6186**	**0.1534**	**0.0618**	**0.6602**

Table 4: Statistical Significance of Gains Comparison between Physical Science & Robotics Populations

	Questions Gains T-Test (Type 2)	% Gains T-Test (Type 2)
ECCE	**0.5529**	**0.3381**
DIRECT	**0.1794**	**0.2920**

Discussion of Data

When the **robotics** data sets were put together and had the type 1 t-test performed on them, the gains and/or losses were found to be statistically insignificant at the 95% confidence level for the DIRECT (p=0.6186) and the ECCE (p=0.0618) (Table 3). The ECCE would show statistically significant gains at a 90% confidence level probability, but not 95%. The effect size (ES = 0.6602) (Table 3) would suggest that there was a medium effect in score gains with this group. The ECCE gains for robotics were statistically insignificant, but the effect size of the student gains fits within the "medium effect" category. One may have to form their own conclusions based on the group size and t-test probability. At the end of the day, the ECCE gains and DIRECT gains are still not statistically significant and this does not necessarily mean that schools need to adopt robotics programs just to teach about electric circuits.

According to the data, the physics class showed losses in their scores from the DIRECT and ECCE pre-test to post-test. The DIRECT average loss was 22.63% and the ECCE average loss was 10.90% (Table 2). There are several reasons that this could've occurred. 1. The Physics students were never taught electric circuit concepts, but instead were taught about the theories behind how electricity and magnetism work. 2. The Physics students took the posttest the day before the start of Christmas break meaning that students potentially could have been distracted. 3. Since the Physics students didn't know their pre test scores and weren't taught electric circuit concepts, they could've chosen alternative answers on the post tests reasoning that their original answers were wrong based on the new knowledge they've gained from learning about electricity and magnetism theory. One should note that all three of these reasons are purely speculative. The one fact that remains with this group is that they were not taught about electrical circuits.

According to the data, the physical science class saw positive gains. The ECCE average question gain was 1.595 and this gain was significant with 95% confidence (p=0.0172, Table 3). The DIRECT question gain was 2.071 and this gain was also significant with 99% confidence (p=0.0004, Table 3). The effect size in both cases should be considered to be valuable as well as the ECCE effect size (ES = 0.5229) is medium and the DIRECT effect size is medium-large (ES = 0.7621). All in all, one can take away that there was a significant increase in the scores for the DIRECT and ECCE for the physical science class.

As we dive deeper into the data, two trends seem to appear:

- There was a gain in student scores for the robotics group, but that gain was not significant.
- Physical Science students saw a significant increase in their DIRECT and ECCE scores.

As a result of these two trends, the questions on the DIRECT and ECCE were analyzed to find out if they were covered in the FTC robotics or Physical Science curriculum. Questions were then broken up into two groups for each respective test: 1) Questions relating to Physical Science only, and 2) Questions relating to both FTC robotics and Physical Science. One should note that there were some questions left out in this analysis if they didn't fit the realm of being related to either physical science or robotics.

Table 5

Average percentage of correct responses on DIRECT Questions related to BOTH Physical Science & FTC Robotics (4, 7, 8, 10, 16, 17, 19, 25)

Group	% Correct
Physical Science	**38.4%**
Physics	**37.5%**
FTC Robotics	**37.5%**

Table 6

Average percentage of correct responses on DIRECT Questions related to Physical Science ONLY
(1, 2, 5, 9, 10, 11, 13, 14, 18, 21, 22, 23, 26, 27)

Group	% Correct
Physical Science	**40.5%**
Physics	**34.3%**
FTC Robotics	**39.8%**

Table 7

Average percentage of correct responses on ECCE Questions related to BOTH Physical Science & FTC Robotics
(1, 2, 3, 4, 6, 8, 9, 10, 12, 13, 14, 15, 16, 23, 24, 25, 26, 33, 37)

Group	% Correct
Physical Science	**28.6%**
Physics	**21%**
FTC Robotics	**36.9%**

Data Table 8

Average percentage of correct responses on ECCE Questions related to Physical Science ONLY
(17, 18, 19, 20, 21, 22, 27, 28)

Group	% Correct
Physical Science	**37.5%**
Physics	**50%**
FTC Robotics	**39.3%**

In the DIRECT test relating to questions covered by BOTH Physical Science and FTC robotics, both student groups answered those questions correctly at a nearly identical rate. Results were similar for the DIRECT test relating to Physical Science only questions.

In the questions on the ECCE test relating to both Physical Science and FTC robotics, the FTC students answered the questions correctly at a greater rate than the physical science students. In the questions related to physical science only on the ECCE it was a much narrower margin, but the FTC students answered the questions correctly at a slightly better rate.

In order to further compare the results, a type 2 t-test was performed on the data for physical science and robotics groups where their question gains and percent gains were compared against one another to see if the gains by one group was significantly better than the gains achieved by the other group for the ECCE and DIRECT tests. The results of the test showed that the gains for the robotics group when compared to the physical science group was NOT SIGNIFICANT for the question gains ($p=0.5529$) or the percent gains ($p=0.3381$) at a 95 percent confidence level on the ECCE test. The results were the same on the DIRECT at a 95 percent confidence level for the question gains ($p=0.1794$) and the percent gains ($p=0.2920$) (Table 4).

On a final note in dealing with the physical science only questions on the ECCE, one should note that the physics students out-scored both groups in this area, getting the questions correct 50% of the time. One must note that Physics students took Physical Science 2-3 years earlier (depending on the student) and since these students are older, it may indicate that the questions in general were simpler to understand based on the (in general) higher level of cognitive development of the Physics students. My examination of the two tests suggests that the ECCE is more theory based. Theory types of questions do tend to require a higher level of thinking which may be easier for the physics students.

Chapter 4: Reflection on the Project

The results of this project may be used to inform personal classroom practice and the wider professional community.

1. Robotics is another way that electrical circuit concepts can be taught in the classroom. The data shows that there is no significant difference in the gains in scores between physical science and robotics on either the DIRECT or ECCE tests (table 4), which means that using a robotics curriculum is at the very least comparable to traditional electricity curricula in terms of learning gains evidenced by these specific tests on learning electric circuit concepts. On the flip side of this, results also seem to indicate that neither approach was as effective as the results of Engelhardt and Beichner (2004). It was still effective in causing statistically significant increases in student understanding, at least as evidenced by the assessment scores. Granted, this was one study performed under specific circumstances and it was not a big increase (it would've been nice to see them double) in scores, but again the statistics do tell that the scores improved. I, myself would need to teach these units several times to see if the results were typical for the population that was tested.

2. Robotics could be another way for schools to reach students who may not do as well in the traditional classroom setting as compared to a group/club where the concepts are applied to a practical application such as the building and programming of a robot. In other words, schools could take the initiative to start FIRST Lego League and FIRST Tech Challenge teams in order to further reach and educate students in the STEM areas who might have more difficulty learning in the traditional classroom setting. In addition to this, robotics would be reinforcing what students learn in a physics and/or physical science course and vice versa.

3. Looking for different approaches to teach electrical circuits could lead to more teachers looking for and implementing programs like FLL and FTC and other STEM-related programs. By doing this, teachers can reach out and expand their curriculum and teaching methods in order to offer more

hands on opportunities for students. Based on anecdotal observations, robotics curricula could in turn create classroom environments where students are more engaged and learn about the inter-connected nature of subjects as opposed to the compartmentalized nature that they get in a traditional classroom setting where students learn one subject but aren't able to connect it to others.

This project was inspired through past projects and also through the inquiry into how students learn in an after-school club setting where they learn a practical application of subjects. This project could be continued and repeated and/or extended with future classes as electricity is a topic that will continue to be taught in physical science and physics as well as in the after-school setting of the robotics clubs. Conceptual understanding of electricity is one of the requirements of the Next Generation Science Standards of the Iowa Core Curriculum (specifically standards HS-PS1-3, HS-PS2-4, HS-PS2-5, HS-PS3-5) (NGSS, 2013), so it is something that has to be taught in physical science at because it is one of only two required science classes for students at our school (the other is sophomore biology). This instruction will help prepare them for the challenges that college science classes may present them.

One thing I noticed when examining scores for all groups, whether it be on the ECCE or on the DIRECT, was that the scores themselves were relatively low. When the DIRECT posttest scores from the project were compared to the DIRECT scores from Engelhardt and Beichner's (2004) study, I noticed that their average scores (even though they only tested students one time) were already higher than that of the posttest scores for this project. This got me thinking and reflecting about what I could (and should) do differently the next time I teach electrical circuit concepts in physics, physical science, and robotics as this was the first time that I taught these topics in any of my science classes. For starters, a future study could include a physics course in which direct instruction on electrical circuits could be conducted which would allow me to compare a high school robotics curriculum to a high school physics curriculum.

In a previous chapter, it was mentioned how Iowa has adopted the NGSS for its new science standards. The more one reads the NGSS standards, understands all of what needs to be covered both in breadth and depth, the more one realizes that A LOT of time needs to be spent teaching these standards to students. Currently, the students in my school only take one year of required science where they learn about physics, chemistry, and earth science standards (currently titled physical science). This is simply not enough time if the students are to learn about all the standards in these three areas along with learning the crosscutting concepts and science and engineering practices that go with them. In order to treat the new NGSS standards with the respect they deserve, I would recommend that the curriculum at my school be changed in which two years of “physical science” would be required instead of one where the first year would be Chemistry and the second year Physics. Earth Science would be its own separate required course that could be taken anytime. Biology would not be taken until one’s eleventh grade year (after the Chemistry and Physics years) since Chemistry and Physics help to build the foundation for a stronger understanding of Biology. In terms of Physics, the basic required course for everyone again would occur during the tenth grade year and would start with “Motion and Stability: Forces and Interactions” (HS-PS2) where students would first learn about force, motion, and Newton’s Laws. This would set the stage for learning about electricity in order for the performance expectations to be met in the latter half of the above mentioned category as I think having students learn about forces helps them to understand the idea of charge in an electrical circuit and how it is “pushed” through wires. Students would also learn about the fifth expectation of energy (HS-PS3-5) when learning about electricity and magnetism. In the later part of the year, students would be learning and demonstrating the performance expectations of, “Waves and Their Applications in Technology for Information Transfer”. Learning about electricity first sets the stage for better understanding of the concept of waves and how they work. Altogether, these are my thoughts about how to put together the science curriculum in a school so that it is taught and understood by all, but these ideas are based on my own research, and more examining of data would have to be done to determine its effectiveness.

In the project, electrical circuits were taught in the first trimester of class without any preceding physics concepts being taught. As a result of my findings from the project, an ideal situation would include having ninth graders take a year of basic Chemistry, which would help to set the basis for electricity when students learn about the electron (when learning about the atom). In the tenth grade year, students would be taking a basic physics course where they would learn about forces (and motion) during the first half of the year, which would set the stage for learning about electrical circuits.

The reasoning for having physics concepts taught in tenth grade is so that students could take an Algebra I class during their ninth grade year. Since the students would be one year stronger in math, this would make learning the physics concepts much simpler as there is a lot of math involved in learning force and motion. Algebra I in my school covers those specific math concepts used in teaching the physics concepts.

Granted, this was my first year of teaching electrical circuits and with experience as a result of doing this project, I have gained some insights about how to be more effective in teaching (of which you will continue to read about in this chapter). The ideas presented about changing the length of a required course are my ideas at this point based on my own research, but I would need to keep examining student data as I make course changes in order to figure out what an ideal instructional sequence would be.

Physics (which is currently an elective course and would remain an elective course) would ideally go from being a one-year course to being a two-year course. The first year of physics would be all about motion, force, and energy (Newtonian physics). Since students would have a much stronger conceptual understanding of forces, this would set the stage (like physical science) for teaching electricity and magnetism in the second year course in physics (once electricity and magnetism were completed, other advanced topics could be pursued). Modeling Instruction (American Modeling

Teachers Association, 2015) uses this same approach in how its curriculum is set up for physics where mechanics is the emphasis for most of the year in order to effectively address student preconceptions. In both physics and physical science, I do feel that a better understanding of forces would've assisted in helping students understand electrical circuit concepts.

Robotics in this study was an after school activity, but the ideal situation would be to make this into a class. Most of the time in this "after school club setting" is spent working on the robot, engineering notebook (FTC), individual competitions and qualifying competition (FTC), project (FLL), judges interview(s) (both), and community outreach (FTC) that hardly any time is actually spent helping these young minds learn about the science and engineering practices and core concepts that are truly at the heart of what they're doing. If FLL and FTC robotics could be turned into classes, more time could be spent with the students helping them to understand the science and engineering concepts behind the designing of their robot for the specific competition at hand and also generally speaking. Time could also be spent helping them tie together how an electrical circuit works and how this applies to not only wiring, but also the programming of their robot. These features I think would strengthen their conceptual understanding and make them more successful not only as individual learners, but also as a team going forward. Robotics would still remain an enrichment-style course for interested students.

Regardless of whether I am teaching physics, physical science, or robotics, I will be using more formative assessments so that I could collect data on what the students know and understand during the process of learning about electrical circuits. I would also do an analysis of the individual instrument (ECCE and DIRECT) questions so that more time could be spent on concepts where the majority missed the questions as opposed to concepts where the majority of students got the questions correct on the pretest. Due to the time constraints of the project, formative assessment is one area where I do not feel like I did very well. My focus in this project was more on getting through the material rather than taking the time to figure out if students truly “got it” or not. As one can see, this is obviously not characteristic of effective instruction found in the Iowa Core. When a person teaches a subject for the first time, they tend to struggle with it and learn along with the students as many teachers can empathize. In time, the more practice that I gain with this, the better I hope to become in teaching the concepts and in using the formative assessment process to help my students gain conceptual understanding. I feel that increased use of formative assessments, along with the other changes previously mentioned (in addition to time and practice in teaching these concepts), will help my students achieve greater score gains and greater conceptual understanding than what they did in this project.

The preceding project can be modified for future use in which one could examine the concepts to be addressed within the electricity curriculum, and examine the questions on the ECCE and DIRECT for evidence of student learning tied to specific standards. This way an analysis could be done on how many students already correctly understand the concept so that instructional time could be assigned based on the specific concepts identified that the majority of students didn’t show evidence of understanding. Those who already show conceptual understanding can work on a higher level of understanding of the concept. Granted at this time I haven’t had the opportunity to investigate what types of labs or projects are out there for advanced students to work on, but the goal would be to find them so that students could gain that higher level of understanding. In other words, further attention needs to be paid in the formative assessment process. With this idea in mind, if further and better attention is paid to:

- Identifying what the learning gaps are,
- Giving descriptive feedback in the learning process,
- Making instructional modifications based on student evidence,
- Scaffolding ongoing instruction, and

- Eliciting evidence of learning by the teacher, student, and student's peers and then interpreting the evidence

The teacher can identify whether the student has learned the concept or if there is still a learning gap in which the teacher has the student repeat this cycle to help the student(s) learn the concept. The student would be repeating the cycle of learning the concept rather than completing some kind of a summative exam to end the cycle of the unit. Using the formative assessment process in a more proper fashion should help conceptual achievement.

Doing this project has helped me to realize that I need to implement question-by-question analysis of student responses on pre-assessments so that I can more carefully design my lessons with all learners in mind.

This project has helped me to be more active in trying to elicit evidence of learning from my students so that I can be more aware of what my students know and don't know. Since I've spent more time eliciting evidence and analyzing data, it has led me to continuously think about what I need to do as a science teacher to help my students gain more and better understanding of science concepts. It made me think of what I need to do better, but also what I need to do differently in order for each student to be helped in their learning. It has led me to start doing more differentiated instruction in my class so that I can help those who struggle gain the basic conceptual understanding, but yet also give those who already have the basic understanding an opportunity to display their greater depth of knowledge by giving them a challenge that makes them stretch their mind further and shows them how they can apply these concepts to other areas. For example, in my Chemistry class, when I had a student who really struggled with writing chemical formulas, I worked with the student one on one to help identify what the issue was and worked with them on several examples before they mastered the concept. The rest of the class worked on a challenge lab where they had to figure out the identities of unknown chemical compounds based on molar relationships (when given additional information of course). I've figured out that if I collect enough evidence (and each teacher needs to determine what the right amount is for them), the more informed I am of what my students know and don't know and that if I continue in the process of collecting evidence, the more easily I'll be able to figure out whether a student truly "gets it" or not. This in turn will help me to decide whether or not to move onto something else in my teaching.

Doing this project has given me four new directions and ambitions for professional growth for the future.

1) Diving deeper into the formative assessment process: In the fall of 2015, I was approached by my administrator to become part of a class at AEA 267 where we would be learning more about formative assessment. One of my school's professional development goals has been to create and use learning goals and success criteria in our own classes and I was one of the first teachers in the high school to really embrace this process. As a result of this, my administrator has pointed me out as being a leader in this area. Knowing the focus of my creative component project, he urged me to take this class so that I could also connect my project to my own professional development as an instructor. Now, at the time of this writing, I am deep into this class and am feeling as if I'm learning so much more about how to become a better instructor and to help my own students become better thinkers and learners by engaging them in the formative assessment process with the ultimate goal of closing the gap between low and high achievers. This has also led to me implementing more differentiated instruction in my classes so that my higher achievers will have more challenges to stretch their minds and display greater depths of knowledge.

2) I do think that I would like to pursue a STEM endorsement so I can apply what I know as a science teacher to other subject areas and help my students make more connections, better connections and stronger connections between how science relates to other subjects and how it can be applied in all areas. I figure that this may also lead to different opportunities in the future not only for me, but especially for my students.

3) Since most/all school districts are now either starting or have their Teacher Leadership Compensation (TLC) grants in place, I do think that I would like to help others become engaged not only in the formative assessment process, but also I'd like to help out my fellow science teachers in improving their own practice in any ways that they feel they could use improvement. I'm thinking that I would like to become either a mentor teacher or a learning lab instructor as part of the TLC grant. Since my school is in a unique situation where it is part of a TLC consortium with three other schools, I feel this could be a way where I could help out several science teachers and expand upon the work I've already done.

4) I'm lastly thinking this may lead me to wanting to become a "National Board Certified Teacher"(National Board for Professional Teaching Standards, 2016). This would allow for me to gain a better understanding of the teaching standards and would drive me to continuously improve my own instructional practices.

In closing, this project is only the tip of the iceberg for what could be some even better and greater research in the area of robotics instruction and how it can help to improve science classroom instruction. It not only can contribute to comparisons of smaller vs. larger classrooms and robotics (applied conceptual) instruction vs. traditional instruction, but it can also lead to further understanding of the formative assessment process and better instructional practices so that we can help ALL students gain conceptual understanding of the Next Generation Science Standards and the Iowa Core. It is also potentially the tip of the iceberg in terms of future professional development directions for many teachers of STEM areas, not just myself!!

References

American Modeling Teachers Association (2015). Modeling Instruction Curriculum Resources, Physics, E&M. Retrieved from: https://www.eweblife.com/prm/AMTA/membership-page/view?record=23

Barker, B., and Ansorge, J. (2007). Robotics as means to increase achievement scores in an informal learning environment. *Journal of Research on Technology in Education, 39*(3), 229-243.

Barnes, D. (2002). Teaching introductory Java through Lego Mindstorms models. *Proceedings of the 33rd Special Interest Group on Computer Science Education technical symposium on computer science education*. Retrieved from: http://portal.acm.org/citation.cfm?id=563397&coll=GUIDE&dl=GUIDE&CFID=11715560&CFTOKEN=40703716

Beer, R., Chiel, H., and Drushel, R. (1999). Using autonomous robotics to teach science and engineering. *Communications of the Association for Computing Machinery*, 42(6), 85-92.

Bonvillian, W. (2002). Science at a Crossroads. *The Federation of American Societies for Experimental Biology Journal, 16*, 915-921.

Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological Bulletin,* 112(1), 155-159.

Engelhardt, P., and Beichner R. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal of Physics*, 72(1), 98-115.

Fagin, B., and Merkle, L. (2002). Quantitative Analysis of the Effects of Robots on Introductory Computer Science Education. *ACM Journal of Educational Resources in Computing, 2*(4), 1-18.

Fagin, B., and Merkle, L. (2003). Measuring the effectiveness of robots in teaching computer science. *Proceedings of the 33rd Special Interest Group on Computer Science Education technical symposium on computer science education*. Retrieved from: http://portal.acm.org/citation.cfm?id=611994&coll=GUIDE&dl=GUIDE&CFID=11715560&CFTOKEN=40703716

Flowers, T., and Gossett, K. (2002). Teaching problem solving, computing, and information technology with robots. *Journal of Computing Sciences in Colleges, 17*(6), 45-55.

Gindling, J., Ioannidou, A., Loh, J., Lokkebo, O., and Repenning, A. (1995). A rule-based programming, simulation and manipulation environment for the LEGO programmable brick. In *Proceeding of Visual Languages* (pp. 172-179). Darmstadt, Germany: IEEE Computer Society Press.

Gonzales, P., Guzmán, J.C., Partelow, L., Pahlke, E., Jocelyn, L., Kastberg, D., and Williams, T. (2004). *Highlights From the Trends in International Mathematics and Science Study (TIMSS) 2003* (NCES 2005–005). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office.

Hmelo, C., and Bransford, J. (1997). A theory-driven approach to assessing the cognitive effects of PBL. *Instructional Science, 25*(6), 387-408.

Iowa Department of Education (2010). *Iowa Core Curriculum: 21st Century Skills—Technology Literacy.* Des Moines, IA. Retrieved from: https://www.educateiowa.gov/sites/files/ed/documents/K-12_21stCentSkills_0.pdf

Iowa Department of Education (2010). *Iowa Core: Characteristics of Effective Instruction*. Des Moines, IA. Retrieved from: https://iowacore.gov/content/characteristics-effective-instruction-0

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Lemke, M., Sen, A., Pahlke, E., Partelow, L., Miller, D., Williams, T., Kastberg, D., and Jocelyn, L. (2004). *International outcomes of learning in mathematics literacy and problem solving: PISA 2003 results from the U.S. perspective.* Washington, DC: U.S. Department of Education, National Center for Education Statistics.

Linn, J. (2012, August 16). STEM scale-up programs ready for statewide distribution. *Iowa governor's STEM advisory council*. Retrieved from: http://www.iowastem.org/imsep/media/press-releases/stem-scale-programs-ready-statewide-distribution

Linn, J. (2014, February 19). Governor's STEM advisory council announces 10 scale-up programs for 2014-15. *Iowa governor's STEM advisory council*. Retrieved from: http://www.iowastem.gov/sites/default/files/press_release-_scale_up_2014-15_0.pdf

Marx, J. and Cummings, K. Noramlized change. *American Journal of Physics, 75(1), 87-91.*

Mauch, E. (2001). Using technological innovation to improve the problem-solving skills of middle school students: Educators experiences with the LEGO Mindstorms Robotic Invention System. *The Clearing House, 74*(4), 211-213.

Moore, V. (1999). Robotics: Design through geometry. *Technology Teacher, 59*(3), 17-22.

Moundridou, M., and Kalinoglou, A. (2008). Using LEGO Mindstorms as an instructional aid in technical and vocational secondary education: Experiences from an empirical case study. *Lecture Notes in Computer Science, 51*(92), 312-321.

National Board for Professional Teaching Standards (2016). http://boardcertifiedteachers.org/

NGSS Lead States (2013). *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

Norman, G., and Schmidt, H. (1992). The Psychological basis of problem-based learning: A Review of the evidence. *Academic Medicine, 67*(9), 557-565.

Nourbakhsh, I., Crowley, K., Bhave, A., Hamner, E., Hsiu, T., Perez-Bergquist, A., Wilkinson, K. (2005). The Robotic autonomy mobile robotics course: Robot design, curriculum design and educational assessment. *Autonomous Robots, 18*, 103-127.

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

Robinson, M. (2005). Robotics-driven activities: Can they improve middle school science learning? *Bulletin of Science, Technology & Society, 25*(1), 73-84.

Rogers, C., and Portsmore, M. (2004). Bringing engineering to elementary school. *Journal of STEM Education, 5*(3), 17-28.

Steinberg, M., and Wainwright, C. (1993). Using models to teach electricity—The Castle Project.

The Physics Teacher, 31(6), 353-357.

Stolkin, R., Hotaling, L., Sheryll, R., Sheppard, K., Chassapis, C., and McGrath, E. (2007, September). A Paradigm for vertically integrated curriculum innovation – How curricula were developed for undergraduate, middle and high school students using underwater robotics. Paper presented at the International Conference on Engineering Education, Coimbra, Portugal. Retrieved from: http://icee2007.dei.uc.pt/proceedings/papers/355.pdf

Sullivan, F. (2008). Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching, 45*(3), 373-394.

Pitsco Inc. (2011). Tetrix Getting Started Guide

Thornton, R., and Sokoloff, D. (Unpublished Test). The Electric Circuits Concept Evaluation.

Wadsworth, B. (1996). *Piaget's theory of cognitive and affective development (5th edition).* White Plains, NY: Longman.

Appendix

Data Table A1

Physical Science Scores on DIRECT & ECCE Pre & Post-Tests

Student #	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
1	11	10	9	10
2	8	9	9	6
3	8	13	7	16
4	10	8	5	3
5	11	13	11	9
6	10	9	8	9
7	10	9	9	7
8	10	11	10	8
9	4	8	9	8
10	1	8	13	12
11	8	10	9	12
12	7	11	4	11
13	9	10	9	10
14	7	4	7	5
15	8	10	7	15
16	7	8	7	13
17	4	12	3	10
18	6	12	5	17
19	8	17	6	13
20	11	10	10	9
21	9	11	11	11
22	7	9	11	12
23	6	9	7	8
24	13	13	7	11
25	11	9	5	7
26	4	6	9	10
27	5	10	10	13
28	5	4	8	3
29	4	10	10	5
30	8	6	6	2
31	7	11	5	9

Student #	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
32	8	6	8	17
33	12	9	7	14
34	7	8	7	10
35	5	15	**9**	13
36	9	15	12	11
37	10	10	5	2
38	11	8	9	7
39	7	14	13	12
40	7	13	5	9
41	6	8	8	7
42	12	12	9	9

DIRECT Pre-Test Avg.	**7.88**
DIRECT Pre-Test Std. Dev:	**2.63**
DIRECT Post-Test Avg.	**9.95**
DIRECT Post-Test Std. Dev:	**2.80**
DIRECT Question Gain:	**2.07**

ECCE Pre-Test Avg.	**8.05**
ECCE Pre-Test Std. Dev:	**2.37**
ECCE Post-Test Avg.	**9.64**
ECCE Post-Test Std. Dev:	**3.73**
ECCE Question Gain =	**1.60**

Data Table A2

Physical Science % Increase or Decrease (-) in scores from DIRECT & ECCE Pre-Test to Post-Test

Student #	DIRECT % CHANGE	ECCE % CHANGE
1	-9.09%	4.00%
2	4.76%	-33.33%
3	23.81%	33.33%
4	-20.00%	-40.00%
5	11.11%	-18.18%
6	-10.00%	3.85%
7	-10.00%	-22.22%
8	5.26%	-20.00%
9	16.00%	-11.11%
10	25.00%	-7.69%
11	9.52%	12.00%
12	18.18%	23.33%
13	5.00%	4.00%
14	-42.86%	-28.57%
15	9.52%	29.63%
16	4.55%	22.22%
17	32.00%	22.58%
18	26.09%	41.38%
19	42.86%	25.00%
20	-9.09%	-10.00%
21	10.00%	
22	9.09%	4.35%
23	13.04%	3.70%
24		14.81%
25	-18.18%	6.90%
26	8.00%	4.00%
27	20.83%	12.50%
28	-20.00%	-62.50%
29	24.00%	-50.00%
30	-25.00%	-66.67%
31	18.18%	13.79%
32	-25.00%	34.62%

33	-25.00%	25.93%
34	4.55%	11.11%
35	41.67%	16.00%
36	30.00%	-8.33%
37		-60.00%
38	-27.27%	-22.22%
39	31.82%	-7.69%
40	27.27%	13.79%
41	8.70%	-12.50%
42		

DIRECT Average % Gain = 6.14%

ECCE Average % Loss = -2.46%

Data Table A3 -- Lego League Scores on DIRECT & ECCE Pre & Post-Tests

Student #	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
1	4	9	7	8
2	15	6	1	6
3	15	13	13	5
4	6	7	2	4
5	3	8	6	10

DIRECT Pre-Test Avg.		**8.6**
DIRECT Pre-Test Std. Dev:		**5.94**
DIRECT Post-Test Avg.		**8.6**
DIRECT Post-Test Std. Dev:		**2.70**
DIRECT Question Gain/Loss	**=**	**0**
ECCE Pre-Test Avg.		**5.8**
ECCE Pre-Test Std. Dev:		**4.76**
ECCE Post-Test Avg.		**6.6**
ECCE Post-Test Std. Dev:		**2.41**
ECCE Question Gain	**=**	**0.8**

Data Table A4 -- Lego League % Increase or Decrease (-) in scores

from DIRECT & ECCE Pre-Test to Post-Test

Student #	DIRECT % CHANGE	ECCE % CHANGE
1	20.00%	3.70%
2	-60.00%	15.15%
3	-13.33%	-61.54%
4	4.35%	6.25%
5	19.23%	14.29%

DIRECT Avg. % Loss: -5.95%
ECCE Avg. % Loss: -4.43%

Data Table A5 -- FTC Robotics Scores on DIRECT & ECCE Pre & Post-Tests

Student #	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
Name	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
1	9	14	11	10
2	10	9	6	13
3	13	14	7	9
4	7	7	9	14
5	8	9	3	5
6	4	7	6	9
7	12	12	9	9
8	8	6	8	17

DIRECT Pre-Test Avg. 8.88
DIRECT Pre-Test Std. Dev. 2.85
DIRECT Post-Test Avg. 9.75
DIRECT Post-Test Std. Dev. 3.20
DIRECT Question Gain = 0.88

ECCE Pre-Test Avg. 7.38
ECCE Pre-Test Std. Dev. 2.45
ECCE Post-Test Avg. 10.75
ECCE Post-Test Std. Dev. 3.73
ECCE Question Gain = 3.38

Data Table A6 -- FTC Robotics % Increase or Decrease (-)

in scores from DIRECT & ECCE Pre-Test to Post-Test

Student #	DIRECT % CHANGE	ECCE % CHANGE
1	25.00%	-9.09%
2	-10.00%	25.00%
3	6.25%	7.41%
4		20.00%
5	4.76%	6.45%
6	12.00%	10.71%
7		
8	-25.00%	34.62%

DIRECT Avg. % Gain = 2.17%
ECCE Avg. % Gain = 13.59%

Data Table A7 -- Physics Scores on DIRECT & ECCE Pre & Post-Tests

Student #	DIRECT Pre-Test (Max 29)	DIRECT Post-Test (Max 29)	ECCE Pre-Test (Max 34)	ECCE Post-Test (Max 34)
1	14	10	8	14
2	11	9	8	7
3	13	6	12	7
4	11	7	8	7
5	8	13	10	10

DIRECT Pre-Test Avg.	**11.4**
DIRECT Pre-Test Std. Dev.	**2.30**
DIRECT Post-Test Avg.	**9**
DIRECT Post-Test Std. Dev.	**2.74**
DIRECT Question Loss =	**-2.4**
ECCE Pre-Test Avg.	**9.2**
ECCE Pre-Test Std. Dev.	**1.79**
ECCE Post-Test Avg.	**9**
ECCE Post-Test Std. Dev.	**3.08**
ECCE Question Loss =	**-0.2**

Data Table A8 -- Physics % Increase or Decrease (-) in scores from DIRECT & ECCE Pre-Test to Post-Test

Student #	DIRECT % CHANGE	ECCE % CHANGE
1	-28.57%	23.08%
2	-18.18%	-12.50%
3	-53.85%	-41.67%
4	-36.36%	-12.50%
5	23.81%	

DIRECT Avg % Loss = -22.63%
ECCE Avg. % Loss = -10.90%