A longitudinal study of the effects of a high school robotics and computational thinking class on academic achievement

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***Abstract*—While there has been a rising interest in computational thinking (CT) and a push to include it into the K-12 curriculum, there is little empirical evidence that a class that teaches CT will have any measurable long-term effects on student performance. Using robotics as an example of CT instruction, I propose to examine a high school that has had a large number of robotics students over the past six years to find evidence for the long-term benefits of CT. I will analyze school records (e.g. STEM class enrollment, STEM test scores, SAT scores) for differences between robotics and non-robotics students and compare interviews with selected students.**

Keywords—robotics, computational thinking, longitudinal

I. Introduction

In 2006, Wing [1] wrote an influential opinion piece that described "computational thinking" (CT) as the way that computer scientists think about problems, design systems, and understand behavior. She asserted that CT is applicable to a wide variety of other fields and that it should be considered a foundational skill to be taught to all students. Since then, CT has been the subject of many papers and panels, e.g. [2]-[5]. Proponents have advocated for CT instruction in public K-12 education and have hypothesized how students with CT skills, such as problem decomposition and abstraction could apply them to medicine, law, and other disciplines [6]. While enthusiasm for the subject is high, the connection between CT skills, and long-term benefits is still theoretical. There is little direct evidence that actual CT students are able to apply the skills to other disciplines to perform better than students who do not have CT experience.

II. Background

As an emerging field, the exact definition and boundaries of CT are still forming [6]. To move the field forward, the Computer Science Teachers Association and International Society for Technology in Education have published an operational definition that states:

> CT is a problem-solving process that includes (but is not limited to) the following characteristics:
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> - Formulating problems in a way that enables us to use a computer and other tools to help solve them
> - Logically organizing and analyzing data
> - Representing data through abstractions, such as models and simulations
> - Automating solutions through algorithmic thinking (a series of ordered steps)
> - Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
> - Generalizing and transferring this problem-solving process to a wide variety of problems [7, p7]

While there have been disagreements on the precise definition of CT, one principle that is commonly held is that CT is not the same as programming. "CT is an approach to solving a problem that empowers the integration of technologies with human ideas" [7]. Some researchers believe that CT is a prerequisite skill for programming [8]. Thus separated from programming, it is argued that parts of CT can be taught outside of a traditional programming class.

One non-traditional field where CT skills may be learned is through educational robotics, such as LEGO MINDSTORMS or VEX. Through robotics, students are exposed to open-ended problem-solving tasks that require design, implementation, and debugging. In addition, students are required to program the microcontroller to accept input from the sensors and drive the motors. Though there is some programming, they do not learn a general purpose programming language as in a traditional programming class. Depending on the age of the students and the scope of the curriculum, a full year class in robotics has the potential to address most or all of the CT characteristics listed above.

While there have been some studies on the effects of robotics education, they have typically had strong limitations. Barker and Ansorge [9] tested the domain knowledge gained by students, but had a very small number of students and only tested information about robotics instead of transfer to other subjects. Lindh and Holgersson [10] and Hussain, Lindh, and Shukur [11] tested a large number of students in math and problem solving skills, but they did not follow the students for multiple years to find if the gains were maintained over time. Similarly, Iturrizaga [12] had examined several hundred students on a diverse set of subjects, such as math, technology and reading, and triangulated his data with interviews, but did not follow up with his participants over multiple years. Gibbons [13] measured the effect of a robotics intervention on convergent and divergent thinking, but the intervention time was only a few hours long and the post-tests occurred shortly after the intervention. While not strictly a study on robotics, Wolfgang, Stannard, and Jones [14] followed students from pre-school through high school. They compared students who were proficient in constructing with LEGO when they were young against ones who were not, using standardized test scores and enrollment in advanced STEM classes. While certainly taking a long-term perspective with transfer to other subjects, the study has less than 20 subjects. None of these studies were able to study a large number of students who have had a long, consistent intervention and examine the effects on other academic subjects over multiple years.

III. Study proposal

I have identified a public high school in the southern United States that offers a full year educational robotics elective class for academic credit. Over the past six years, between 400 and 600 students have taken the class. The curriculum incorporates topics identified by [7] as CT skills, such as algorithmic thinking, and identifying and implementing possible solutions. My project will use existing school records to compare the robotics students to control groups of students who are enrolled in the same school, but did not enroll in robotics. The research hypothesis is that students who complete a robotics course will outperform students who do not take robotics on:

1. Math/science standardized grade-level test scores
2. Grades in math/science classes
3. Enrollment and grades in elective math/science classes, including AP scores
4. SAT/ACT scores

Since I am particularly interested in long-term effects, I will be emphasizing the scores, grades, and elective enrollment that occur several years after the robotics instruction.

Where appropriate, I will use matched data sets by selecting control group students so that each robotics student will have a corresponding non-robotics student that has one or more similar demographic or previous achievement measure (e.g. gender, ethnicity, or previous math standardized scores). This will allow the matching variables to be used as covariates in an ANCOVA statistical analysis.

In additional to the quantitative data, I will also conduct semi-structured interviews with a number of students who have recently completed the robotics classes. The questions they will be asked include:

1. What did you learn in robotics class?
2. What did you expect to learn in robotics when you enrolled in the class?
3. What did you not learn in robotics that you wish you did?
4. What factors influenced your decision to enroll in the class?
5. Are you more likely to take more STEM classes than before you took robotics?
6. What did you learn in robotics that you believe will be useful in your other classes or in your life?

A number of students who completed the robotics class in previous years will also be interviewed. In addition to some of the questions above, they will also be asked:

7. What skills did you learn in robotics class that you still use?
8. Did your robotics experience cause you to enroll in classes they would not have enrolled in otherwise?
9. Did robotics change the way you approach challenges?
10. Did robotics make you more enthusiastic about STEM classes or a career in a STEM field?

The quantitative data and the interviews will be analyzed separately, but also compared to each other. While it is likely that the results of the data sources will reinforce each other to provide a consistent conclusion, it is also possible that they will contradict. Robotics may leave a strong impression on the students, but have non-significant effects on test scores and class enrollment. Robotics may also have more subtle effects, nudging the students in a particular direction, but outside of their perception. In former case, we must stop and revisit whether our chosen quantitative instruments are the appropriate ones to measure effects of the curriculum.

IV. Summary

In the past few years, there has been a tremendous push to incorporate CT into an already crowded K-12 curriculum. The rationale for this movement is the theoretical hypothesis that students who study CT will be able to apply this knowledge to a wide variety of fields that they will encounter in future. While the arguments are persuasive and the benefits tantalizing, there has been relatively little empirical evidence that learning CT skills results in higher academic performance or the transfer of skills into other domains. Robotics has a high overlap with CT skills and is already being taught in some schools. However, previous studies on robotics classes have frequently suffered from small sample size, limited intervention time, inconsistent instruction, or a lack of a long-term study.

This proposed study focuses on a high school where over the last six years, a relatively large number of students have completed a full year academic robotics class. There are a significant number of samples, extended intervention time, relatively consistent instruction, and student data for multiple years after the class. Using a combination of high school transcripts and semi-structured interviews, I will statistically analyze the quantitative data and triangulate with the interviews. When completed, this longitudinal study will provide some empirical research to support or refute the assertion about the usefulness of robotics (and by extension, CT) education.

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