

Computational Thinking in the Science Classroom: Preliminary Findings from a Blended Curriculum

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Abstract: Computation is changing the way modern science is conducted, but relatively few students have access to or take courses that adequately prepare them for the increasingly technological nature of these fields. Further, the students who do study computational topics tend to not reflect the greater student body, with female and minority students being disproportionately underrepresented. To address this issue, we propose embedding computational thinking content into high school science coursework. This paper presents initial findings showing that despite significant gaps in attitudes and confidence between male and female students towards science and computational thinking, no difference in aptitude between genders was found. Additionally, female students who participated in the project showed improved confidence with computational thinking and interest in scientific fields.

Keywords: Computational Thinking; Computational Science Education; High School Science Classrooms

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Introduction

Computer science education in the United States faces two interrelated challenges. First, there is significant concern that our education system is not producing enough people with computational thinking skills to fill both current and projected industry demand (National Research Council [NRC], 2011; President's Council of Advisors on Science and Technology, 2010). Second, more than any other major STEM discipline, women and minorities are significantly underrepresented in the educational pipeline and in the workforce (Ericson & Guzdial, 2014; Hill, Corbett, & St Rose, 2010; Zweben & Bizot, 2012). According to the National Science Foundation's National Center for Science and Engineering Statistics (2013), female undergraduates enrollment has remained below 30% since 1991. Despite numerous ongoing college, university, and national campaigns targeting women, the numbers continue to drop in STEM (National Science Board, 2012) and CS (Klawe and Levenson, 1995) enrollments. Among the reasons for these trends, researchers have identified a lack of interest and confidence (Margolis, Fisher, & Miller, 2000), limited visibility of positive role models (Townsend, 2002), and lack of positive experiences with both computer science and in STEM fields more broadly (AAUW, 1994; Miliszewska, Barker, Henderson, & Sztendur, 2006).

Fortunately, there are a number of promising efforts underway to address these challenges. These efforts include projects intended to greatly expand student exposure to computer science and programming (code.org, CE21, CS10K, etc.); pending legislation that would allow computer science to count as a core scientific discipline; and efforts to make computer science a requirement for high school graduation. These efforts are primarily focused on developing a new sequence of elective CS courses leading to a redesigned Advanced Placement (AP) CS course.

The success of a separate elective CS course sequence rests on several key assumptions. The first is that stand-alone course content will be appealing enough to attract a diverse range of students. Otherwise there is a danger that new course offerings will perpetuate the existing gap for underrepresented groups. The second assumption is that qualified teachers for these new courses can be found or trained and retained. Retention of teachers is of particular concern due to a surplus of high-paying jobs in the tech industry. Finally, there is an assumption that students will have room in their already-full high school schedules to take elective CS courses.

In this paper we present preliminary findings from our three-year study supporting math, chemistry, biology, and physics teachers in embedding computational thinking enhanced lesson plans into their curriculum. This method directly addresses pursuing an embedded strategy that brings CT into classrooms that addresses the challenges mentioned above. Instead of introducing stand-alone computing courses to schools, we bring CT into existing math and science classrooms. Through developing CT enhanced activities that fit within existing STEM classes, and training in-services STEM teachers to teach these lessons, we can draw on the existing teacher workforce and provide computing instruction to all students through the courses they are already taking. Below we briefly present the theoretical framework that motivates this work, the study design

that accompanies this project, and the preliminary findings from our three-year project, highlighting our successes and the challenges we still face moving forward.

Why Bring Computational Thinking to STEM Classrooms

A primary motivation for introducing CT practices into science and mathematics classrooms is in response to the increasingly computational nature of STEM disciplines as they are practiced in the professional world (Foster, 2006). Computation is now an indispensable component of STEM disciplines (Henderson, Cortina, & Wing, 2007, p. 195). This rise in importance of computation with respect to the STEM fields has been recognized both by those within the STEM education communities and computer science education organizations (ACM/IEEE-CS Joint Task Force on Computing Curricula, 2013). Bringing computational tools and practices into STEM classrooms gives learners a more realistic view of what STEM fields are and better prepares students for STEM careers (Augustine, 2005).

Preparing students for the modern STEM landscape is not the only reason to bring CT into STEM classrooms. From a pedagogical perspective, the thoughtful use of computational tools and skillsets can deepen learning of STEM content (National Research Council, 2011; Repenning, Webb, & Ioannidou, 2010; Sengupta, Kinnebrew, Basu, Biswas, & Clark, 2013; Wilensky & Reisman, 2006). The reverse is also true – namely, that science and mathematics provides a meaningful context (and set of problems) within which CT can be applied. This differs markedly from teaching CT as part of a standalone course where the assignments tend to be divorced from real-world problems and applications. This sense of real-world applicability has been deemed important in the effort to motivate diverse participation in computational professions (Margolis & Fisher, 2002).

There is an equally pressing need to train future scientists, engineers, and mathematicians who understand and make use of computational thinking (CT) to address complex and increasingly data-driven challenges. In addition, we take seriously the goal of preparing an educated citizenry capable of participating and contributing in an increasingly computational world.

A final motivation for bringing CT into STEM classrooms is to reach the widest possible audience and address longstanding issues of the underrepresentation of women and minorities in computational fields discussed above. Currently, only a fraction of high school students have the opportunity to take a computer science course due to a lack of qualified teachers, inadequate facilities, or a lack of student interest. Embedding CT activities in STEM coursework directly addresses the issue of students self-selecting into (or out of) computer science classes, which has been a challenge long plaguing the effort to reach underserved youth (Margolis, 2008). It also avoids practical issues of fitting new classes into overcrowded schedules and finding teachers to teach them.

Methods and Data Sources

Our work bringing CT into STEM classes involved three main efforts: 1) defining CT in STEM; 2) developing CT enhanced STEM lessons; and 3) creating online assessments to evaluate the success of our interventions. In the first year of our grant we developed a CT in STEM practices taxonomy that outlines a set of 22 skills across four categories that serves as a structured definition of CT in STEM (Weintrop et al., in preparation). Over

the first two years of the study we developed a portfolio of 22 classroom-tested CT activities for high school biology, chemistry, physics, and mathematics classrooms. All of these activities are aligned with our CT-STEM practices taxonomy and mapped onto relevant Common Core, CS Curricula and the Next Generation Science Standards. Each CT-STEM lesson plan includes classroom materials and a teacher guide and requires 2-3 class periods¹. Finally, to assess student learning, we created five CT in STEM skills assessment sets (Weintrop et al., 2014) that were administered by participating teachers immediately after teaching a CT-STEM lesson plan.

The data we present in this paper were collected during the 2013-2014 school year at 11 participating schools in a Midwestern city. Over the course of the project we had 58 teachers attend our professional development workshops from 38 schools. The data presented below are from teachers who participated in the third year of the project. The student attitudes and perceptions data we present are drawn from attitudinal surveys that were administered to students in participating classrooms at the beginning and the end of the school year. A total of 704 attitudinal surveys were completed (475 pre and 229 post) with 49.7% of the surveys being filled out by female students. These surveys included a total of 162 questions focusing on students' attitudes towards CT and STEM, their confidence with the subjects, and their interest in fields related to computation. The survey primarily used a 5-point Likert scale and asked students to respond to statements such as "I feel comfortable working with computers" and "I am interested in pursuing a career in engineering." We also report a preliminary analysis of the student response to our CT-STEM skills assessment sets. A total of 1,022 assessment sets were completed by 549 students during the 2013-2014 school year.

Preliminary Findings

One of our motivations for embedding CT in STEM is to address issues of students self-selecting into or out of elective computer science courses. As a result of our approach, all students enrolled in conventional science and math classes are exposed to CT, thus addressing issues of low numbers of female and minority students taking computer science. Of the 549 students who took one of our assessment sets during class, 49% (271) self-identified as Hispanic, 37% (203) as African American, 15% (83) as white, and 10% (53) as Asian. Of this same sample, 52% were male while 48% were female. The diversity of students taking our assessments and the equality with respect to the gender of students suggests our approach of bringing CT into STEM classes is an effective way to introduce a broad and diverse set of students to CT.

Comparing the responses given on the pre survey between male and female students, we see disparities that match those reported in other studies on gender and STEM and computer science fields. Female students were significantly less interested in the STEM fields, felt CT was less important, and reported being less comfortable with computers than their male counterparts. When asked about interest in possible future professions, female students were significantly less interested in careers in computational sciences, engineering, mathematics, and computer science. Finally, female students were less confident in all 20 questions pertaining to CT in STEM contexts.

¹ Visit the project website for more information: <http://ct-stem.northwestern.edu>

A preliminary analysis of student responses shows no significant difference in performance between students based on gender. Looking at the subset of responses to our General CT in STEM skills assessment set that can be automatically scored, we see that the 161 females had an average score of 2.21 out of 5, while the 192 male students had an average score of 2.27 out of 5, a difference that is not statistically significant $t(352) = .377, p < .706$. The fact that female students at the start of the year saw themselves as less confident in computational fields as well as less interested in pursuing careers in computational fields, paired with findings that show female students have the same level of aptitude, highlights the importance and potential of integrating CT with mandatory course work. If the content were reserved for an elective course, these students would likely self-select out of computational learning opportunities if given the chance.

At the end of the school year, we administered our attitudinal survey a second time to see if students being exposed to our CT in STEM activities improved their perceptions of and attitudes towards CT. Responses in the post-test show significant gains on questions relating to interest in pursuing careers in science $t(349) = 2.018, p < .044$, enjoyment related to using computational tools for schoolwork $t(439) = 2.905, p < .004$ and the learning benefits of doing so $t(349) = 2.531, p < .012$. Most importantly, girls showed positive gains on 19 of the 20 questions pertaining to confidence in CT in STEM questions. This shift highlights the effectiveness of CT learning experiences situated within STEM for female students.

Conclusion

The finding of no difference in CT aptitude between girls and boys, but large differences in attitudes towards and perceptions of CT suggests that reserving CT instruction to opt-in, elective courses will perpetuate the issue of under-representation of girls in CT. Our approach of bringing CT into STEM classrooms is designed to provide hands-on, empowering CT experiences for all students. In this short paper we have shown preliminary results showing the effectiveness of this approach. In the full version of this paper, we will present a more detailed analysis of the data presented in order to more fully defend the claims we make about the positive effects of bringing CT in STEM classrooms and how the approach broadens participation and changes attitudes of students historically underrepresented in both STEM and computational fields.

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