Strengthening Computational Thinking within Upper Elementary Classrooms

A Strategy for Broadening Participation in Computer Science

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ABSTRACT

This paper describes a research-practice partnership (RPP) in western South Dakota involving twenty 4th and 5th grade teachers and a support team of university researchers and K-12 learning specialists. For three years, the RPP has been exploring ways to strengthen computational thinking within elementary math and science instruction, attending to policy considerations and the local education landscape. The RPP is motivated in part by the hypothesis that a larger, more diverse group of students will choose to enroll in computer science courses in high school if they gain familiarity and confidence related to computational concepts at earlier grades. Feedback from participating teachers along with student attitude and problem-solving data suggest this is a promising approach.

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CCS CONCEPTS

• Social and professional topics → Professional topics → Computing education → Computational thinking; • Social and professional topics → Professional topics → Computing education → K-12 education.

KEYWORDS

Elementary computer science; Computational thinking; Research-practice partnership; Broadening participation; Equity

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1 INTRODUCTION

In 2014, with few or no computer science opportunities in most of South Dakota's high schools, a K-12/university partnership was established to support districts in adding a yearlong introduction to computer science to their curriculum. Supported by a grant from the National Science Foundation (NSF), teachers from six high schools on the western side of the state worked in collaboration with local university faculty and K-12 learning specialists to pilot-test the *Exploring Computer Science* curriculum [1]. Favorable feedback from teachers and students led to a second grant from NSF, and ultimately the effort expanded statewide to involve 74 teachers, 53 schools, and 48 districts [2].

Despite concerted recruitment efforts, many of the participating schools consistently struggled to enroll enough students. South Dakota has no high school graduation requirement related to computer science, and few districts require students to take a computer science class. Course enrollments also skewed male, attracting more boys than girls in districts where the course was not required for all students. Participating teachers were invited to administer an attitude survey at the start of the course, and female students indicated significantly lower confidence related to computer science than male students -- even among the female students who had chosen to take the course as an elective.

The high school effort led project leaders to develop a new initiative (the subject of this experience report) that seeks to boost interest and confidence related to computer science at earlier grade levels. In 2020, a third grant from NSF was secured focusing specifically on grades 4 and 5. Project leaders set out to determine if differences in confidence and interest levels by gender already exist at 4th and 5th grade and to attempt to influence student dispositions in favorable ways at those grades.

In addition to having no high school graduation requirement related to computer science, South Dakota also has no K-12 computer science standards. In an education climate in which there exists significant pressure to focus heavily on reading and math at elementary grades, teachers report difficulty finding time for everything else in the elementary curriculum. Rather than asking elementary teachers to make time to teach computer science as yet another content area (one that is not required by the state), project leaders gravitated toward the body of research about infusing computational thinking (CT) into elementary science and math instruction [3, 4, 5]. Computational thinking is called out in both South Dakota's K-12 math standards [6] and K-12 science standards [7] and also in state's K-12 education technology standards [8]. Given the existing policy landscape, focusing on CT-related standards within math and science seemed potentially approachable and manageable for teachers and a feasible way for students both to experience the power of computational thinking in solving problems and to find early success with that facet of computer science.

2 DESCRIPTION OF PRACTICE

2.1 Audience

Similar to the launch of the high school effort, project leaders sought to engage a small group of teachers to start the elementary project. Cohort 1 was established in the summer of 2021 with twelve 5th grade teachers, and Cohort 2 began in the summer of 2022 with eight 4th grade teachers. These 20 teachers represent 13 schools in 8 districts. All of the districts are within 100 miles of Rapid City in western South Dakota and have K-12 enrollments ranging from 277 to 12,333. The 5 smallest districts are highly rural, two serve medium-sized towns (populations around 10,000), and the largest serves a small city (population around 75,000). On average, across the 13 participating schools, 32% of students qualify for free or reduced-price lunch and 25% are from racial and ethnic groups historically underrepresented in computer science, primarily Native American and Latinx. For disaggregating student data by race, the project uses the National Center for Science and Engineering Statistic's classification of underrepresented minorities (URM), which includes both subgroups [9].

2.2 Approach

The project is using a research-practice partnership (RPP) approach [10] in which Project Support Team members learn alongside partner teachers about the nature of elementary computational thinking and about strategies for incorporating it successfully into math and science instruction. Ten members strong, the Project Support Team (PST) includes university researchers and K-12 learning specialists. The PST identifies journal articles and other resources for the full RPP to explore together, coordinates the collection and analysis of quantitative data about student attitudes and problem-solving, and coordinates the involvement of an external evaluation team. An individual PST member visits each teacher monthly in his, her, or their classroom, watching, teaching, co-teaching, and/or coaching, depending on what the host teacher desires. These visits generate information on what is working and what is challenging within individual classrooms, helping to guide the overall direction of the RPP and informing future professional development offerings for the participating teachers.

For the first six months of the project, functioning as its own professional learning community, the Project Support Team studied the literature on elementary computational thinking -- while concurrently recruiting Cohort 1 teachers. Different scholars define computational thinking slightly differently, but the PST landed on the following four components as the primary emphasis: Decomposition, Pattern Recognition, Algorithmic Thinking, and Abstraction [11]. The PST asked teachers to focus first on "noticing and naming" these components within existing math and science lessons. In professional development sessions, teachers would often experience an activity (facilitated by a member of the PST) as a student first and then put on their teacher hat. Teachers were also provided opportunities to find CT within their own math and science instructional materials. Much of the project's focus has been on "unplugged" activities [12], which feel particularly approachable and require no special equipment. Although as teachers have become more familiar with the four pillars, they have expressed increasing interest in computer-based learning tools for their students and in possibly incorporating other facets of computer science such as coding.

In the second year of the project, the RPP landed on a helpful framework that distinguishes between lessons in which CT naturally exists, where a teacher might help students to notice and name the CT components, a lesson that the teacher adapts to enhance the presence of CT, and a lesson in which a teacher might extend beyond the CT that is naturally present [13]. The transition for teachers from just noticing and naming CT components to deliberately trying to find ways to use CT to solve problems has been significant over time and quite evident during the classroom visits.

The professional development for Cohort 1 over the past three years has included three 5-day (30-hour) summer institutes plus two 3-hr follow-ups per academic year for a total of 108 hours. Cohort 2 teachers have participated in two 30-hour summer institutes plus two 3-hr follow-ups per academic year for a total of 72 hours. Monthly classroom visits are in addition to the times of coming together as a full RPP. Despite Cohort 2 teachers have had fewer hours in the project, they took to the project readily, and beginning with the 2023 summer institute, all professional development offerings have been joint across the two cohorts.

Following a similar approach to what was used with the high school project, the Project Support Team suggested to the partner teachers that it might be valuable to collect student attitude and problem-solving data and offered possible instruments. The teachers agreed that collecting and analyzing student data would be valuable, and they helped to refine the instruments. For two and a half years, the project has used a 21-question attitude survey adapted from Tapia and Marsh's *Attitudes Towards Mathematics Instruction* [14]. The project has also used measures of problem-solving from the Mathematics Assessment Resource Service (MARS) [15]. On the attitude assessment, the questions have been modified from focusing solely on "mathematics" to include questions specific to "computer science" and "computational thinking." The questions continue, however, to probe the same four factors: self-confidence, enjoyment, value, and motivation. For assessing problem-solving, the RPP has identified math tasks from MARS in which the computational thinking is especially prominent. The RPP has also added a final question on post-test tasks asking students about their use of computational thinking in solving the tasks.

The purpose of collecting student data has been two-fold: 1) on a short timescale, to inform and guide the RPP's path forward; and 2) on a longer timescale, to potentially inform the field of computer science education more broadly. After each administration of attitude surveys and problem-solving tasks, the RPP has come together to review the preliminary findings and consider implications for classroom practice. These have been some of the RPP's most vibrant discussions.

2.3 Outcomes

Three years into the project, the integration of computational thinking into 4th and 5th grade math and science is seeming like a successful approach. Based on classroom visits, external evaluation findings, and the quantitative measures, partner teachers and their students appear to be doing quite well with CT. Also, the RPP is learning interesting things about student attitudes and problem solving, including that gender differences in CS confidence are evident already in upper elementary grades. For example, among 193 5th graders in the fall of 2023, male students agreed more strongly with the statement, "I know I could become a scientist, engineer, or computer programmer one day" (Cohen's Effect Size = 0.4, $p < .05$). Despite having lower confidence, female students outperformed male students in that same sample on the problem-solving assessment (Effect = 0.6, $p < .05$). An interesting difference associated with race and ethnicity from the fall of 2021 was that URM 5th graders agreed more strongly than non-URM students with the statement, "I would like to have a career that involves computer science" (Effect = 0.3, $p < .05$, $n = 359$). Across all students, male, female, URM, and non-URM, preliminary findings show a number of student dispositions improved within participating classrooms over the span of the school year with Effect Sizes > 0.2 and $p < .05$.

Students have also shown strong growth from pre-test to post-test in problem solving. For example, at 5th grade during 2022-23, among 286 students, growth in problem-solving from pre-test to post-test had an effect size of 0.7 with $p < .001$. Moreover, an affirming 83% of students indicated on the post-test that they had employed computational thinking on the problem-solving tasks, and they were able to provide at least a modestly compelling explanation.

In addition to favorable student-level data, project leaders are encouraged that fully half of the initial 20 participating teachers are now involved in formally sharing CT with other teachers in their schools and beyond. Modes of sharing include presentations at school staff meetings, sessions at statewide conferences, and a 3-day introduction to "Integrating Computational Thinking Across the K-8 Curriculum" that is being planned for summer of 2024.

3 POSITIONALITY STATEMENT

Most of the authors have had extensive experience teaching at the K-12 level, primarily in math and science, spread evenly across elementary and secondary levels. Most of the authors had limited experience related to computer science education and computational thinking prior to working on this elementary-focused project and its two precursor projects at the high school level. The team of authors has had significant experience supporting the preparation and professional development of math and science teachers. The team has a deep commitment to equity. The team appreciates constructivist instructional methodologies in which students actively figure out math and science concepts for themselves. The team has profound respect for the challenging work of teachers.

4 LIMITATIONS AND ASSUMPTIONS

An underlying assumption of this effort is that if students gain confidence, enjoy, and find value in using computational thinking at elementary grades, they are more likely to pursue future opportunities to learn computer science (e.g., enrolling in elective computer science courses in high school). We are unable to test that assumption within the scope of the current project -- beyond asking the participating students about their motivation to pursue future opportunities to learn computer science and their interest in a career that involves computer science.

The scope of this project is limited to grades 4 and 5 and the involvement of only 20 teachers from 8 school districts within a 100-mile radius of Rapid City, SD. Will this approach work in other settings and at higher or lower grade levels?

The attitude survey from Tapia and Marsh was tested for validity and reliability in mathematics with secondary students. The adapted version, focusing on computer science and computational thinking and being used at lower grade levels, has not undergone similar psychometric testing.

The project has no control group of 4th and 5th grade students whose teachers have not been part of the RPP.

5 IMPLICATIONS AND NEXT STEPS

5.1 Future Directions

One significant area for further work involves student-level data collection and analysis. As noted above, the project is due to collect a third year of post-test data at the end of the 2023-24 academic year. Once those data have been collected, all three years of data will be thoroughly analyzed, disaggregating by gender and race/ethnicity. The data team will compare 4th grade to 5th grade attitudes and also upper elementary attitudes to high school attitudes on questions asked in common between the two groups. There also exists the potential to test if student attitudes and problem-solving skills changed more profoundly the longer a teacher was part of the RPP.

The external evaluation team will also be conducting a summative evaluation during spring and summer of 2024, paying special attention to the relative contributions of different project components (summer institutes, academic-year gatherings, data discussions, classroom visits by project support team members, and interactions among colleagues) to teachers' dispositions and growth.

5.2 Professional Development Needs

The RPP is eager to see how the 3-day introductory workshop goes this summer with a broad range of K-8 teachers who are new to CT. Project leaders anticipate that three days will be a meaningful duration but unlikely to be entirely sufficient. What number of hours of professional development is palatable and necessary in supporting teachers to recognize CT and to attend to it intentionally in their instruction? Are there other facets of the RPP that could be replicated in some way as part of dissemination at larger scale?

Another area of interest is to strengthen the preparation of pre-service elementary teachers related to integrating CT into math and science.

As the quantitative analysis is completed, the RPP will also be asking what additional professional development activities might specifically target gaps that emerge in attitudes and problem-solving skills associated with gender, race, and ethnicity.

5.3 Implications For Policy

The development of broader reaching professional development offerings that focus on computational thinking and also the incorporation of CT more fully into pre-service teacher preparation have strong potential. Project leaders are interested in the possibility of large-scale, systemic teacher professional efforts to support elementary teachers who received limited exposure to CT in their pre-service preparation. Project leaders are also interested in developing related content for broad dissemination within the state's pre-service programs.

From a policy perspective, it is also worth thinking about and potentially advocating for a statewide high school graduation requirement related to computer science. With a graduation requirement, all students would be exposed to the discipline. But even if there were a graduation requirement, there would still be considerable value in providing students with high quality CT exposure prior to high school, so that when they enter their high school CS class(es), they are that much more interested and confident.

Finally, it is worth looking to contribute to the development of K-8 computer science standards. South Dakota's Department of Education has recently initiated the process, and members of this RPP are well positioned to contribute to it.

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