Computational Thinking as a Context for Ambitious Math Instruction

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Abstract: Current efforts to improve math education often call for ambitious math instruction, which promotes student thinking and conceptual understanding. Such instruction can be difficult for many teachers because it differs from how they learned math. Incorporating computational thinking (CT) into math teacher education might support teacher learning of ambitious math because it moves teachers out of their familiar math context. We use data from a middle grades math and science methods course to show how some pre-service teachers tend to focus on ambitious math goals to make sense of CT and its connections to math.

Introduction
In math education, many have sought to improve K-12 mathematics through ambitious math instruction. Ambitious math instruction promotes student inquiry, communication of mathematical ideas and connecting different math content (NCTM, 1989). Yet, many teachers struggle to teach according to ambitious math practices because it asks them to think about math differently than how they were taught (Ball, 1988; Borko et al., 1992).

One way to help teachers shift toward ambitious teaching might be to change their familiar math context. Computational thinking (CT), which is currently expanding in schools, might be that context change. CT includes the skills and ways of thinking in computer science and uses practices like pattern recognition and abstraction (Grover & Pea, 2013). Engaging students in such practices are also goals of ambitious math. By incorporating CT into an undergraduate math and science methods course, we noticed that pre-service teachers (PSTs) often focused on these practices as they learned about CT. Based on our observations of PSTs, we posit that including CT in math teacher education might be a helpful context for learning about ambitious math instruction.

The purpose of this paper is to discuss the possible affordances of CT to teach teachers about ambitious math. We first review the literature on ambitious math and CT and how they overlap. We then use data from a middle grades math and science methods class to show that PSTs seem to center ambitious math practices and goals in a CT context, making CT a plausible path for developing teachers’ ambitious math instruction.

Background
Ambitious math instruction calls for teachers to engage students in solving open-ended problems, to facilitate math discussions, and to guide students as they construct math ideas (Fennema et al., 1993). The goals include helping students to reason mathematically, make content connections, and communicate their thinking. Standards like the Common Core State Standards for Mathematical Practice (SMPs) reinforce these goals (CCSS, 2010).

However, it can be difficult for teachers to learn and use ambitious teaching. Many teachers learned math through traditional instruction that involves procedure memorization and routine problem solving. Shifting to ambitious teaching often asks teachers to rethink how math is learned and taught (Ball, 1998; Borko et al., 1992).

While most research promotes ambitious instruction in the current school math context, another path might be through CT. There are differing definitions of CT, but it is generally thought of as the practices and strategies used in computing (Grover & Pea, 2013). Many have worked to define CT in the context of education (Barr & Stephenson, 2011; Dong, et al. 2019; Weintrop et al., 2016). For example, in their teacher-friendly CT framework known as PRADA, Dong et al. (2019) defined the key components of CT as (1) pattern recognition, which is using patterns in meaningful ways; (2) abstraction, which is determining the general properties of a problem that are useful; (3) problem decomposition, which is breaking a problem into tractable component parts; and (4) algorithmic thinking, which involves solving a problem through a series of steps. CT can give students technological skills and can help to develop dispositions like persistence in problem solving and the ability to collaborate (CSTA & ISTE, 2011; NRC, 2010).

Recently, there has been a push to expand CT in K-12 classes (White House, 2016). In addition, researchers have highlighted the role that math plays in science fields, like computer science, and have argued that math education should reflect this connection (NRC, 2013). In response to these calls, efforts have often examined possible areas of CT-math overlap (Fofang et al., 2020; Pérez 2018). For example, Pérez (2018) developed a framework to show how CT dispositions can support mathematical thinking. He also noted the
potential for a CT context to help teachers maintain the cognitive demand of math tasks, which is important to ambitious math teaching (Stein et al., 1996).

Others have reported important differences between CT and math (Rich, et al., 2020; Tatar et al., 2017). In one study, Rich, et al. (2020) looked for intersections between CT ideas and mathematical thinking seen in the Common Core State Standards (CCSS). They found that CT and math thinking can intersect in ways that are productive for student learning, but that not all mathematical thinking skills correspond to similar ideas in CT.

The ways that teachers connect CT and math has also been a research focus. (Duncan et al., 2017; Rich, et al., 2019; Walton et al., 2020). For example, Rich et al., (2019) examined elementary school teachers’ thinking on the connections between CT and the math they teach. They found that some teachers could relate CT practices and the SfMPs, which could be leveraged during CT professional development.

Efforts by Rich and others are a great start in understanding how math and CT connect. However, their work is primarily from a computing perspective; they aim to develop teachers’ CT understanding to expand computing in classrooms. Bringing computing to more students is certainly a worthwhile goal, but we argue that CT can also be valuable from a math perspective, like for teachers’ ambitious math learning. Pérez (2018) showed what a math perspective could look like in his discussion of CT as a context for task implementation. We build on this work as we describe how CT seemed to provide a context for PSTs to highlight ambitious math goals.

PSTs' identification of ambitious math goals in a CT context
The following examples were taken from data collected over two years in a middle grades (grades 4-9) math and science methods course at a large mid-Atlantic university. There was a total of 32 PSTs in the two years. The course included a three-class CT module aimed at introducing PSTs to key CT components and at helping them integrate CT into their instruction. Activities included reading practitioner-focused articles that introduced key CT ideas (Years 1 and 2), discussions about how CT connects to the SfMPs (Year 1), and discussions about how CT fits into math and science classrooms in general (Years 1 and 2).

In both course years, we recorded class discussions about CT and how it relates to math and science instruction. We also conducted semi-structured interviews with four PSTs (two in each year) at the conclusion of the module. The four PSTs were chosen because they made strong connections between CT and classroom instruction during discussions, and we wanted to explore their thinking further. The questions we aimed to answer were (1) How do PSTs begin to conceptualize computational thinking? and (2) How do PSTs begin to learn about CT practices in relation to teaching math? While reviewing the data, we noticed that PSTs often centered ambitious math goals when making sense of CT and connecting CT to their instruction.

The first example is from an interview with a PST named Amy that took place at the conclusion of the CT module in Year 1. Throughout the interview, Amy seemed to ground her understanding of CT in pattern recognition. Pattern recognition is an important ambitious math idea for connecting different math topics and for problem solving. Early in the interview, when asked if she had seen CT in any previous experiences, Amy referred to activities from her teaching methods classes. She said, “Well whenever I think of computational thinking, I think about patterns...kind of like what we did in class earlier today [with a math task].” She continued by discussing another math methods class and said, “I had seen those concepts of, like, building and constructing a pattern from something you observe.”

Amy also made connections between CT dispositions and ambitious math goals related to student discourse. When asked how she thought CT related to the SfMPs, Amy connected the CT ideas of negotiation and consensus building to SfMP3, construct viable arguments and critique the reasoning of others. Amy said,

Collaboration and consensus building...ties into this other practice of constructing arguments and critiquing... Students should engage with their peers and if they're given a task where it's not so straightforward, then they should be having discussions where they say, “Hey this doesn't look right,” or, “I agree with you because,” or, “I disagree with you because...” And it ties into [SfMP3] because there's a collaboration of students working together and negotiation of what's actually correct, and from that cooperation and negotiation they build a consensus.

Here, the terms negotiation and consensus building, important to the CT disposition of collaboration, came from one of the articles PSTs read during the CT module (Barr & Stephenson, 2011). Amy connected collaboration with students critiquing each other’s ideas, an important ambitious math practice and part of communication in mathematics.

Similarly, Cara, another student in year one of the course, related the CT idea of abstraction to SfMP6, attend to precision, when asked to make connections between CT and the SfMPs. In her interview, she said,
The goal of abstraction in CT is to take something that’s very complex and muddled and make sense of it, which relates to Standard Six because attending to precision... it’s very difficult to communicate your thoughts clearly and precisely to others when in your head you’re like, “Oh, this does that with this number...” In your head it’s different from what you actually verbalize to your classmates...so I think that’s how they’re related because abstraction is trying to understand and make clarity of a situation.

Like Amy, Cara focused on the importance of being able to communicate mathematical ideas and saw the generalization involved in abstraction as helpful for that goal.

We also saw instances of PSTs identifying ambitious math practices in the context of CT with different PSTs in Year 2 of the CT module. It is important to note that in Year 2 PSTs were never prompted to make connections between CT and the SfMPs. One example again related to abstraction. After reading the practitioner articles, PSTs engaged in group discussions about what CT means and how what it could look like in K-12 classrooms. One PST, Jackie, said,

I feel like [the articles] also talked a lot about... this is part of that abstraction, but generalizing a situation for problem solving. Because when you think through it you try to create this general situation where if you change factors about your problem you could still use that method.

Later in the class, she related this idea to deriving a general formula in math. She said, “If you show students the derivation, that’s more of the process of how you get this generalized formula, but then they know the reasoning behind why they use a generalized formula and why their inputs will get the correct outputs.” She later continued, “So students know why they can use that formula as a general rule for a specific type of problem.” Here, Jackie showed abstraction could give students a better conceptual understanding of the math, while also giving them an appreciation of the power of using one formula for multiple situations, which are both aspects of ambitious math.

**Discussion and conclusion**

The examples above show some of the ways we saw teachers highlight ambitious math as they tried to make sense of CT. PSTs connected CT ideas, like pattern recognition, collaboration, and abstraction, to ambitious math goals like communicating thinking, critiquing others’ reasoning, and building conceptual understanding. These observations are similar to Rich et al.’s (2019) findings that show that teachers can connect CT, the SfMPs, and other areas of their math instruction. Our work is notable because PSTs made these connections with and without prompting. This not only shows the potential for CT to reinforce ambitious math standards in math instruction, but also that teachers may tend to naturally incorporate ambitious math practices into their CT lessons.

Rich et al. (2019) see CT-math connections as an entry point for teaching teachers more about CT. We see an additional benefit of supporting teachers’ ambitious math instruction. Our examples of PSTs show that CT could also provide a context for teachers to focus on ambitious math goals. Current ambitious math efforts often try to support teachers’ learning of these ideas solely in a math context. As seen in our examples, a more indirect approach that uses CT might be helpful because it takes teachers out of their math context, where their apprenticeship of observation (Lortie, 1975) could direct them toward traditional math instruction. Instead, CT might place teachers in a context where they can more readily focus on ideas related to ambitious math.

More work is needed to determine whether such an approach could be successful. Given that others have found that CT and mathematical thinking overlap in some ways but not others (Rich et al., 2020), future studies could examine whether there are more or less productive ways that CT can support ambitious math. In addition, while the PSTs here highlighted ambitious math in the context of CT, our work does not address how teachers would develop instructional moves that would achieve such goals. Future work could look at how teachers’ focus on ambitious math goals in a CT context might be leveraged to also support instructional practices.

Finally, the increasing push to include computing in school disciplines, like math, adds to teachers’ constantly growing list of responsibilities. It is important to consider how these additions benefit teachers and grow their current practice. In the case of CT, we think it could provide a valuable context for teachers to focus on ambitious math goals and develop their ambitious math instruction.

**References**


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