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Confronting Frame Alignment in CT Infused STEM Classrooms

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ABSTRACT

While the Next Generation Science Standards (NGSS) have presented computational thinking (CT) as an integral part of scientific inquiry, little work has been done to explicitly enable this connection in classrooms. We report on the efforts of one such design-based implementation research project which, with participation from local teachers, has been implementing CT infused STEM units in biology and chemistry classrooms. Using teacher reflections facilitated by an external evaluator, research field notes, and interviews, we identify possible issues of frame alignment in our implementations–that CT practices, particularly using computational models, were valued but would not enable students to gain a deeper understanding of scientific content. We then use this analysis and Schulman's definition of teacher case knowledge to design a new element of the project that aims to enable teachers to promote collaborative scientific practice using computational models in the classroom that we call Lesson 0. We conclude with the discussion of a pilot implementation of this new lesson.

KEYWORDS

computational thinking, STEM education, teacher learning, computational modeling

1. INTRODUCTION

For many years, Computational Thinking (CT) practices have tended to only be featured in standalone computer science (CS) courses, resulting in unequal access for students from historically underrepresented groups in CS, such as women and racial minorities (Margolis & Fisher, 2003). However, in our increasingly computational world, CT has become a necessary and integral part of nearly every discipline, particularly STEM disciplines (Weintrop et al., 2015). In recent years, the Next Generation Science Standards (NGSS) have made clear that using computational thinking (CT) is a cornerstone of modern science education (Quinn et al., 2012; Wilensky, Brady & Horn, 2014). By embedding CT practices into high school STEM classrooms like biology, chemistry and physics, we can simultaneously improve access to CT for all students, particularly those underrepresented in CS, while also providing a more authentic STEM experience for students in these classes.

This work is part of a research practice partnership between a Midwestern U.S. research university and a network of urban high schools in a large Midwestern U.S. city. In this paper we analyze and discuss the experiences of 6 teachers who taught one of our CT-embedded curricula during the academic year in the 2nd iteration of a design-based implementation research (DBIR) project, where research and practice are collaborative, iterative, and systematically analyzed (Fishman et al., 2013). We identify shortcomings of our previous curricular design and professional development program that may have caused an issue in frame alignment between scientific inquiry and CT. We then propose a new introductory lesson to our curricula which attempts to address these differences by framing CT as an authentic part of scientific inquiry.

2. THEORETICAL FRAMEWORK

The character of CT practices in the science disciplines is not yet well understood, nor is how to create curriculum and assessments that develop and measure these practices (Grover & Pea, 2013). To address this gap, our group has explicitly characterized core CT practices through a taxonomy of CT practices in STEM (Weintrop et al., 2016). The taxonomy consists of practices related to *Data*, *Modeling and Simulation, Computational Problem-Solving,* and *Systems Thinking*. We translated our taxonomy into a set of learning objectives and used these to guide the development of the two CT science curricular units, one biology and one chemistry, used in this study. Our curricular approach, which aligns with that of the NGSS, emphasizes figuring out core ideas through engaging in CT practices, rather than treating the dimensions separately (NRC, 2012).

In this manner, we see *frame alignment* as one of the major roadblocks to integrating CT into STEM classes (Farrell et al., 2018). Frame alignment refers to "the linking of two ideologically congruent but structurally unconnected frames regarding a particular issue or problems" (Benford & Snow, 2000, p. 624). While NGSS embeds CT as one of its core practices, competing frames of promoting scientific discourse in the classroom, integrating CS for all ideas, and even simply encouraging student agency in using CT for inquiry can all be vying for precedence in a teacher's sensemaking of new curricula.

3. METHODS

As part of the second iteration of the DBIR project, 6 teachers, 2 biology and 4 chemistry across 2 high schools, implemented one of our two week (10 class period) curricular units during the 2016-2017 school year. The two schools (one urban and one suburban) were all located near a large Midwestern U.S. city. Each of the teachers had at least five years of experience in their respective subject. Prior to their implementation, each of the six teachers participated in a professional development program which defined CT practices in STEM, familiarized the teachers with the curricular units they would implement through selective enactment, and allowed teachers to review and redesign the curricula with edits and tweaks based on their particular classroom needs.

3.1. CT Science Curricular Units

Both the chemistry and biology curricular units were explicitly designed to teach traditional subject matter content through the enactment of CT practices. The units focused on helping students develop practices for Modeling and Simulation through exploring NetLogo (Wilensky, 1999b) models. NetLogo models were chosen because the agent-based representations in this modeling environment make complex systems phenomena (like population dynamics in ecosystems), more accessible (Wilensky, 2001). The chemistry unit covered the basics of the Ideal Gas Laws through exploring how micro-level particle interactions give rise to the macro-level effects like pressure and temperature (Wilensky, 1999a). The biology unit focused on the principles of ecosystems and evolution with students designing and interacting with models of competition between species to discover how ecosystems reach equilibrium.

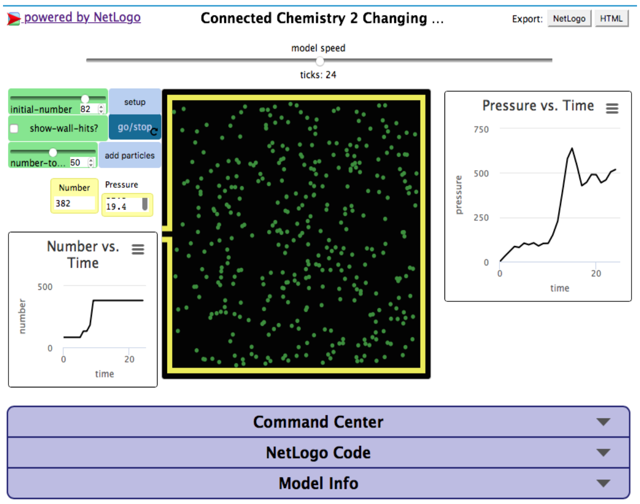

Figure 1. A chemistry model of gas particles colliding with the walls of a box which gives rise to the emergent phenomenon known as pressure (link blinded for review).

In both units, students explore the relationship between micro elements of the models and how they give rise to system level effects. Students observe trends within their data, use models to make and test predictions, and follow the steps of scientific inquiry in order to construct a deeper understanding of these phenomena (Wilensky & Reisman, 2006). These units are intentionally designed so that students engage in CT practices as part of an authentic scientific inquiry experience (NRC, 2012). The units are presented in the form of guiding questions, which encourage students to use either their prior knowledge or the exploration of a computational model to engage with the curricular content.

3.2. Data Collection

Data collection took place across twenty-two classes amongst our 6 teachers. Class periods were videotaped resulting in around 118 hours of video data. In addition, at least one researcher attended each class period and recorded written field notes. Because the curricula were hosted on our website, all student responses were recorded digitally). Finally, the teachers participated in interviews with an external evaluator about their experience with the professional development program and curricular implementation. For this paper, we use these teacher reflections and field notes to discuss frame alignment issues and motivate our new design efforts to mitigate those.

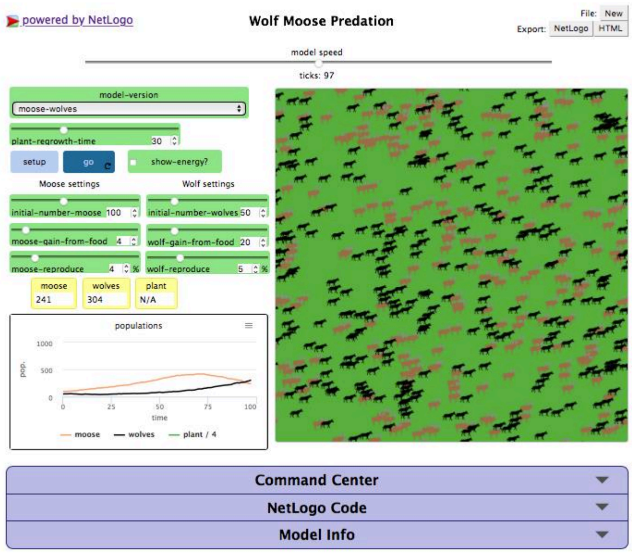

Figure 2. A biology model which allows students to manipulate behaviors of wolf and moose and reason about their emergent population dynamics (link blinded for review).

4. RESULTS

We had theorized that the students would emergently collaborate using this shared curriculum and computational models, with the teacher acting as a facilitator and modeling classroom talk (McNeill & Pimentel, 2010). In this manner, students would be participating in teams for scientific discovery–to discover the core ideas of gas laws and ecosystem stability. Computational models have been shown to be fruitful for this sort of classroom-level knowledge building (Wilkerson et al, 2007). In addition, in a pre-survey, 484 of 526 student participants agreed with the statement “People who have careers in science or computing need to work well in teams.” In essence, we expected that students would use the computational models of anchoring phenomena for classroom talk and construct knowledge at the classroom level.

While we did see episodes of students debating computational methodologies in order to solve problems, we rarely saw classroom-level discussions of using a computational model for scientific inquiry. Some teachers facilitated classroom discussions at the end of each period on the “takeaways” (i.e. “organisms can compete indirectly if they are sharing a finite resource”) for the day–an activity they classified as “usual practice” in their classrooms. Although these takeaways served as fruitful points of classroom discussion, none of the teachers explicitly talked about CT practices in these wrap-up discussions. In fact, one chemistry teacher Veronica saw the CT and chemistry content in direct conflict with each other.

I felt that, if the purpose is for them to see CT within content, yeah, but content was—I don't think it was as cohesive. Like the idea [was supposed to be], “Okay, so we're gonna teach gas laws and incorporate CT.” It was more, “We're using that law to teach you computational—to teach you how to—to show you how models work.”

Even the most experienced teacher in our study Ulyana, who was the head of the biology department at her school, admitted that her number one concern during her implementation was to teach her students the biology content of the unit. Francine, another chemistry teacher made a similar comment,

I like the use of models in the classroom... I would have liked to see more of them walking away with more of the typical expectations for gas laws that you would expect students to get in those kind of conversations, but I like the use of models and the learning that they had with the models.

As such, Francine followed up the two-week implementation with a lecture-based repeat of gas laws to each of her classes. Her interview suggested she saw the models as a way of *reinforcing* a concept rather than an *introductory* or *exploratory* instrument. While each of our teachers saw the need to have CT embedded in the classroom, there was no indication that they saw our curricular approach, emphasizing figuring out core ideas through engaging in CT practices, as aligned with their content-specific goals.

While we believed our curricular design would help teachers elicit student thinking about both content and CT, from these results, we see that there was a significant discrepancy between how our team and how the teachers/students saw the alignment between content and the computational models and activities. We became interested in how to address this lack of frame alignment and whether we could design an introductory lesson that would provide a frame from which all the goals could be seen as aligned. In the rest of the paper, we describe our proposed solution.

5. PROPOSED SOLUTION AND PILOT OUTCOMES

Our analysis of teacher reflections revealed that the lack of clarity about connections between content and CT to the students and teachers may have led to the lack of collaboration and discussion related to CT practices and scientific inquiry. To use Schulman's (1986, pg. 11) term, we had provided teachers with a small amount of case knowledge–a *parable* which conveyed CT practices as the norm of the scientific community–without providing the associated *prototype* and *precedent* (1986). We used this framing from Schulman to design a new preparatory element for each of the curriculum we call *Lesson 0: How to Learn with Computational Models* (see it here: link removed for blinding). The lesson is meant to be used by both teachers and students as a sort of rehearsal of learning with computational models in order to get ready for the more discipline specific content coming later in each curriculum.

New science standards and reforms articulate a commitment to greater student agency with a disciplinary focus: that students should take on increased responsibilities for deciding what to figure out in science classrooms and how (Berland et al., 2016). In our curricular implementations, these frames seemed to conflict with the frame of CT as a way of scientific inquiry. As such, *Lesson 0* is designed with three main principles: 1. Scaffold students into discussions of how scientists use models; 2. Engage students with computational models as a method of scientific experimentation; 3. Demonstrate how to develop new understandings of using a computational model.

The lesson centers on a computational model of a forest fire and is divided into four sections meant to make explicit the ways in which computational models can be used to explore scientific concepts and engage in scientific inquiry practices. It was designed to scaffold teacher and student sensemaking with Schulman's (1986) three types of case knowledge in mind. In Step 1 (Using models to learn science), we make explicit the *precedent* that scientists use models, and specifically computational models, as methods of inquiry. In Step 2 (A not-so-sneak peek into the code), we encourage classroom-level discussion of debugging as a *parable*, establishing discussions about the code behind computational models are a valued norm of a CT classroom. In Step 3 (Systematically investigating the spread of wildfire), we present an implementation of a *prototype* of scientific inquiry, where students make hypotheses, design computational experiments, and draw conclusions based on the computational models. Finally, in Step 4 (Constructing knowledge by engaging in scientific inquiry practices), we further enforce the *parable* of the classroom as an arena for knowledge construction through discussion of both experimental conclusions as well as computational model design.

We implemented this new lesson with a group 8 High School science teachers at a Computational Thinking in STEM workshop hosted at a large Midwestern U.S. University. The second author served as the instructor, taking on the role as teacher educator. Teachers were asked to "play-as" students with the teacher educator serving as the teacher with the goal of the teachers entering into a participatory relationship with the lesson.

Ulyana, the same teacher from the prior iteration of the study, was one of the participants in this workshop. In addition to participating in the lesson as a student during the workshop, she also implemented the very same lesson in her classroom as the very first lesson of her biology unit. When asked about her experiences teaching the unit in this new iteration, Ulyana reflected upon her new understanding of what it meant to use computational models in the learning process:

So...in my head, my models were always the ones I did with very physical models. I never thought about using computational models until I met you guys. And those are even more important, because they can then use those computational models. That it can be seamless that you can take the concepts that you're already going to teach and put them into this model...and show the kids the value of computational models. Yeah, I mean, they were I felt like they what I learned is that they were [doing] what a real scientist would do in collecting the data.

In addition to seeing students participate in the practice of real science, Ulyana singled out how framing debugging and code inspection as an expected classroom practice, as is done in Lesson 0, allowed students to interact with models in a deep way:

…we are going into the code and fixing any problem there was so yeah, the kids, I can see that you could put a bug in,

and the kids can fix it. And sometimes there were bugs in accidentally, and we still had to fix so and that it isn't like the end of the world is a win. It's just a code. You fix the code. So nothing was ever really broken.

She also remarked how her students performed well on her typical AP-style assessments after completing the CT curricula: "So, they not only learned how to use a computational model, they learned the content I needed for their AP test." In short, Ulyana saw the computational models as opportunities for students to engage simultaneously in both science and CT. In the coming months, additional teachers will be implementing a similar curricular structure featuring Lesson 0 as the beginning of a CT infused STEM unit. We hope to continue to analyze student and teacher data to further learn how we can refine Lesson 0 to support CT as a normal classroom practice.

6. CONCLUSIONS

In this paper, we presented an analysis of data from an iteration of DBIR project that suggested that frame alignment was an obstacle in our goal of allowing students to use computational models to discover core disciplinary content ideas. We then presented a modification to our curricula: a prepended lesson to help both teachers and students better understand how computational models might serve as tools (and objects) of scientific inquiry. In order to assist teachers in integrating CT into STEM classrooms, we see a need to provide explicit prototypes, precedent, and parables in order to help teachers align the seemingly competing frames of teaching expected content, scientific inquiry practices, and computational thinking. We see Lesson 0 as one possible method of allowing both teachers and students to make sense of how these frames align in service of a new form of scientific learning.

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