Title: Analysis of teachers' involvement in co-design and implementation of CT (Computational Thinking) integrated biology units

Abstract

There is a clear need to integrate computational thinking into science classrooms to better reflect the computational nature of STEM disciplines and to deepen learning of math and science. Our team has worked with high school teachers to co-design and implement biology units with integrated computational tools and methods. We present an analysis of teachers' involvement in co-design, their roles in classrooms during the implementations, and their perceptions of students' learning. We use a model of professional growth to discuss teachers' involvement in co-design and implementation of a CT integrated biology unit. Teachers followed similar pathways of professional growth, but their participation and perceptions varied. Results and implications are discussed.

Purpose

There is an increased demand for incorporating Computational Thinking (CT) in K-12 curricula (Grover & Pea, 2013). Wilensky, Horn, and colleagues have worked to characterize the nature of computational thinking practices in STEM disciplines, and have developed a taxonomy of CT-STEM practices (Weintrop et al. 2016; Beheshti et al. 2017). Incorporating CT practices in STEM classrooms is important not only to bring school science more in line with the work of modern STEM practitioners, but also to deepen learning of mathematics and science content (e.g., Sengupta et al., 2013; Wilensky and Reisman, 2006).

In order to integrate new standards into existing classrooms, it is necessary to reimagine teaching practice and how teachers learn these practices (Ball & Forzani 2009; Lampert et al. 2013, Windschitl et al., 2012). Our team has built deep and sustained relationships with schools and teachers as we introduce, support, and engage in curricular reform (Byrk, Gomez, Grunow, & LeMahieu, 2014). In our design process, teachers are active co-designers in modifying their existing science curricula to include computational tools and practices. This approach foregrounds teachers' views on curriculum alignment with student goals, teaching strategies, and expectations (e.g., Allen & Penuel, 2015; Coburn, 2005).

We partnered with three high school teachers in two schools in a large Midwestern city to co-design and implement CT integrated biology units about evolution. Units leveraged constructionist design principles to scaffold and support open-ended disciplinary explorations using computational models (Papert, 1980; Authors and colleagues, 2018, 2019). In this paper, we present an analysis of teachers' involvement in the co-design efforts, their roles in classrooms during the implementations, and their perceptions of students' learning. We use a model of professional growth to investigate the following research question:

How does co-design and implementation of a CT integrated biology unit impact teachers' professional growth?

Theoretical Frameworks

This work is framed with the operational definition of CT-STEM as a set of practices (Weintrop et al. 2016). This taxonomy categorizes CT-STEM practices in terms of four major strands: *data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices*. This project focused on the first two CT-STEM practices for the co-design work. For example, students used NetTango (Horn & Wilensky, 2012; 201x), a block-based programming interface to NetLogo (Wilensky, 1999), which uses semantically meaningful blocks tuned to the content domain (Wilkerson-Jerde & Wilensky, 2010; Wilkerson-Jerde et al, 2015), to model predator-prey relationships (Figure 1). Students also used a pure NetLogo model of rock-pocket-mice evolution (Authors and colleagues, 2019) to explore disciplinary ideas such as population genetics and natural selection by collecting and analyzing data. Table 1 depicts the practices within each of these two strands (Figure 1).

Interconnected Model of Professional Growth (IMPG). Curriculum reform, such as integration of CT in STEM classrooms, and teachers' professional growth are highly intertwined (Clarke & Hollingsworth, 2002). As such, this research is framed with the integrated model of professional growth (IMPG; Clarke & Hollingsworth, 2002), which characterizes sequences of change in four professional domains: the *external domain*, the *personal domain*, the *domain of practice*, and the *domain of consequence* (Figure 2). The *external domain* includes interactions outside the teacher's professional world, which is the research team. The *personal domain* consists of changes in teachers' knowledge, beliefs and attitudes. The *domain of practice* is changes in practice through implementing the CT integrated unit. The *domain of consequence* consists of changes in teachers' perception of salient outcomes. Change in one domain can lead to change in another through enactment or reflection. Enactment (solid arrows) is the translation of a change into action. For example, the teachers in this project enacted new CT integrated units from the research team, thus linking the external domain and the domain of practice with a solid arrow. Reflection (dashed arrows) facilitates change through active reflection on the change and its impacts. The IMPG was used to characterize change sequences for each teacher as they co-designed and implemented a CT integrated bio unit.

Methods & Data Sources

The CT-STEM biology units focused on ecology and evolution with eight class periods of 45-50 minutes. The units were co-designed and taught in the winter and spring of 2019 at Greenville High School (pseudonym) in a biology teacher's Advanced Placement classrooms and at Highland High School (pseudonym) in two biology teachers' Freshman Biology classrooms. See Table 2 for school demographics.

The analysis was triangulated using post-implementation teacher interviews and classroom implementation video data. The multiple case-studies method (Yin, 2003) was used to analyze differences in teachers' *personal domain* regarding their knowledge, beliefs and attitudes and how that impacted their involvement in co-design (*external domain*), their implementation (*domain of practice*), and their views of student outcomes (*domain of consequence*). Interviews were coded for the four IMPG domains and a secondary round of coding was used to identify change sequences for each teacher. Cross-case analysis was used to identify trends and differences between teachers. Video implementation of the units were used to identify the changes in the domain of practice.

Results and Discussion

The analysis revealed how teachers' pre-existing knowledge, beliefs and attitudes shaped their interaction with researchers (the *external domain*) early in the project, beginning the change sequence identified for the teachers in this study (Figure 3). The interaction with the researchers resulted in new CT integrated biology units that the teachers enacted in their classrooms (the *domain of practice*). From that implementation, teachers reflected on their new views of student outcomes (the *domain of consequence*). Teachers reflected on these outcomes, which impacted their knowledge, attitudes and beliefs (the *personal domain*), which then changed their planned enactment with the *external domain* in the future. Table 3 displays example codes of each domain for the three teachers.

Lydia. Lydia (pseudonym) did not expect the co-design process to be very collaborative, so due to time constraints, she did not review the lessons or provide feedback prior to implementation as she would have liked. Video data reveals that she demonstrated agency by making changes to the lesson to scaffold student learning during the implementations. She viewed student outcomes as positive, indicating students learned CT practices and science content. She viewed the integration as beneficial to her students because it introduced them to using computing to do and learn about science. Upon reflection, she was excited about incorporating computational modeling into future units and she said, "I highly recommend for all science classrooms" (Lydia Interview). She wants to be involved in co-designing more CT integrated biology units.

Tracey. Tracey (pseudonym) previously taught population genetics and evolution with a pen-paper activity focused on Hardy-Weinberg Equilibrium, which she shared during co-design. The co-designed CT integrated unit included a computational model based on her activity. During the implementation, Tracey encouraged students to work in groups, explore their ideas, asked questions to seek clarification of what they were doing and made suggestions to support their engagement with the unit. She also conducted lecture periods where she highlighted specific connections between model-based learning and disciplinary ideas. Tracey valued the integration of CT for students' learning of disciplinary ideas and CT practices. She wants to continue teaching the CT integrated unit and add CT components in her other units too.

Felicity. Felicity (pseudonym) was given the CT integrated unit and did not review the lessons or provide feedback prior to implementation and felt she had autonomy over the lessons. During implementation, her students struggled with the natural selection content. She did not make any changes to the lessons and said her students got overwhelmed. This struggle impacted her views about salient outcomes and she indicated students learned how to use models and design investigations, but did not learn science content. Felicity stated she wanted to be more involved in the design of future units, but has declined to participate in the team's upcoming co-design workshop.

Cross-Case Analysis. The comparison across cases resulted in the identification of three distinct differences in teachers. Although all three teachers followed the same change sequence pathway, their involvement differed. Teachers' perceived autonomy throughout the process varied. Lydia, Felicity, and Tracey discussed areas for potential CT integration within their natural selection units with researchers, which framed unit design. Teachers were given the opportunity to review the lessons and provide feedback, but teachers did so to varying extents. Tracey provided feedback and helped with design ideas prior to implementation. After reflecting, both Lydia and Felicity indicated their involvement did not meet expectations. Tracey was more involved in unit design prior to implementation, which made the unit more cohesive from her perspective. To make teachers feel comfortable with actively contributing in design and implementation, researchers need to increase teachers' perception of autonomy (Table 3, see quotes in *personal domain and external domain*).

All three teachers indicated they could have supported students' learning more, but only one teacher, Lydia, felt she had autonomy to make changes to the unit during implementation. For example, she leveraged her science content knowledge to add Punnett squares and her technological knowledge to integrate shared data collection strategies (Implementation Video). Tracey said students did not like that the unit was primarily on computers, but they learned the content, which prompted her to reflect on her teaching. She demonstrated her pedagogical autonomy by saying, "I will get better at doing [lessons] with kids so they feel more organic" (Tracey Interview). Felicity, on the other hand, said when students struggled with unfamiliar vocabulary and technological issues they shut down. In contrast to Lydia, Felicity felt she had no autonomy, so she did not make any changes during implementation (Table 3, Felicity – *external domain*).

All three teachers discuss the benefits of integrating computational modeling. However, the teachers' specific views on salient outcomes fall on a spectrum. Felicity viewed the integration as beneficial because the computational models provided an additional representation of the phenomenon and allowed students to test their ideas. Lydia built on these salient outcomes and said the integration allowed students to design and carry out investigations that would have been too difficult in classroom settings due to material and time constraints. Continuing with these ideas, Tracey indicated her students were able to learn things about natural selection with the computational models that they had not learned in her non-CT natural selection units. She refers to student learning as “much more powerful” with CT compared to without CT. “I think that they really understood evolution and natural selection deeper than by just reading it in a textbook” (Tracey, Interview). Combined with the varied change sequences described above, these results indicate the success of implementation is highly dependent on the teacher and their beliefs and attitudes towards co-design and implementation.

Scholarly Significance

There is little known about how teachers implement CT in science, and even less is known about how to support teachers in designing and implementing this integration (Sands, Yadav, & Good, 2018). This work describes three different experiences with the same process and highlights areas for further support in co-design and implementation. Results indicate future co-design should support teachers’ perceived autonomy and comfort with altering lessons for student success. Teachers are key in the implementation of CT in science, and, as seen in this paper, teachers range in their attitudes towards CT integration. More attention should be given towards designing professional development programs and co-design experiences to support teachers with varied attitudes and comfort. Although challenges arose during implementation, teachers recognized the benefits of computational modeling integration. In this study, teachers’ views ranged from representation to new kinds of learning that was not previously possible. This range also highlights the need to support teacher understanding of the affordances of computational modeling for student learning.

Acknowledgements

Removed for anonymization

Tables

Table 1. CT-STEM Practices

Data Practices	**Modeling and Simulation Practices**
Collecting Data	Using Computational Models to Understand a Concept
Creating Data	Using Computational Models to Find and Test Solutions
Manipulating Data	Assessing Computational Models
Analyzing Data	Designing Computational Models

Visualizing Data	Constructing Computational Models

Table 2. Demographics of Two Schools where the Biology Unit was taught

School	**Race Demographics**	**Free/Reduced Price Lunch**	**English Language Learners**	**Individualized Education Plans**
Highland	79.6% Hispanic, 11.2% Black, 5.9% White, 1.5% Asian, 0.5% Native American	92.5% free or reduced-price lunch	18.6% ELL	10% IEP’s
Greenville	44% White, 30% Black, 18% Hispanic, 5% Asian, 0.4% Native American	39% free or reduced-price lunch	4.2% ELL	12% IEP’s

Table 3.

Teacher	IMPG Domain	Quote	Explanation
Tracey	Personal Domain	“I was (concerned about whether they learned or not). Teachers are very controlling and I did not have that control, you know. I couldn’t see what was going on in their brain, you know.”	Tracey believed that during the CT-STEM lessons she did not have control on how students were learning. She was also concerned if they learned or not.
	External Domain	“So this time because you changed the storyline to match the storyline that I already do, it’s more cohesive. And all of the activities had the same storyline, so it was very cohesive to the kids.”	Tracey appreciated the co-design efforts that resulted in better alignment of the CT integrated unit with her regular curricular unit.

	Domain of Practice	"I could go around more, ask them questions and see what they were doing. And they had some really good insights"	During the implementation Tracey would walk around the class, ask students specific questions about how they were engaging in CT practices and learning of the content. She appreciated their responses and shared some of those with the entire class.
	Domain of consequence	"....I think that they really understood evolution and natural selection deeper than by just reading it in a textbook"	While comparing her students' learning with computational tools in the CT integrated unit to the regular way of learning, Teresa expressed that the students developed a deeper understanding of disciplinary ideas.
Lydia	Personal Domain	"I like the models and I want to use them. Everything in the world is technology-based". It is so important. "They don't get that in school".	Lydia saw benefits in bringing more computational approaches into the classroom to mirror the integration of technology in the world.
	External Domain	"But I didn't do my part to provide feedback... I wish it had been more collaborative… I thought it was just going to be handed to me...Collaboration is more meaningful…it's still my lessons, but you are adding things I don't know how to do".	Lydia recognized that the co-design process added to her curricula and wished she had participated more actively in the initial co-design.
	Domain of Practice	My role was more "hands-off, but hands-on at the same time."	At first Lydia read through introductions to make sure students knew what to do. She shifted into letting them explore and go in different directions, which was different than what she normally did. She reflected this type of experimentation and exploration would be "chaos" without computers.

	Domain of consequence	Students learned about using computers to do science and to learn science… It makes it more interesting and gives them different representations. We don't have to be outside or working with animals to do this experimentation.	Lydia saw the benefits of using computational approaches to support students in the experimental design process. She reflected that this experimentation with evolution is impossible when you don't have the physical materials like mice populations.
Felicity	Personal Domain	"I liked the blocks. I liked the first three lessons."	Felicity had a positive attitude towards the earlier lessons in the unit.
	External Domain	"I didn't create the lessons, so I didn't have autonomy over them… If I had designed them, I would have felt more comfortable and familiar with them."	Felicity did not feel comfortable making changes to the lessons before or during implementation, even when students struggled with the content and were overwhelmed.
	Domain of Practice	"I usually have more group work, but that's hard because students are at different places [on the computer]."	This unit differed from prior non-CT units because Felicity did not engage students in group activities. Rather, students worked on their computers at their own pace.
	Domain of consequence	"Students learned how to use computational models and saw how they are beneficial for scientists… the lessons focused on how to use the blocks, not the content."	Felicity recognized student learning about CT through computation modeling, but she did not identify science content learning gains.

Figures

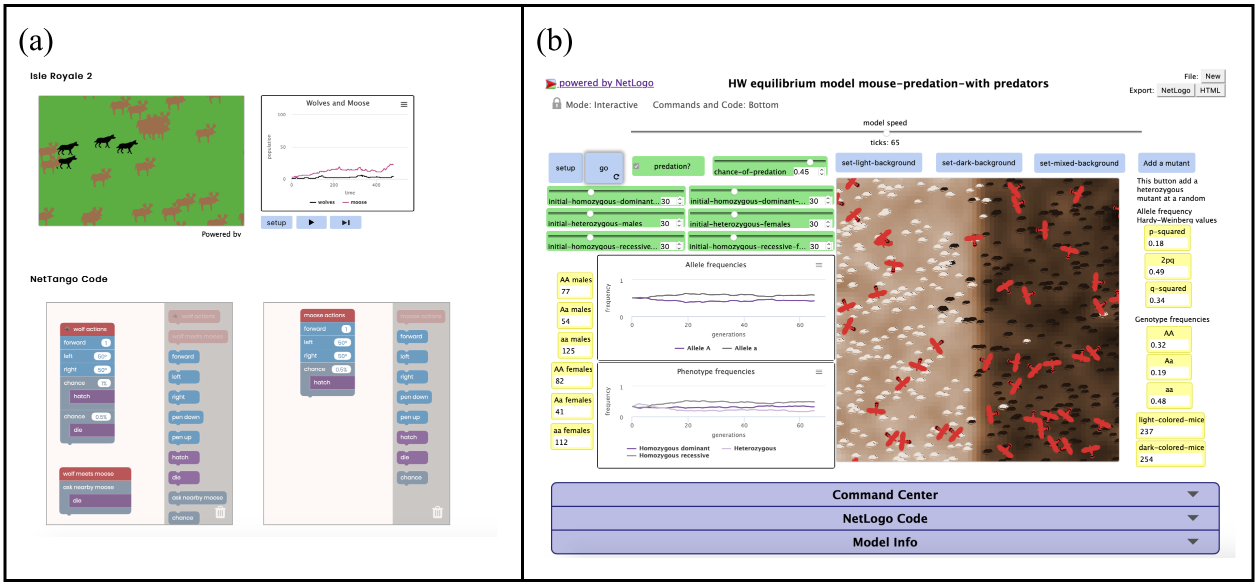

Figure 1: (a) Block-based NetTango modeling interface to model prey-predator interactions, (b) An agent-based NetLogo model to learn about Hardy-Weinberg equilibrium and natural selection

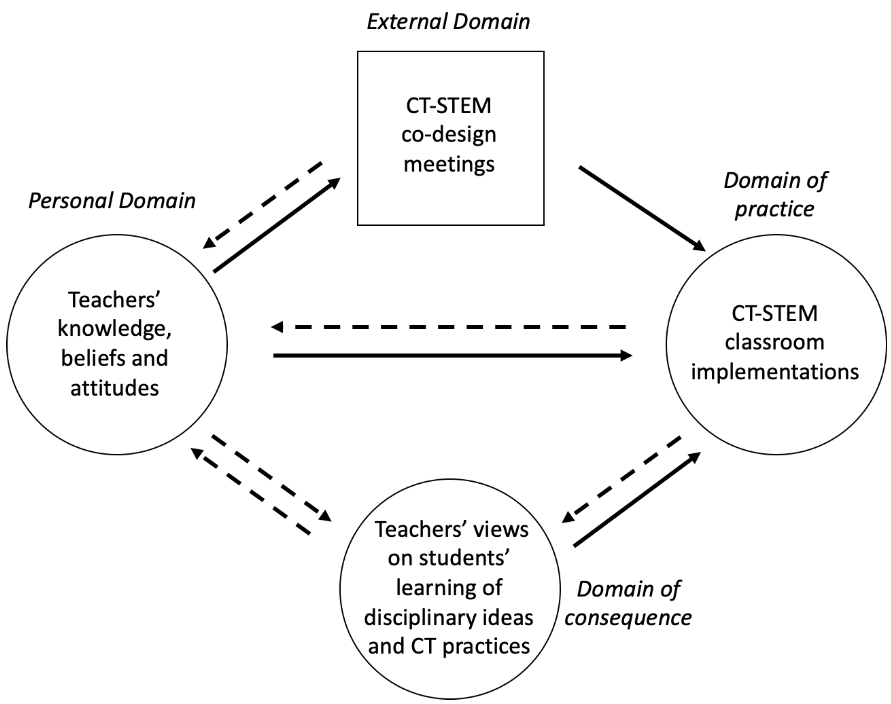

Figure 2: Interconnected model of professional growth in CT-STEM context (adapted from Clarke & Hollingsworth, 2002)

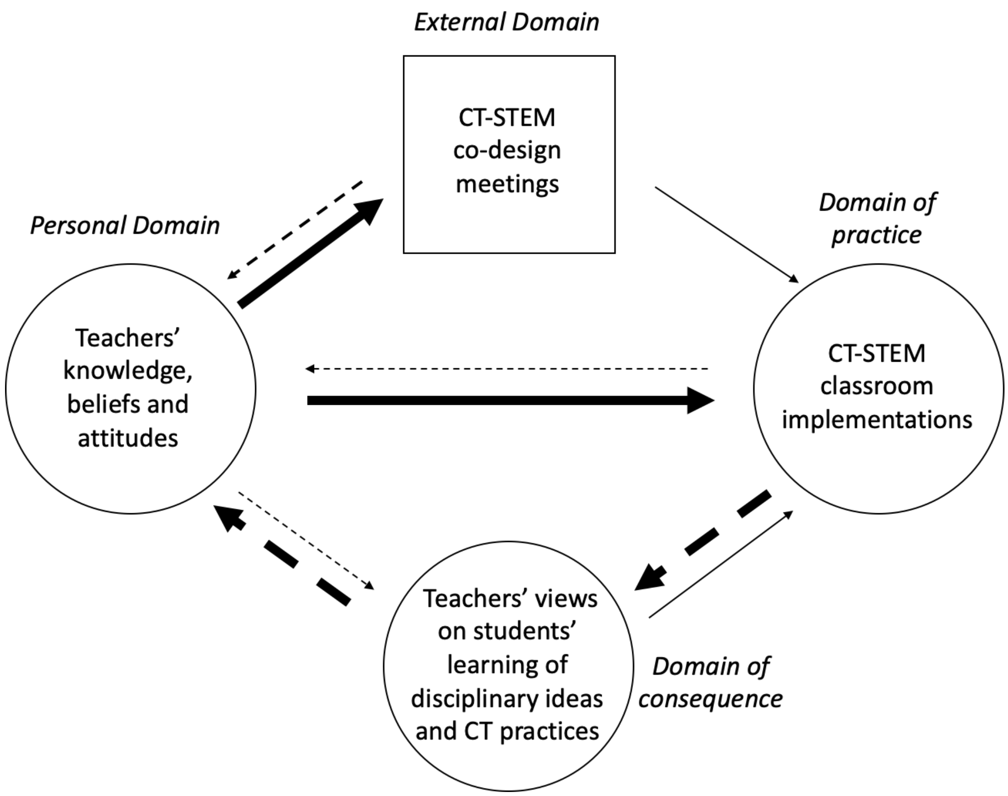

Figure 3: Salient connections (shown with bold arrows) between the domains

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{Also need a full NetTango software citation}.

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