Board 69: Integrating Computational Thinking, Engineering Design, and Environmental Science through Smart Greenhouses

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Computational thinking (CT), or "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" [1, p. 33], is now recognized as a foundational competency for K-12 learners, to address a variety of economic, social, literacy, civic, technological, educational, and personal needs [1–3]. CT in education, however, remains scarce in schools, in particular, in K-8 classrooms for multiple reasons. For instance, the field of CT education has not reached a consensus with regard to what and how CT skills and knowledge should be addressed in school [2], [4], [5], which has confused practitioners [6]. Second, many efforts to embed CT in school coursework have been limited to computer science or computer literacy classes, despite CT's promise for all disciplines [2], [4]. To broaden participation in computation – in part by expanding notions of what "counts" as computation [3] – more empirical work is needed to refine educational design principles for embedding CT in K-12 settings for all disciplines, including engineering.

In this NSF DRL funded project we use "smart" (automated) tabletop greenhouses to engage middle-school youth in practices of computation, engineering, and environmental science. We take a design-based approach [7] with multiple stakeholders (curriculum designers, classroom teachers, researchers) in iterative refinement of educational design. This paper reports the design, implementation, and findings from the first iteration of this project where Grade 8 students were engaged in engineering practices [8] through the design and building of tabletop greenhouses that feature microcontrollers and Internet-of-Things connectivity, to carry out self-driven scientific investigations. The goal of the study was to investigate whether and how students struggled to integrate practices of computation, engineering, and science in this project. Further, we were also interested if we could make any educational design conjectures from our implementation. This first iteration of our project was guided by two research questions:

1. What tensions, if any, do eighth-graders in a mainstream environmental science class experience when engaging in practices of computation, engineering, and science during a smart-greenhouse project?
2. What design conjectures, if any, can be made for learning environments that embed computational thinking practices outside of computer science coursework?

Methods

The NSF-funded project employed a design-based approach [7] to create and implement a 10-day curriculum on smart-greenhouse design with two, 8^{th}-grade science classrooms in a public school of "Mills City", a culturally and linguistically diverse urban-ring city in Massachusetts, USA. The 199 participating students worked in pairs and trios. An overview of the curriculum is presented in Table 1, below. In practice the curriculum lasted 14 days, as teachers provided extra time for learners who needed remediation or extra challenge.

We generated data from pre- and post-surveys ($N = 120$ paired); pre-, post- and follow-up interviews (14, 17, and two, respectively); students' design artifacts; and classroom observations of eight student pairs (including 20 hours of video and 10 hours of screen-capture), all in order to explore student engagement in practices of computation, engineering, and science.

Table 1 *Overview of smart-greenhouse curriculum sequence*	
Day(s)	Topic(s)
1	Brief introduction to “smart” (automated) greenhouses, microcontrollers, and the MicroPython programming language
2-3	How light affects plant growth, and how to monitor and control light
4-6	How temperature & humidity affect plant growth, and how to monitor and control temperature & humidity; links between variation in light, humidity, and temperature
7-10	Using engineering design principles to construct a working tabletop “smart” greenhouse

In this present study we used a nested mixed-methods research design, specifically a participant selection model for explanation, followed by a triangulation design for convergence [9]. First, we analyzed pre-survey results to identify students with computer science interest and confidence at high, medium, and low levels. Then we selected participants for maximum variation [10], choosing to closely observe eight student-pairs of varying interest and confidence, as well as diverse gender and race and ethnicity. We triangulated data generated from surveys, interviews, field notes, work samples, and video, in order to better understand the ways in which students engage in practices of computation, engineering, and science. A three-member team performed qualitative analyses, in periodic consultation with practitioners and the broader research team.

When qualitatively coding interviews, videos, and design artifacts, our conception for practices of engineering and science derived from the Next Generation Science Standards [8], as enhanced by the “dimension of equity, engagement, and diversity” of Rodriguez [12, p. 1043]. For practices of computation, we adopted the Massachusetts Digital Literacy and Computer Science Curriculum Framework [12]. Finally, we conceptualized student engagement in terms of affective/emotional, behavioral, and cognitive dimensions, per the framework of Fredricks, Blumenfeld, and Paris [13].

Results

Our analyses identified three key tensions in students’ engagement with the computational, engineering, and science practices of the curriculum (Research Question 1). First, there was fluctuation between students viewing practices as sequential or simultaneous. For example, “Clara” (all student names are pseudonyms) reported that “as more time went by, we felt like we were doing like, maybe, the three of them [computation, engineering, and science] at the same time”, a sentiment echoed in additional post-interviews and follow-up interviews. That is, practices that at first seemed distinct or even incommensurate, eventually became more connected, per the perceptions of students. This tension is consistent with the spirit of the Next Generation Science Standards [8] and also provides preliminary evidence for connections with the Massachusetts Digital Literacy and Computer Science Curriculum Framework [12].
The second key tension was between engagement via camaraderie and disaffection through stress. Students reported excitement at working in groups of two or three, as opposed to a traditional year-end final exam. Gabriella reported telling her parents, “I’m doing this really cool project instead of a final”, part of her excitement due to working with Clara, a close friend. Despite the fun nature of the project, students experienced stress, especially when their designs

did not perform as expected. One exchange involved Faith and Taylor, who repeatedly experienced difficulty altering the color of their LED lights. When Taylor declared, "I. Hate. Everything. About this", Faith responded "No, have a good attitude", then mumbled "wow, wow, wow" in a manner that caught Taylor's attention. In these ways, the perhaps inevitable stressful moments of a project were mitigated by pro-social behaviors of student teams. These dynamics have connections with cognitive, affective, motivational, and selection processes of self-efficacy theory [14], in ways that will be explored in the Discussion section.

The third key tension was between prior habits of coding and current transfer of skills. Many students indicated in their pre-interviews that they had previously performed block-based coding. However, their block-based practices did not readily transfer to the line-based nature of coding for the greenhouse, consistent with the research literature [15]. In fact, Clara seemed overconfident in her abilities when she quickly dismissed a hashtag symbol (#) that turned about half of a line of code into a comment (rendering it inexecutable). Clara's extensive experience with commenting in block-based environments did not transfer to the conventions of commenting in a line-based environment. Perhaps paradoxically, this difficulty suggests that more experienced students might need *more* scaffolding [16] than inexperienced students.

In addressing our first research question (about how students engaged in practices of computation, engineering, and science), we identified three key tensions with implications for educational design. Given that we have only conducted one iteration to date, we lack the warrant to make strong claims about design considerations. However, we do make conjectures as we consider redesign for iteration two, as we explore in the Discussion section.

Discussion

This paper reports findings from an intervention in a grade-eight mainstream environmental science class, wherein students engaged in processes of computation, engineering, and science to answer their own scientific research questions. Different from broadening youth's participation in CT/CS education through computer science or computer literacy electives, this study took place in science classrooms, presenting another promising approach to increased access to computational experiences. Further, this approach broadened individuals' conceptions of what "counts" as computation, highlighting social, civic, and personal dimensions of a topic that can be dominated by economic, technological, literacy, and educational conversations [3].

Our future work will build upon findings from this current study, per the design conjectures described below. In planning our second iteration, we are using conjecture mapping [17] to connect *embodiment* of educational design with *mediating processes* towards *intervention outcomes*. In terms of embodiment, we believe that formative assessment, metacognitive scaffolds, and team-based learning are key considerations towards promoting the affective, motivational, and cognitive processes in students. Formative assessment will help practitioners, researchers, and students identify prior knowledge, skills, and practices, which could act in generative or inhibitory ways [18]. Metacognitive scaffolds can improve transfer of learning [16], which could have averted Clara's mishap with hashtag-style commenting. Team-based learning can improve attitude and motivation [14], as shown in the exchange between Faith and Taylor. While the intervention outcomes are more distal than the scope of this current paper, preliminary results suggest higher interest in selection of computational activities, increased personal connections with practices of computation, engineering, and science, and the potential for greater transfer of learning from prior computational experiences. In these ways, the smart-greenhouse intervention shows great potential towards realizing the theoretical promise of integrating the disciplines of computation, engineering, and science for K-12 students.

References

[1] J. M. Wing, "Computational thinking," *Commun. ACM*, vol. 49, no. 3, pp. 33–35, 2006.

[2] S. Grover and R. Pea, "Computational thinking: A competency whose time has come," in *Computer science education: Perspectives on teaching and learning in school*, S. Sentance, E. Barendsen, and C. Schulte, Eds. London, UK: Bloomsbury Academic, 2017, pp. 19–39.

[3] S. Vogel, R. Santo, and D. Ching, "Visions of Computer Science Education," in *Proceedings of the 2017 ACM SIGCSE Technical Symposium on Computer Science Education - SIGCSE '17*, 2017.

[4] J. Voogt, P. Fisser, J. Good, P. Mishra, and A. Yadav, "Computational thinking in compulsory education: Towards an agenda for research and practice," *Educ. Inf. Technol.*, vol. 20, pp. 715–728, 2015.

[5] D. Weintrop *et al.*, "Defining Computational Thinking for Mathematics and Science Classrooms," *J. Sci. Educ. Technol.*, vol. 25, no. 1, pp. 127–147, 2016.

[6] P. J. Denning, "Remaining trouble spots with computational thinking," *Commun. ACM*, vol. 60, no. 6, pp. 33–39, 2017.

[7] P. Bell, "On the theoretical breadth of design-based research in education," *Educ. Psychol.*, vol. 39, no. 4, pp. 243–253, 2004.

[8] NGSS Lead States, *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press, 2013.

[9] J. Creswell and V. Plano Clark, *Designing and conducting mixed methods research*. Thousand Oaks, CA: SAGE Publications, 2007.

[10] J. W. Creswell, *Qualitative inquiry and research design: Choosing among five approaches*, 3rd ed. Los Angeles, CA: Sage Publications, 2013.

[11] A. J. Rodriguez, "What about a Dimension of engagement, equity, and diversity practices? A critique of the Next Generation Science Standards," *J. Res. Sci. Teach.*, vol. 52, no. 7, pp. 1031–1051, 2015.

[12] Massachusetts Department of Elementary and Secondary Education, "2016 Massachusetts Digital Literacy and Computer Science (DLCS) curriculum framework," 2016.

[13] J. A. Fredricks, P. C. Blumenfeld, and A. H. Paris, "School engagement: Potential of the concept, state of the evidence," *Rev. Educ. Res.*, vol. 74, no. 1, pp. 59–109, 2004.

[14] A. Bandura, "Perceived self-efficacy in cognitive development and functioning," *Educ. Psychol.*, vol. 28, no. 2, pp. 117–148, 1993.

[15] S. Grover, R. Pea, and S. Cooper, "Expansive framing and Preparation for Future Learning in middle-school computer science," in *Proceedings of the 11th International Conference of the Learning Sciences*, 2014, no. 1999, pp. 992–996.

[16] B. J. Reiser and I. Tabak, "Scaffolding," in *The Cambridge Handbook of the Learning Sciences*, 2nd ed., R. K. Sawyer, Ed. New York, NY: Cambridge University Press, 2014, pp. 44–62.

[17] W. Sandoval, "Conjecture mapping: An approach to systematic educational design

research," *J. Learn. Sci.*, vol. 23, no. 1, pp. 18–36, 2014.

[18] National Academies of Sciences, Engineering, and Medicine, *How people learn II: Learners, contexts, and cultures*. Washington, DC: The National Academies Press, 2018.