Murthy, S. et al. (Eds.) (2018). Doctoral Student Consortium Proceedings. 26th International Conference on Computers in Education. Philippines: Asia-Pacific Society for Computers in Education.

Developing Learning Environments that Support Synergistic Learning of STEM+C

Nicole HUTCHINS
Vanderbilt University, USA
*nicole.m.hutchins@vanderbilt.edu

Abstract: Exploiting the synergies of computational thinking and STEM domains has proven to have significant pedagogical benefits, supporting learning with understanding in STEM that is active and engaging, while also providing for the development of computational thinking (CT) concepts and practices. Proliferating the applicability of this form of learning to more classrooms requires a systematic approach to system, curriculum, and feedback design that targets key domain learning objectives and personalizes learning for a variety of student abilities in the context of traditional STEM classrooms. This proposal outlines one such approach with the goal of developing a learning-by-modeling environment to support effective and inclusive opportunities for synergistic learning.

Keywords: Learning-by-modeling, synergistic learning, CS for All

1. Introduction

Computing knowledge and skills provide the foundations for modern competency in a multitude of STEM-related fields. The practice of modeling is fundamental to science and research has shown that programming and computational modeling can serve as effective vehicles for learning challenging STEM concepts (Basu, Biswas, & Kinnebrew, 2017). This importance on model- and inquiry-based instruction has been further solidified by the Next Generation Science Standards (NGSS Lead States, 2013) as a means of engaging students in more authentic science and engineering practices. In addition, in an age driven by technological advancement and globalization, there is increased recognition that students need to learn computational thinking (CT) to become creators, and not just consumers of the next wave of computing innovations (Wing, 2006). Harnessing the synergies of CT and STEM has the potential to bring about a fundamental change in the way learning occurs, offering a means of integrating computation into existing curricular applications. This provides us with a unique and timely opportunity to develop computer-based learning environments that leverage the synergies between STEM and computing education, and bring a learning by modeling and problem-solving approach to support learning with understanding that is active and engaging.

The introduction of foundational computational constructs into current classroom environments can be challenging (Grover & Basu, 2017). Traditional STEM classes are required throughout K-12, resulting in classes containing a variety of student abilities in the STEM domain and relevant prior knowledge for the application of computation through constructs such as computational modeling. Integration of these constructs into introductory STEM courses may further exacerbate difficulties that students have when working in coupled domains (Basu et al., 2016). Moreover, given the general lack of computer science (CS) standards, teacher certification processes often do not require CS backgrounds, limiting potential integration of synergistic learning applications due to an increased need for teacher training and resources for such an application. Careful consideration must be given to address these limitations to not only limit impact, but to also promote inclusive learning.

This provides the framework for my research on the development of adaptive, learning-by-modeling environments aimed at providing effective synergistic learning opportunities to K-12 students in order to address a small number of the difficulties described above. To do so, key research questions include: (1) What are the key design and development approaches for the development of adaptive, learning-by-modeling environments?, (2) How can we extract or identify the processes of how the learners acquire CT concepts and practices, STEM concepts and practices, and modeling and problem-solving skills in a visual, learning-by-modeling environment?, and (3) How can those processes be used to develop learner models and adaptive feedback to support more personalized, synergistic learning opportunities? This work will be used to support secondary topics that include: (1) aiding teachers in classroom integration of synergistic learning-by-modeling environments in their classrooms, and (2) ensuring the scope of this work is inclusive, especially for girls, as a means of promoting equal engagement and opportunities to learn skills that are instrumental in the 21st century job market.

2. Theoretical Framework

2.1 Learning by Modeling as a Framework for Synergistic Learning

The potential to acquire synergistic learning of STEM and CT can be achieved by getting students to construct computational models of scientific processes. The visualization of an object(s) behavior evolution using simulations simultaneously with model building (i.e., code generation) through the knowledge of equation-based models may allow for a deeper understanding of the fundamental STEM concepts (e.g., position, velocity, and acceleration in physics or ecosystem phenomena such as phenomena such as evolution, natural selection, and population dynamics in biology). In addition, advancements in modeling environments allow for the use of domain specific modeling languages (DSMLs) implemented using block-structured constructs (Jackson & Sztipanovits, 2008; Maroti et al., 2014; Hasan & Biswas, 2017). DSMLs not only provide relief from the burden of learning the syntax of programming languages, but they allow for a deeper focus on CT concepts and practices, such as use of abstractions to define and characterize phenomena, systematic algorithm generation, use of variables, their initialization and update functions, and debugging and refinement to build correct and complete models (Grover & Basu, 2017). Moreover, the implementation of DSMLs centered in the STEM domain affords students the ability to develop solutions expressed in the concepts and practices of the target domain (Hasan & Biswas, 2017). Finally, the ability to execute models in real time to observe behaviors generated from their model allows for immediate feedback to students, extending a level of reasoning and inquiry that may not be applicable in traditional, equation-based modeling. These affordances provide a framework for synergistic learning that has proven to be effective in increasing learning gains in STEM and CT (Hutchins, et al., 2018; Basu, et al.,2016).

2.2 Adaptive Scaffolding for the Classroom

Scaffolding describes pedagogical support that is calibrated to a learner's current level of understanding and helps the learner accomplish tasks that he or she could not accomplish alone (Wood, Bruner, & Ross, 1976). The original notion of scaffolding assumed that a single, more knowledgeable person, such as a parent or teacher, would help an individual learner, providing exactly the help he or she needed to move forward (Bruner, 1975). However, in classrooms where students engage in solving ill-structured problems, instead of a single tutor providing many forms of support, multiple tools and practices are now used to scaffold learning. Each tool may be designed to support a specific task or multiple tools may support a single task through a distributed scaffolding system (Puntambekar & Hübscher, 2005). In the context of synergistic learning for STEM classrooms, adaptive scaffolding will be implemented to support learning gains in both the STEM domain and CT. In addition, to support efforts to limit classroom difficulties described in the introduction, the classroom teacher can use information gained from the implementation of adaptive scaffolding tools to support more personalized teaching approaches.

2.3 Inclusive CT Learning - Bringing Girls to the Table

While enrollment in computer science programs have largely increased recently (Kurose, 2015), the percentage of female graduates still significantly lags their male counterparts (Google for Education, 2014). Notwithstanding the progress made towards addressing the underrepresentation of women in computing, more effort needs to be made to understand the behavioral and scholarly patterns of secondary school students that affect their choice of degree programs and eventual career paths. Significant research has been conducted to improve girls' participation in computer science. Most applicable for this study is that girls have shown to benefit from assignments that highlight the relevance of computing tasks to other disciplines (Vekiri, 2013). In addition, while stereotypes have negatively affected girls' interest in computer science, Stout and Tamer (2016) found that collaborating while learning in CS helped lessen the negative impact of stereotypes. As such, this research aims to incorporate gender-related analysis in the hope of generating tools and processes that support increased female engagement.

3. Research Methodology

3.1 System Design and Implementation

Bransford et al.'s (1999) seminal synthesis **How People Learn** recommends that formal learning environments that aim to foster conceptual understanding need to align four primary perspectives: (1) *learner-centered*, (2) *knowledge-centered*, (3) *assessment-centered* and (4) *community-centered*. To follow these perspectives, a design-based research approach is being utilized for the development of the technology, including the component tools and scaffolds needed to appropriately personalize synergistic learning in the classroom context. In order to incorporate the goal of classroom-based design, this approach considers the presence and content knowledge of the teacher, as well as the role the learning environment would play as part of the complete classroom unit - from the learning needs of different types of learners and the resources the teacher needs to manage the classroom to the technology capabilities of the class environment (e.g. WiFi capabilities).

3.2 Data Sources and Analysis

In order to analyze the role the learning environment played in STEM and CT learning gains for students, instruments will be developed to target strategies of participating students. These instruments include the development of pretests and posttests as well as embedded, formative assessments on CT and applicable STEM domains developed through an evidence-centered design (ECD; Mislevy & Haertel, 2006) approach. ECD is integrated into the design-based research as a means of targeting key educational standards in the STEM and CT domains and coordinating effective curricular implementations of those standards. Finally, student actions on the environment will be logged, including tools used and code-development processes in the modeling environment.

Student learning gains will be assessed through an evaluation of the formative and summative assessments described above. These assessments will be evaluated in coordination with the log file analysis to provide a deeper understanding of the effectiveness of synergistic learning opportunities in our system. The log file analysis process consists of a three-part implementation process. Log file analysis will initially be used to support: (1) the identification of CT practices that support and aid in model development, (2) applications of STEM knowledge or misunderstandings that are reflected in model development, and (3) the coordination of CT practices with the use of STEM domain concepts and relations to develop computational models and solve problems (e.g., appropriate use of operators to simulate STEM phenomena). Following this analysis, a preliminary adaptive feedback framework will be designed, implemented, and analyzed in coordination with the classroom teacher(s) to provide students with feedback as they build their models and to return needed student progress information to the classroom teacher.

4. Initial Results and Implications

At this time, pilot studies have been completed utilizing a physics curriculum and a marine biology curriculum. In addition, a semester-long, empirical classroom study was conducted in the Fall of 2017. Results indicate that our synergistic, learning-by-modeling approach provides for learning gains in both the STEM and CT domains (Hutchins et al., 2018; Basu et al., 2018), and when compared to a control group (utilizing traditional classroom instruction and lab work) students utilizing our environment show significantly higher gains in the STEM domain and in CT than those not using the system. This work is being used to target student computational and problem-solving processes to better understand synergistic learning actions that supported these gains and to improve our logging efforts to ensure we are capturing all needed data.

In an age driven by technological advancement, we have been tasked with the development of educational tools and curriculum that ensure students are best prepared for the 21st century workforce and lifelong learning (Sengupta et al., 2013). This research will provide for a better understanding of how to evaluate CT concepts and practices, computational modeling and problem solving via simulations, and the role synergistic learning opportunities can play in established STEM classrooms through the development of learner models and adaptive feedback based on student performance. Finally, as highlighted throughout this proposal, the application of this environment is meant for traditional classroom settings given potential setbacks in the prior knowledge of the teacher, classroom limitations. Through classroom implementations and coordinated design with teachers, this research aims to provide feedback to the teacher on student performance aimed at better supporting teachers for a more generalizable approach to synergistic, learning-by-modeling for a variety of classrooms.

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