A High School Computational Modeling Approach to Studying the Effects of Climate Change on Coral Reefs

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Abstract: The devastating impact of climate change on coral reefs has reinforced our need to better understand their causes, especially the ones related to humans. Simultaneously, we need to raise awareness about the significance of reefs, both as an ecological host to twenty-five percent of marine life and as a key economic resource for millions of people. Opportunities afforded through coral reef research coupled with advances in computational modeling platforms may provide a unique opportunity to introduce the study of corals into K-12 STEM curricula by combining computational thinking (CT) constructs to build computational models that allow students to explore and systematically study the effects of climate change on the reefs. We outline such a computational modeling curriculum in this paper.

Introduction

Following an extensive marine heatwave in 2016, 29% of the reefs that comprise the Great Barrier Reef lost two-thirds or more of their coral species (Hughes et al. 2018). The magnitude and significance of this catastrophic die-off is significant, given its size and its role in supporting other life forms in the ocean ecosystem. Unfortunately, this series of adverse events is not local to one reef. Across the globe, the high frequency of adverse events is decreasing the capacity of reefs to overcome phenomena, such as large-scale coral bleaching (Pierre-Louis & Plumer 2018).

Research that links behavioral changes in different coral species as environmental conditions change continues to advance our knowledge on the human-impact of these devastations (Klein 2018). In the spirit of the AERA conference theme, affordances including the data collected by scientists to monitor the state of health of coral reefs and the advances in computational modeling may provide the opportunities for developing computer-based learning environments for K-12 classrooms to support scientific inquiry, perform data analysis, and participate in model building, analysis, and problem solving tasks to study the causes for degradation in our coral reefs, and the consequences they may have on marine life in the future.

Our work extends the teaching of core biology constructs by developing computational modeling tools that develop and enhance students understanding of the effects of climate change on coral reefs. This application warrants the use of computational thinking (CT) concepts and practices that would otherwise not be covered in traditional classroom instruction where students may watch a video of a biological process that is followed by a classroom discussion on the observed phenomena. Not only does such an approach help students develop competency in CT, but this approach allows students to be involved in authentic science inquiry, and learn by exploration, modeling, and problem solving. Our research outlines a design based research approach to developing an integrative, computational modeling high school curriculum unit for studying the impact of climate change on coral reef ecosystems that aligns with educational standards. We conducted an initial study to determine if this approach supports synergistic learning of concepts and practices in biology and CT.

Theoretical Framework

Exploiting the synergies between science and computational modeling has the potential to bring about a change that better aligns science education with NGSS (Hutchins et al. 2018). Computation has become the third pillar of science and engineering disciplines along with theory and experimentation (Wing 2016), and recent efforts have demonstrated its effectiveness in enhancing science learning (e.g., Basu et al. 2013, Weintrop et al. 2016). Given the recent focus on integrative STEM education (Honey et al. 2014), a multimodal approach employing available scientific data with computational modeling and analysis may provide effective problem-based learning opportunities for exploratory inquiry-based science learning in K-12 classrooms (Hmelo-Silver 2004).

Computational modeling includes iterative design, implementation, testing, and refining processes that utilize CT practices, such as the decomposition of problems, building and analyzing models, and debugging (Sengupta et al. 2013). Coupled with the utilization of real-world scientific data, the synergistic learning of STEM+CT through computational modeling can engage students in scientific inquiry that provides a deeper understanding of our natural world. While significant evidence exists showing that programming and computational modeling can serve as effective vehicles for science learning in K-12 settings (e.g. Sengupta et al. 2013; Wilensky & Reisman 2006), little evidence exists of the application of computational modeling utilizing data in high school biology classrooms.

Methods

Evidence-Centered Design (ECD)

We have adopted ECD (Mislevy & Haertel 2003) as a means of supporting the structuring of the curricular content and formative assessments to support student learning. ECD "promotes coherence in the design of assessment tasks and rubrics and the interpretation of students' performances by explicitly linking claims about student learning, evidence from student work products, and design features of tasks that elicit the desired evidence" (Basu et al. 2018).

Figure 1. Curriculum Design Process for Climate Change Unit

Domain Analysis	*Domain Modeling*	
NGSS Life Science Framework: Use computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales	**Integrated Learning Goal**	**Curriculum Task:** ***Inquiry***
Marine Biology Concepts: Impact of ocean pH levels on species of coral.	Use a computational model to define how changes in the ocean's pH level affect specific coral species.	Edit values of given variables related to the ocean's pH level and run simulation for each change to predict how pH level changes affect coral.
K-12 CS Framework - CT Concepts: Initializing and updating variables; Control structures: conditionals		
NGSS Practices - Computational Modeling: Use computational models to explain or predict phenomena		
NGSS Life Science Framework: Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem	**Integrated Learning Goal**	**Curriculum Task:** ***Model Building***
Marine Biology Concepts: Symbiosis; Relationship between coral and zooxanthellae algae	Develop a computational model that simulates the relationship between coral and zooxanthellae algaa given optimum ocean temperatures.	Program global ocean temp. to increase at a constant rate until 84F. Program each coral taking into account the zooxanthellae growth rate change based on data for when bleaching occurs.
K-12 CS Framework - CT Concepts: Initializing and updating variables; Control structures: event handlers, conditionals, iterations;		
NGSS Practices - Computational Modeling: Develop computational models by specifying model elements and representing their relations and interactions		

The ECD process is initiated by a thorough domain analysis of the targeted domains - Biology and CT. Using this approach, we unpacked disciplinary concepts in coordination with a marine biology subject matter expert utilizing the NGSS (NGSS 2013), the K-12 Science Education Framework (NRC 2012), and the K-12 Computer Science Framework (K–12 Computer Science Framework 2016). The unpacking of these concepts was followed by the creation of domain maps (Basu et al. 2018) to be used in support of the second component of the ECD process: domain modeling.

Domain modeling focuses on designing synergistic learning tasks, starting with developing integrated biology and CT learning goals to be addressed in the coral reef curriculum. These goals form the basis for designing and developing the curriculum sequence, scaffolds, and the assessment tasks and rubrics, ensuring coordination among all curricular components. Figure 1 demonstrates our ECD process for two example curriculum tasks. The relevant domain concepts and practices for biology and CT are identified in the domain analysis ECD component. The domain modeling component includes the associated integrated learning goals and the curriculum units for each of the relevant domain analysis components.

Domain Specific Modeling Language (DSML)

Our learning-by-modeling approach is operationalized using a block-based, domain specific modeling language (DSML) designed in coordination with our ECD approach. DSMLs are programming languages designed to focus on a particular problem domain through relevant domain notations and abstractions (Van Deursen 2000), thereby affording the ability "to build programs that are concise and self-documenting" (Hasan & Biswas 2017). We have designed a biology DSML to focus students on the relevant domain-specific learning objectives, helping them understand and interpret the computational constructs needed to build correct biology models.

Curriculum Design

Our curriculum is designed to simultaneously teach high school students biology and computer science by building models of the effects of climate change on coral reefs. We developed curricular units: (1) Introduction to Coral Reefs, (2) Effects of Temperature on Coral Reefs, (2) Effect of pH Levels on Coral Reefs, and (4) Use of computing and technology to support Coral Reef Research (Table 1).

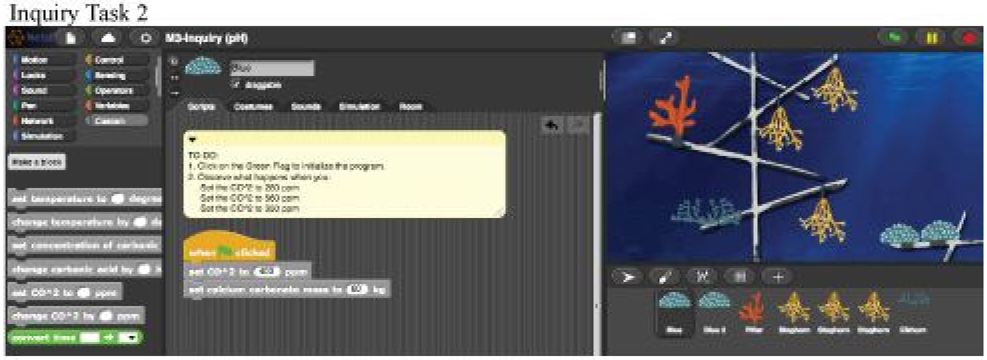
Table 1. Units for the Climate Change Curriculum

Unit	**Description**
Introduction to Coral Reefs	A brief overview of the lifecycle of a coral reef, with particular attention to four coral species used throughout the curriculum.
Effect of Temperature on Coral Reefs	Initiated by an overview of the symbiotic relationship of the zooxanthellae algae and corals, this unit dove into the increasing global ocean temperatures and what happens during coral bleaching.
Effect of pH Levels on Coral Reefs	Initiated by a task on how increasing CO2 levels in our atmosphere affect the pH levels of the ocean, this unit focused on how pH levels affect coral reefs.
Use of computing and technology in Coral Reef Research	This additional unit incorporated more advanced computing constructs by introducing how CS is used in climate change research. Students were given inquiry and instructional tasks on photo recognition and the identification of bleached corals.

Figure 2. Marine Biology Curriculum Tasks

Inquiry Task 1

Inquiry Task 2



Instructional Task

Model Building Task

C2STEM Learning Environment

This study utilized C2STEM (Hutchins et al. 2018), an open ended learning environment (OELE) that combines block-based, visual programming (Kelleher & Pausch 2005) with DSMLs to promote synergistic STEM+CT learning through computational modeling and problem solving exercises. The computational modeling component uses NetsBlox (Broll et al. 2016), an extension of the Snap! programming language (http://snap.berkeley.edu/).

Curriculum Tasks

The first three units of our curriculum were scaffolded into four tasks: *inquiry, instructional, embedded assessments, and model building*. *Inquiry tasks* were designed to focus students on developing a conceptual understanding of domain processes (e.g., the effect of ocean temperature increases on coral species). *Instructional tasks* allowed students to develop simple models using the learned science knowledge and CT concepts and practices. For instance, students were given a program in which the ocean temperature fluctuates (similar to the annual changes in ocean temperatures experienced by coral reefs), and are guided to program (i.e., build a model of) the resulting behavior of a specific coral species for certain temperature ranges (as temperature increases, the coral expels symbiotic algae that live in their tissues). *Model building tasks* extended this application through more advanced CT constructs. In this example, students are asked to construct computational models that describe the effects of temperature change (temperature is modeled as a global variable) on four different coral species taking into account the conditional behavior changes for each type of coral. Parameter values for these models are derived from real-world data acquired from domain experts. Finally, formative, *embedded assessments*, designed using the ECD process, were integrated into our curriculum for monitoring and assessing student learning gains through the study. Figure 2 illustrates two example inquiry tasks, an instructional task, and a model building task for our unit on pH and coral reefs.

Classroom application

Twenty-five high school sophomores participated in our 8-day, 12 hour study. Students worked on all tasks individually. Instruction, including lectures and video (selected during the ECD process with the help of our marine biology expert), were given as introductions to each unit topic. A pre-test was administered prior to Unit 1 and the accompanying post-test was administered following the completion of Unit 4.

Data Sources

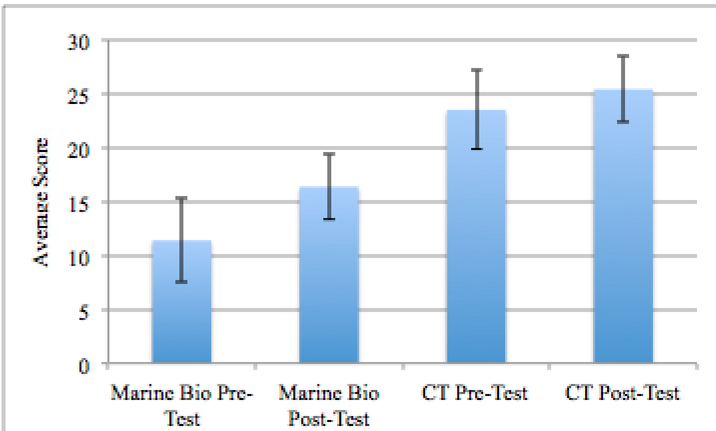
The research presented in this paper is guided by the question: *Does a learning-by-modeling, computational biology approach support synergistic learning gains in biology and CT*? The primary data source used to answer this question is the pre-posttest, designed using our ECD approach. In addition, we adapted assessment items coordinated through the ECD process from other studies to measure disciplinary content knowledge in CT (Basu et al. 2018; Grover & Basu 2017).

Results

The class averages for the pre-test and post-test scores with standard error bars are shown in Figure 3. For the marine biology, the class averaged 11.4 (3.92) out of 22 on the pretest, improving to 16.38 (3.02) on the posttest. The class averaged a score of 23.52 (3.64) out of 30 on the CT pre-test and improved to 25.42 (3.02) on the posttest A t-test conducted on these scores showed significant learning gains in marine biology (p = 7.184E-6) and CT (p = 0.05).

Understanding the symbiotic relationship between coral and the zooxanthellae algae was a key learning objective, primarily in terms of how ocean temperature increases impact the mutual relationship causing coral bleaching. Our pre-posttest assessed student knowledge on this relationship with 2 questions. The first question asked students the primary cause of bleaching and 6 students answered correctly on the pre-test, increasing to 19 correct answers on the post test. In terms of the symbiotic relationship, students were tasked with labeling the items that were exchanged between species. On the pre-test, 15 students identified that coral receives oxygen from the algae and 14 students identified that the algae received CO_2 from the coral. These results improved to 22 and 21, respectively, on the post-test.

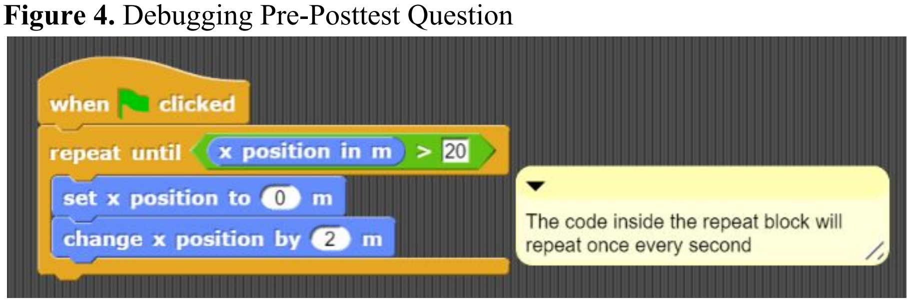
Figure 3. Pre-posttests Class Averages



Conditional logic was an important construct in our computational models. Students needed to model various coral behaviors that were a function of changes in environmental variables. On our pre-posttest, we tested students' abilities to debug a block of code that utilized a conditional to determine how long certain behaviors were active. Students were required to describe how they would edit the problem code (Figure 4) to simulate the motion of a ball traveling horizontally to the right for 20 meters at a velocity of 2 m/s. Students had to place "set *x* position to 0 m" before the "repeat until" block. On the pre-test 6 students correctly debugged the code. 13 students got it correct on the posttest.

These results indicate significant synergistic learning benefits gained in our learning-by-modeling environment. Debugging, an important practice in computing, directly maps on to model testing and refinement, an important component of the NGSS framework.

Figure 4. Debugging Pre-Posttest Question



Discussion, Implications, and Future Works

This paper outlines the design, implementation, and preliminary evaluation of a learning-by-modeling curriculum aimed at synergistic learning of biology and CT. Our results indicate that an ECD approach is beneficial to designing learning by modeling environments that support synergistic learning gains in marine biology and CT, adding to the literature on the benefits of integrating STEM and CT. We are currently analyzing the formative assessments and the log data of students actions on the system to gain a better understanding of their learning processes, and the difficulties they faced in performing their tasks. This analysis will support enhancements to the curriculum and learning environment in future versions of the system.

As alluded to in our introduction, the extent of this global die-off event has intensified research and the availability of data to support our understanding of the impact of climate change on coral reefs. Our future work will integrate publicly available data into our computational modeling environments with data analysis tools that not only support student learning in key NGSS constructs, but may also engage students in in designing, evaluating, and refining solutions "for reducing the impacts of human activities on the environment and biodiversity" (NGSS 2013).

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