STEM + Computing: Learning Physics in a Synergistic Scaffolded Programming Environment

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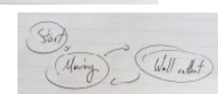
STEPP. The Next Generation Science Standards (NGSS)[1] identify "Developing and using models" and "Use of mathematics and computational thinking (CT)" as two core practices of science and engineering. Although educators, researchers and policy makers widely recognize the importance of modeling and CT, the introduction of these concepts into K-12 STEM education is still in an early stage. We are developing a **Scaffolded Training Environment for Physics Programming (STEPP)** in which students learn physics and cultivate CT skills through state-based modeling by creating their own simulation tools.

Finite State Machines (FSMs). FSMs are a method for state-based modeling and have been used to design algorithms and to teach programming and engineering. FSMs are effective in teaching CT because they help students to learn integral elements of CT including abstractions, structured problem decompositions, iterative thinking, conditional logic, and efficiency. Scaffolding and programing with FSMs will allow students to focus on aspects of programming that complement the physics learning process.

FSMs that two different students develop for a ball bouncing off a wall may be quite different.



Platform. The FSM-based STEPP programming environment is currently being developed using Unity game engine as the platform. The STEPP environment is being designed with a low threshold of prior programming experience, high ceiling for learning potentials, and transferability to other applications in mind. The drag-and-drop, high-quality graphics interface the STEPP team is creating requires no programming language for the student-user.

Modules. A series of learning modules designed to teach physics and CT synergistically at the high-school level are being developed in the STEPP environment. Students will learn to model a physical system as a finite-state machine (FSM) and using FSMs and computational thinking as conceptual tools, they will build their own simulations of physics problems. The first three STEPP modules will focus on (1) 1D kinematics, (2) 2D kinematics, and (3) Newton's laws of motion. The modules are based on both state and national standards[1,2] and local partner district curricula.

Hypothesis. Our hypothesis is that by constructing their own simulation tools, students learning in a scaffolded synergistic environment will master physics concepts and CT more successfully than students learning with pre-made simulation tools.

Timeline. In summer of 2019, a summer institute will be held for in-service and pre-service teachers to learn and experience STEPP and incorporate it into their own curricula and assessments. In the 2019-2020 school year, the three STEPP modules will be tested at two high schools in the Richardson ISD, with a minimum of 160 high school students and two physics teachers participating. Students' gain in physics knowledge will be measured by the Force Concept Inventory[3] and their gain in CT, state-based modeling, and programming concepts will be assessed by rubrics developed in collaboration with high school teachers. Changes in students' attitudes towards computing will be measured by the Computing Attitudes Survey[4].

Research Design. To test the effectiveness of STEPP, we intend to use a 2 (Time: beginning vs. end of academic year) X 3 (Condition: baseline vs. no programming comparison vs. STEPP) mixed experimental design with Time before and after implementation of the three STEPP modules as a within subjects factor and Condition as a between subjects factor. For each group of participants, we will assess physics knowledge, conceptual thinking (CT), and computing attitudes pre- and post- implementation of the modules, once at the beginning of the school year and again at the end of the academic year to assess long-term retention.

In collaboration with the two high schools in Richardson ISD, our research will be conducted in three physics classes (per location) of the identical level and content taught by the same instructor where one class is assigned to a STEPP experimental group; another to the no programming comparison group; the other to the baseline control group. In total six classes at the two locations will participate in the study during the same time period.

Power Analysis. A statistical power analysis with the software program G*power was conducted using the dependent measure from our pilot study reported above. The results indicate that the impact of our STEPP module on students' physics learning was very large (Cohen's $d = .1.71$). Given that our minimum projected sample size is 160, G*power revealed that our projected power to detect a significant effect is .95. Thus, our experiment should have high statistical power.

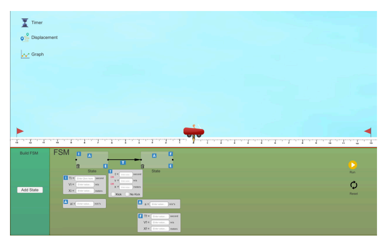
External Evaluation. The external evaluation of the project will be led by Dr. Diane Jass Ketelhut, Associate Professor of Science and Technology Education at the University of Maryland. The evaluation will be an iterative process, working in parallel with the project team. It will have formative and summative components. A formative evaluation report will be provided at the end of years 1 and 2 to the project team leaders; a summative evaluation report will be prepared at the end of year 3. The goals of the evaluation for this project are to: 1) assess the project team's progress towards their stated goals, 2) advise the team on issues and ways to improve the project, 3) review appropriateness of data collection for answering the posed research questions, and 4) evaluate the collaboration process of the team.

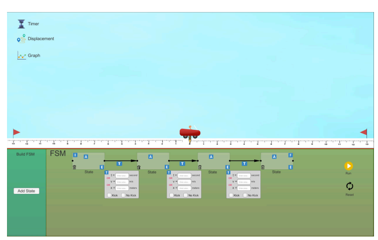
STEPP prototype

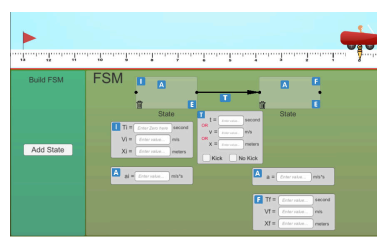
Shown here are simulations with a prototype of STEPP interface in the 1D kinematics module. Right: a simulation with a two state FSM. Left bottom: a simulation with a four state FSM. Right bottom: an enlargement of the two state FSM simulation above it.

States have the following buttons:
I = Opens/closes an input box for initial conditions
F = Opens/closes an input box for a final condition
A = Opens/closes an input box for acceleration
E = Shows/hides equations

Transitions between states have:
T = Opens/closes an input box for a transition condition







Implications. While prior researchers have introduced programming to high school physics classes, this project is the first to take advantage of state-based modeling/programing to promote physics learning and CT. It will go beyond a case study by conducting an experiment with a large enough sample to obtain a statistically significant result.

This research will provide new insights on how the use of dynamic modeling, implemented with cost-effective technology, can best help students understand physics concepts, develop CT, and improve their computing attitudes. By assessing improvements in understanding physics concepts, CT, and computing attitudes, this project will obtain information about relationships between these objectives which could indicate the advantage of synergistic learning.

Impacts. STEPP is being developed with affordable and readily available technology. As a collaborative project between high schools and a research university, it allows these institutions to gain a better understanding of each other's expectations.

For this exploratory study, we are collaborating with two high schools in the Richardson ISD with 72% ethnic minority and 57% economically disadvantaged students. Thus, STEPP will initially be assessed with students who are among the most likely to opt out of STEM careers requiring proficiency in physics and/or computer programming.

Although STEPP modules are initially aligned with Texas's standards and NGSS, the topics covered in the modules are taught in other states as well. Therefore, STEPP could be easily and affordably deployed in other schools, including ones with higher rates of economically disadvantaged students. This will offer students an opportunity to learn physics and programming that might not otherwise be available.

Future funding could be used to expand the use of this tool to other content areas. STEPP has the potential to transform K-20 education in the United States by incorporating the synergistic learning of a STEM subject and computing into classroom education.

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