STEAM-Based Interventions in Computer Science: Understanding Feedback Loops in the Classroom

Dr. Roxanne Moore, Georgia Institute of Technology

Roxanne Moore is currently a Research Engineer at Georgia Tech with appointments in the school of Mechanical Engineering and the Center for Education Integrating Mathematics, Science, and Computing (CEISMC). She is involved with engineering education innovations from K-12 up to the collegiate level. She received her Ph.D. in Mechanical Engineering from Georgia Tech in 2012.

Dr. Michael Helms, Georgia Institute of Technology
Jason Freeman, Georgia Tech

Jason Freeman is a Professor of Music at Georgia Tech. His artistic practice and scholarly research focus on using technology to engage diverse audiences in collaborative, experimental, and accessible musical experiences. He also develops educational interventions in K-12, university, and MOOC environments that broaden and increase engagement in STEM disciplines through authentic integrations of music and computing. His music has been performed at Carnegie Hall, exhibited at ACM SIGGRAPH, published by Universal Edition, broadcast on public radio's Performance Today, and commissioned through support from the National Endowment for the Arts. Freeman's wide-ranging work has attracted support from sources such as the National Science Foundation, Google, and Turbulence. He has published his research in leading conferences and journals such as Computer Music Journal, Organised Sound, NIME, and ACM SIGCSE. Freeman received his B.A. in music from Yale University and his M.A. and D.M.A. in composition from Columbia University.

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Many organizations are seeking to address the need for greater numbers of computer scientists in the US, and in particular, more women and underrepresented minorities. It is not uncommon to develop curriculum that relies heavily on cutting edge technology and computing tools designed to make computing more compelling. Many curriculum developers are seeking to promote creativity as a part of computing, and often do so using STEAM (science, technology, engineering, arts, and mathematics) -based interventions where the arts play a prominent role in the classroom. EarSketch, a web-based computer science instructional tool, is an example of a STEAM-based instructional innovation, where students learn programming skills while engaging in authentic music mixing practices. EarSketch allows students to remix musical samples into original musical compositions, often within hours of first exposure to the application, while simultaneously picking up programming skills. However, there can be hidden challenges to student learning that may go unnoticed without careful observation.

In our efforts to understand the classroom and school level factors that affect successful implementation of EarSketch in computer science classrooms, models were created to explain certain observed behaviors in the classroom. Using Causal Loop Diagrams (CLD's), a tool from systems engineering and operations research, we have identified reinforcing feedback loops that can result in 'virtuous' or 'vicious' cycles of student learning with respect to programming. In both cases, the students appear engaged with the activity, but in some cases, fixation on the arts piece, in this case the music, supersedes the students' active learning of programming and computational thinking practices (the intended learning outcomes in a computer science course.)

In this paper, we present the causal loop diagrams developed to explain the relationships between the actors and attributes involved in implementing EarSketch in a particular school setting. The diagram allows us to better make decisions that ensure both an engaging but also effective STEAM-based computing curriculum. In addition, possible broader ramifications of the results will be explored. The authors expect that virtuous and vicious cycles may be common in other STEAM and technology-based curricular interventions designed to be highly engaging for students. The authors also see potential parallels to engineering curriculum—is time spent 'tinkering' leading to student learning of engineering processes? The hope is that awareness of the possible challenges, as evidenced by the feedback loops, will help other interventions implement successfully.

Introduction

Computing is a highly sought-after skillset, but the United States is failing to produce enough graduates to meet the demand. According to the National Center to Women & Information Technology (NCWIT), there will be 1.1 million computing-related job openings in the US by 2024, and only enough bachelor's degrees in computing to fill about 41% of those openings[1]. In addition, computing is neither attracting nor retaining diverse talent. Many organizations, universities, and K-12 schools are taking action toward addressing the need for more (and more diverse) computer scientists in the US[2, 3]. In particular, Computer Science Principles (CSP) is emerging as a new standard for Advanced Placement (AP) and other high school Computer Science (CS) courses. CSP takes a broader view of computing literacy, focusing not only on algorithms, data structures, and programming, but also on the social, cultural, and technological impacts of computing. The course has already had success at motivating and engaging students in pilot deployments nationwide[4-6]. Our project, EarSketch, uses a STEAM approach (science, technology, engineering, arts, and mathematics) to lower the barriers to entry and increase engagement in computer science through music[7]. In EarSketch, students write computer code to remix sound samples into original music compositions, often within hours of first exposure to the application[8]. This rapid generation of creative artifacts, coupled with sound samples rooted in modern musical genres such as R&B, dubstep, hip-hop and electronica, provides enhanced levels of student engagement and social esteem.

Through observational studies of EarSketch in classrooms, it is clear that engagement in project-based STEM and STEAM curriculum holds some hidden challenges. Specifically, student engagement, in this case meaning active participation in curricular activities, tells only part of the story. While a majority of students in a class may be productively participating, researchers observed that some students fixated on artistic expression without necessarily engaging in substantial algorithmic and computational thinking (as was expected in a computer science classroom). In this paper, we illustrate virtuous and vicious cycles of engagement as observed in EarSketch classrooms[9]. The concept of virtuous and vicious engagement cycles may apply more broadly in computational courses situated in expressive domains such as game design, and to STEAM courses in general where engagement in artistic expression may not always be correlated with the expected technical thinking and learning objectives. We also see potential parallels with the Maker Movement—specifically, is a student learning the intended content when engaging in 'tinkering' types of behaviors? This issue may be particularly poignant when instructors equate engagement or participation with content-specific learning[10]. This belief may be more prevalent among instructors with lower self-efficacy for teaching technical and computational content, as will be illustrated from a modeling perspective later in this paper.

In this paper, we present causal loop diagrams that serve as explanatory models for the existence of virtuous and vicious student engagement cycles[11]. These models serve as a guide for proposing professional development and implementation improvements for the future.

Background: **Modeling and Systems Thinking**

Schools are complex systems with thousands of variables, feedback loops, social networks, and intelligent agents. They are difficult to predict and even more difficult to manipulate. It is difficult to measure the outcomes of educational interventions and often more difficult to understand why they fail or are not sustainable[12]. Some education research has broadened from simply designing and evaluating interventions to studying implementation within the school system[13], but applying systems techniques typically found in engineering is still unusual[14].

Design-Based Implementation Research (DBIR) is an emerging model for education innovations that attempts to address these complexities head-on by engaging many stakeholders, developing partnerships at multiple levels, and using evidence to inform iterations with the goal of creating scalable and sustainable innovations[15, 16]. It is the opinion of the authors that in the context of DBIR, complex modeling techniques from engineering and other disciplines may be useful in informing design decisions and providing insight into issues of performance and scale. During the EarSketch project, model development occurs concurrently with the design and roll out of the education innovation. This is unique from previous efforts to model school systems and the interventions within them, where models were created in a 'post mortem' analysis of the project implementation to add additional understanding to the factors at play[14, 17]. In this work, insights from the modeling efforts not only inform sustainability planning, but also guide the development of the innovation.

In the remainder of the paper, the EarSketch intervention is briefly described and some observation-based causal loop diagrams are presented to better explain classroom behaviors and to illuminate the possible paths forward for improving the EarSketch platform and associated professional development.

EarSketch

EarSketch is a unique web-based learning environment that blends the musical interface of a Digital Audio Workstation (DAW) and a library of culturally-relevant music samples with two popular coding languages, JavaScript and Python[7, 8, 18]. This seamless environment enables students to quickly create novel musical compositions using coding and computational thinking without having to switch contexts, learn a music-specific coding language, or possess prior training in music theory or performance[7]. Moreover, the environment provides a thickly authentic experience closely aligned to the practices and tools used in professional recording studios and consumer software to craft the music to which many students regularly listen[19]. Figure 1 shows the EarSketch environment. In this screen shot, one can see (a) the digital audio workstation, which represents the output of code in a multi-track timeline of sound clips and effects, and (b) the code editor in which students author the Python or JavaScript scripts used to generate the music. The sound library includes over 4000 loops created by music industry professionals in modern genres such as R&B, dubstep, hip-hop, pop, house, and EDM (electronic dance music). In addition, EarSketch includes a curriculum browser with lessons and examples for different computational thinking and music remixing principles. In pilot studies, EarSketch has shown promise in facilitating learning of computational principles and improving engagement for student populations traditionally underrepresented in the field (and especially for women)[20]. As EarSketch is scaled up, these claims are under continual validation; researchers are comparing EarSketch classrooms with comparison classrooms (CSP classrooms using other programming tools) to test for statistical differences in content knowledge growth as well as CS engagement, including intention to persist and belonging in computing[21].

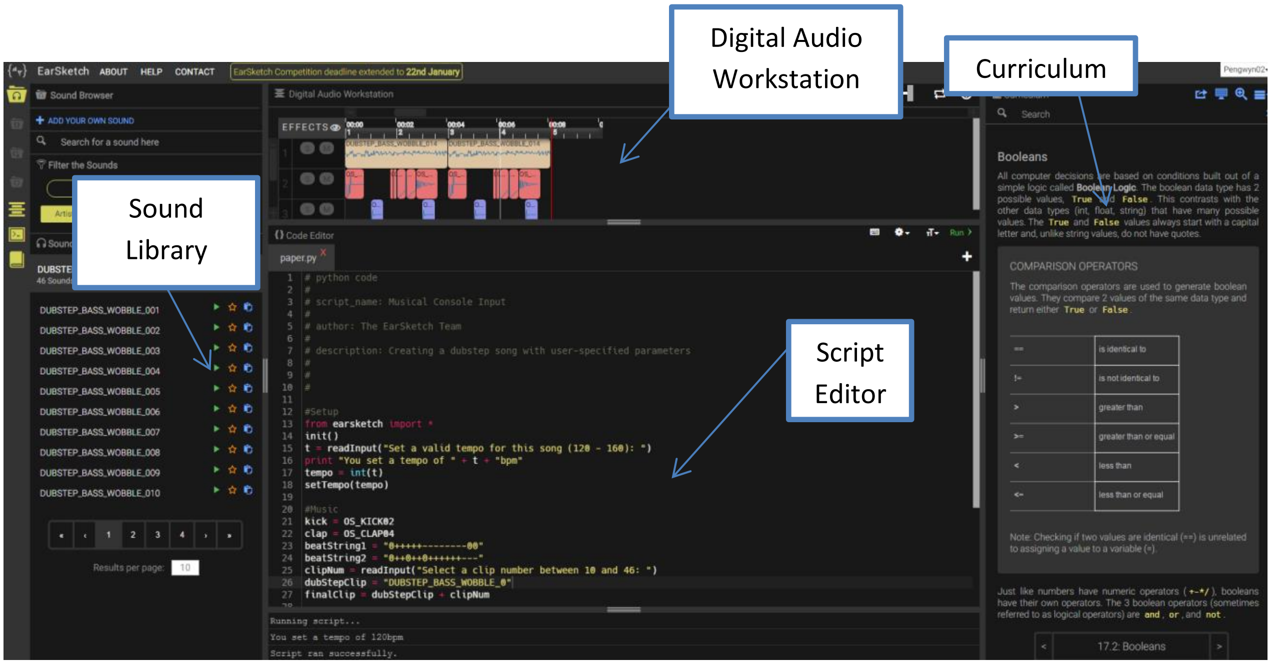

Figure 1: The EarSketch Environment

Implementation Details

EarSketch is currently being piloted in different Computer Science Principles (CSP) high school classrooms across multiple school districts in Georgia. In the curriculum framework published by The College Board, AP CSP is organized around seven big ideas: Creativity, Abstraction, Data & Information, Algorithms, Programming, the Internet, and Global Impact. The intent is to broaden participation in computing by creating a course equivalent to a first-year computing course that emphasizes not only programming content, but fosters creativity, collaboration, and communication[6]. EarSketch is being implemented as a ~10-week module within the ~36 week CSP course that covers all learning objectives in the Programming Big Idea and additional learning objectives in other Big Ideas (Creativity, Abstraction, and Algorithms). EarSketch and AP CSP are well-aligned in their goals of broadening interest in computing and developing a sense of belonging in computing by focusing on the ubiquity and creativity of computing. As a contrast, the long-established AP Computer Science A course is focused more directly on programming, and is organized around the themes of Object-Oriented Program Design, Program Implementation, Program Analysis, Standard Data Structures, Standard Operations and Algorithms, and Computing in Context[22].

At present, we have completed implementation and data analysis in three different schools within the same school district. The three schools offered the Georgia version of Computer Science

Principles, a state standard based closely off of the College Board's AP Computer Science Principles curriculum. (Now that the AP course has officially launched, we are currently piloting EarSketch in the AP version of the course in this year's cohort of schools, with data collection and analysis still underway.) For the purpose of this paper, we are focusing on the original three implementation sites. Within this district, the technical and physical classroom environments for each classroom were very similar, with ample and sufficiently powerful computer terminals available for each student and spatial layouts that allowed students to interact with one another. The student populations and teacher attributes, however, were much more diverse.

No specific recruiting efforts were targeted to any particular demographic at any of the schools; thus, student populations appear to represent typical CSP populations within this district. Student demographics varied in each school along ethnic lines, but were consistently male-dominated.

Developing Causal Loop Diagrams

In order to understand the classroom and school level factors that are likely to have an impact on intervention implementation and sustainability, models are constructed to better explain the relationships between actors and their attributes and to identify attributes likely to either hinder or enable intervention implementation and sustainability. During the EarSketch project, modeling efforts have facilitated internal communication, aiding in decision making with respect to the design of curricular products, informing professional development opportunities, and providing insight into the implications of key relationships. However, communicating about the model requires the establishment of a common language.

To better facilitate model design and model validation as well as to crystallize observation (qualitative) data and the collective experiences of the EarSketch team, Causal Loop Diagrams (CLD's) are introduced as a mechanism for communicating the relationships between the model variables[11, 23]. These models will ultimately be supplemented with mathematical simulations, but the complexity of the governing equations can be a barrier to communicating with an interdisciplinary team and receiving feedback on the validity of the models.

These visual models are the result of many months of discussion and observations. The first step was developing a list of agents (or actors) and attributes that might be impactful and/or might be impacted by the EarSketch intervention. This list was cross-validated with the educational research goals and instruments and has been updated based on the experiences of the team. The links between these attributes are the result of collective experience, qualitative data from a classroom observation protocol, and validation discussions of influencing factors.

Models & Discussion

In each classroom observed, students frequently listened through headphones to the compositions of other students, worked in groups to create compositions, and asked frequent questions both to instructors and to each other about how to accomplish a composition task. The majority of students were highly engaged in practices of both musical composition and computational thinking. We believe this creates a positive feedback loop, or virtuous cycle as shown in causal loop diagram in Figure 2. A virtuous cycle, once started, will tend to perpetuate itself, in this case resulting in increased student coding activity and learning.

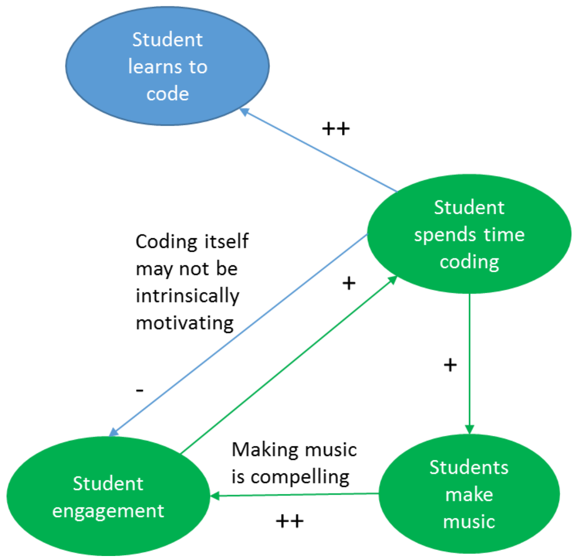

Figure 2: Virtuous Cycle of Student Engagement with Coding

This model is based on two assumptions. The first assumption is that a student may not find the act of coding to be intrinsically motivating. While this is not true for all students, one of the aims of CSP is to broaden participation in computing, so the idea is to engage students who might not ordinarily engage in coding without some prompting or support. The second assumption is that a student who spends time coding will learn to code, as in learn higher level computational thinking practices such as looping and conditionals that will afford them opportunities in computing in the future.

In the diagram, a '+' indicates a positive correlation and a '-' indicates a negative correlation. Since there may be a negative correlation between spending time coding and engagement if the first assumption holds, EarSketch adds the compelling component of making music through coding, which is generally more engaging, particularly among women and underrepresented minorities[24]. From a broader perspective, one could imagine that the compelling activity in this diagram could easily be substituted with something else like creating a game, story, or a wearable[25-27].

While most students were engaged in both composition and coding, observers noted a small number of students in each classroom that produced highly esteemed music without engaging in substantial computational or algorithmic thinking. That is, once students learned basic concepts of using variables, constants, and function calls, they composed "the long way" by copy-pasting music samples and function calls in sequence, rather than by using computational strategies such as looping and lists to perform the same tasks more flexibly, clearly, and efficiently. Moreover, while the researchers were able to quickly recognize "long form" composers, instructors did not necessarily make this distinction. Thus, highly engaged students were provided with positive, reinforcing signals for good musical composition while circumventing the need for algorithmic thinking. In this case, a feedback loop develops that neglects the core CSP learning goals, a so-called vicious cycle as shown in Figure 3. As with the virtuous cycle, this cycle will tend to perpetuate itself unless an external input, such as teacher intervention, interrupts the behavior.

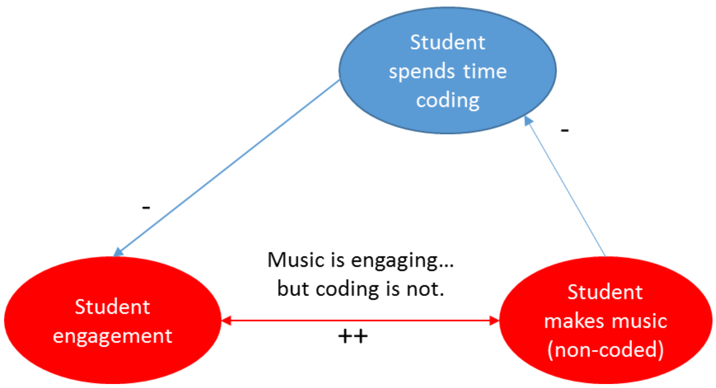

Figure 3: The Vicious Cycle of Student Engagement, Music without Code

The ability of the students to circumvent the 'spend time coding' activity and simply engage in the 'make music' activity might be viewed as a shortcoming of the EarSketch platform, but it is not entirely straightforward. EarSketch is designed so that people with no formal music training can create compelling compositions quickly; if it becomes more difficult to do that, some students could become disengaged because of a learning curve. If a student who would not ordinarily engage in any coding at all engages with EarSketch, the vicious cycle is less vicious. From a learning perspective, however, the student is shortchanging him or herself with respect to computational thinking.

There are several possible paths for breaking the vicious cycle. To facilitate decision making within the project team about how to manage the virtuous and vicious cycles, a more complete causal loop diagram is used. The more complete diagram traces the classroom behaviors back to the professional development offerings and offers a path for preparing teachers to manage this conflation between student engagement and learning. The larger causal loop diagram is shown in Figure 4.

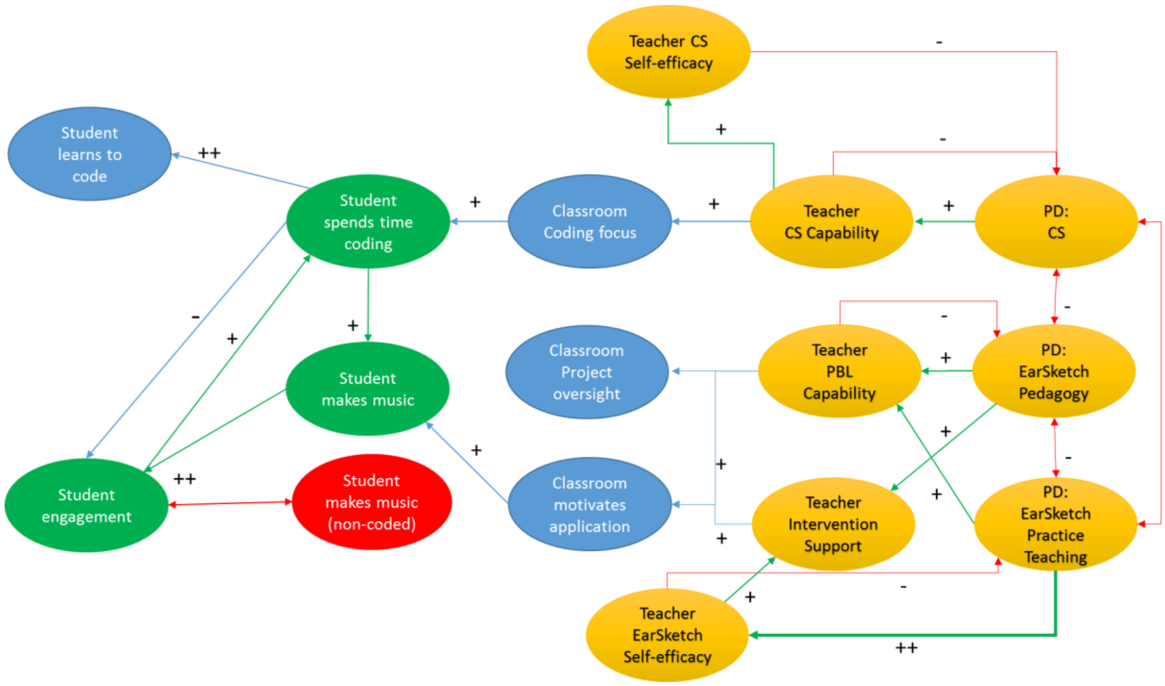

Figure 4: Causal Loop Diagram for EarSketch including Professional Development

In Figure 4, an assumption is made that there are certain key attributes of a teacher that might impact his or her ability and confidence in intervening during a vicious cycle. These attributes are: Computer Science Self-Efficacy[28], Computer Science Knowledge or Capability, Project-Based Learning Capability[29], EarSketch Self-Efficacy, and Support for Intervention (EarSketch). Self-efficacy is defined as one's belief in one's ability to succeed in something—in this case we consider both CS and EarSketch itself to be different and complementary skill sets. Project-based learning refers to a teacher's classroom management style; specifically, are they comfortable in a more facilitator-like role as opposed to simply providing more classic, direct instruction.

In addition, Figure 4 assumes that time for professional development (PD) or training is a fixed resource, which is the reason for the negative correlations between the different types of PD. That is, time spent focusing on core CS content cannot then be spent teaching specifics of EarSketch or pedagogical approaches. Based on the classroom observations and the resultant CLD's, the project team made decisions about the design, delivery, and focus of the PD for future years of the project. Specifically, the team is trying to reduce the amount of time spent on teaching core CS knowledge (e.g. what is a loop), which is sometimes necessary with teachers who are brand new to CS because they have been reassigned from business courses, for example. To do this, an online PD was added to address core CS that was to be completed prior to face-to-face PD, where the focus would be on EarSketch and pedagogical practices like project-based learning. Our hope is that focusing on EarSketch as a teaching tool will empower teachers to intervene more often when students are engaged but not necessarily learning CS content.

The idea is to increase the 'coding focus' of the classroom and increase the overall motivation of the classroom to learn to code by incentivizing the right behaviors. In addition to looking at how professional development affects those classroom attributes, the team also looked at the curriculum and project requirements to encourage more computational thinking without taking away the students' ability to compose quickly early on, something the EarSketch team feels is vital to attracting students who might not otherwise be engaged in a computing course. For example, the EarSketch design team implemented a code concept indicator within the platform, a tool that automatically looks for loops, conditionals, variables, lists, custom functions, and other evidence of good coding practices and assigns a score to the project. In partnership with a teacher, the code concept indicator is first attempt at rewarding good coding practice and discouraging long-form composition. For example, teachers may require students to achieve a minimum score as part of a project assignment.

Broader Implications for STEM & STEAM

The balance between engagement, open-endedness, and core content learning is not a new struggle, particularly in integrated STEM and STEAM experiences[30]. The notion of virtuous and vicious cycles in CS probably applies in engineering and other hands-on courses as well. For example, one could imagine a Figure 3 where 'learning to code' is replaced by 'learning the engineering design process' and the engagement piece is 'building' or 'tinkering'. When appropriately integrated and facilitated by a veteran teacher, learning and engagement can go hand-in-hand. However, school settings, particularly challenging ones, do not always afford luxuries like adequate preparation time, space for activities, teacher professional development, administrative support, and other important variables that may enable or hinder implementation of cutting edge curriculum.

Figure 4 is only a partial model of what is being constructed to understand the implementation and sustainability of EarSketch. Figure 5 gives a more complete picture of what a model of a school setting might look like. The attributes belonging to the students, teacher, administration, school, and community are factors which an intervening agent might hope to influence, but cannot be fully controlled. The attributes over which an intervener has the most control are the attributes of the intervening agency itself and the professional development. Models that capture these complex influences enable interventions to be designed better for their environments and provide an extra level of understanding when it comes to DBIR.

This more complete view of the EarSketch intervention in a particular school setting accomplishes three things. First, the model represents a visual encapsulation of qualitative observations and experiences shared among the research team. Second, the model provides a contrasting view of the more typical linear theories of change posited by education research[21]. It attempts to shed light on the complexity of schools and school systems and the important role that they play in the successful implementation and sustainability of an educational intervention and provides realistic limitations on the effects that an intervention might have. Finally, the model facilitates discussion among stakeholders between the research team, teachers, and administrators. As crucial feedback loops like the virtuous and vicious cycles are identified, decisions can be made to reinforce or break them as necessary. These loops can be hard to break when they cannot be illuminated and discussed. No literature currently exists that makes use of system dynamics models to understand schools and their capacity for interventions, and by extension, no literature exists to illustrate how these models can facilitate better decision-making and discussion amongst key partners.

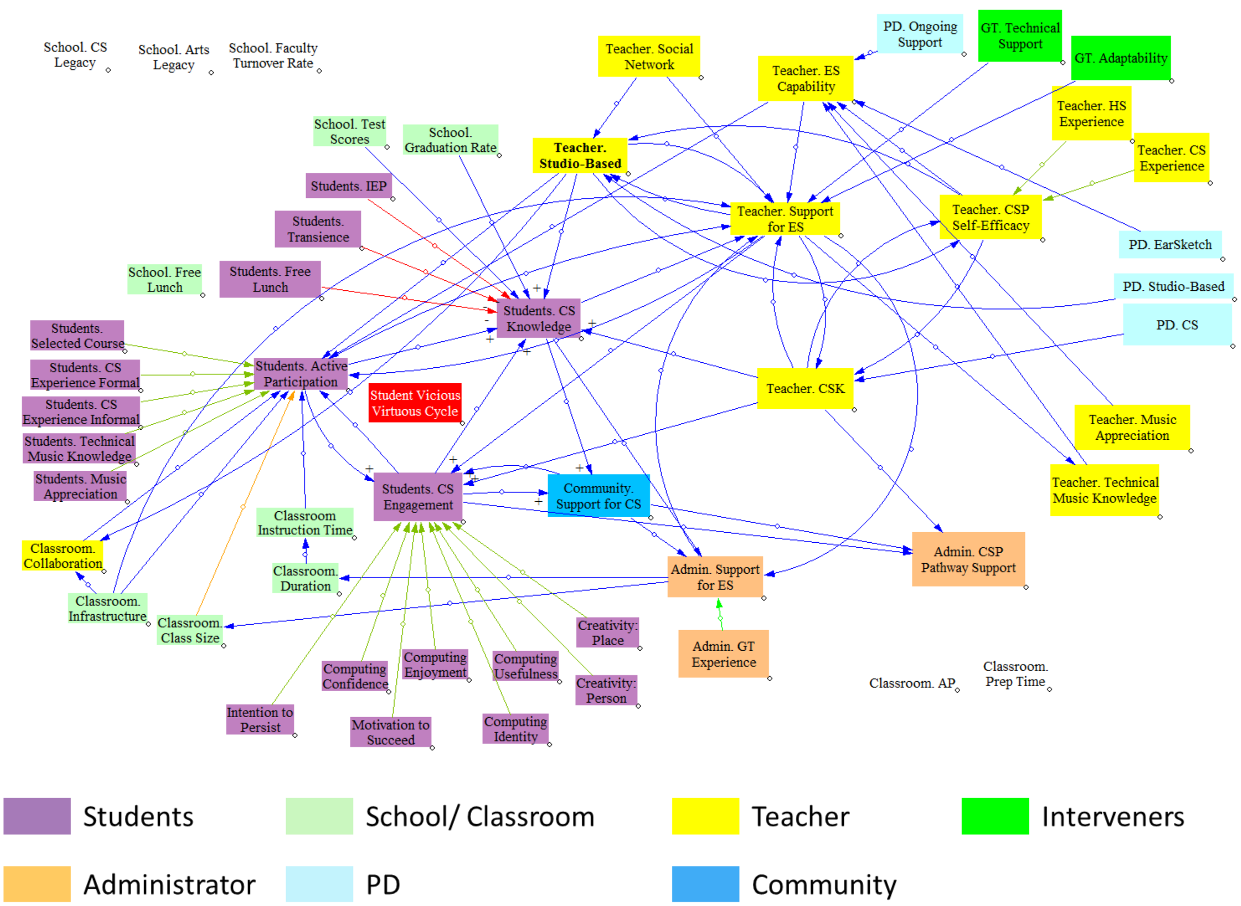

Figure 5: Model of an EarSketch School

Conclusions & Future Work

In order to broaden participation in CS and STEM, cutting edge interventions and curricula are being developed with student interests in mind. Engagement is crucial to learning, and STEAM interventions allow for expression and creativity while achieving technical learning goals. EarSketch demonstrates that learning coding and computational thinking can be made more engaging and appealing to students, especially underrepresented students, through tight coupling to thickly authentic, creative learning environments. However, engagement is not always an appropriate proxy for learning. Instructors must be provided with productive strategies for managing the challenges that come with teaching in a more project-based setting with creative products embedded in the curriculum. Models such as causal loop diagrams can enable deeper understanding in the context of curriculum design and design-based implementation research and can be used in decision making to ensure the best possible outcomes.

In future work, we will be studying the ramifications of the model development on the research team to examine whether or not the models were influential in communication and decisions based on qualitative, semi-structured interviews of the research team. In addition, we will be applying mathematical change equations, influence strengths, and time delays to better understand the key variables in the models and how they enable or hinder intervention sustainability. Understanding key variables and initial conditions that are likely to impact the intervention allows for both better selection of diverse school settings for scaling an intervention, and better decisions with respect to allocation of resources, as well as potentially better intervention designs that are more robust to complex, adaptive school settings.

Acknowledgements

EarSketch receives funding from the National Science Foundation (CNS #1138469, DRL #1417835, DUE #1504293, and DRL #1612644), the Scott Hudgens Family Foundation, the Arthur M. Blank Family Foundation, and the Google Inc. Fund of Tides Foundation. We would like to acknowledge the other members of the EarSketch team who have provided input on these models, including Doug Edwards, Tom McKlin, Brian Magerko, Anna Xambó, Léa Ikkache, and Morgan Miller, as well as Drs. Marion Usselman and Donna Llewellyn for their influence in this work. EarSketch is available online at http://earsketch.gatech.edu.

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