Creativity in Authentic STEAM Education with EarSketch

Shelly Engelman[1], Brian Magerko[2], Tom McKlin[1], Morgan Miller[1], Doug Edwards[3], Jason Freeman[2]

[1]The Findings Group, LLC
2646 Woodridge Drive
Decatur, GA 30033
001-404-633-9091
{Shelly, Tom, Morgan}@the findingsgroup.org

[2]School of Music, Digital Media
Georgia Institute of Technology
Atlanta, GA 30332
001-404-385-7257
{jason.freeman, magerko} @gatech.edu

[3]Center for Education Integrating Science Mathematics and Computing,
Georgia Institute of Technology
Atlanta, GA 30308
001-404-894-0777
doug.edwards@ceismc.gatech.edu

ABSTRACT

STEAM education is a method for driving student engagement in STEM topics through personal expression, creativity and aesthetics. EarSketch, a collaborative and authentic learning tool which introduces students to programming through music remixing, has previously been shown to enhance student engagement and intent to persist in computing. The goal of EarSketch is to broaden participation in computing through a thickly authentic learning environment that has personal and real world relevance in both computational and music domains. This mixed methods study extends previous work by 1) using a newly-developed instrument to assess creativity and 2) testing a theory of change model that provides an explanatory framework for increasing student engagement in STEAM. The results suggest that students who used EarSketch express statistically significant gains in computing attitudes and creativity. Furthermore, a series of multiple regression analyses found that a creative learning environment, fueled by a meaningful and personally relevant EarSketch curriculum, drives improvements in students' attitudes and intent to persist in computing. This work makes a significant contribution to computer science education by establishing the effectiveness of an authentic STEAM curriculum and advancing our knowledge of the underlying mechanisms driving students' motivations to persist in STEM disciplines.

Keywords

Computer Science Education; Creativity; STEAM Education; EarSketch

1. INTRODUCTION

Computer science education has well-documented challenges in attracting and retaining minorities and women at all stages of the pipeline [21]. Even as other STEM disciplines have made recent improvements, the problem with the underrepresentation of women and minorities in computer science has worsened in recent decades [27]. As demand for computer scientists continues to increase nationally, the need to fill this demand and ensure a diverse workforce is of growing importance [9]. The integration of STEM with the arts, called STEAM (science, technology, engineering, arts, and math), is gaining momentum as a method to increase student engagement in STEM topics through personal expression, aesthetic, and interdisciplinary projects [22] [30].

EarSketch is an integrated STEAM programming environment and curriculum that teaches elements of computing and sample-based music composition (i.e. composition using musical beats, samples, and effects) in an effort to engage a diverse population of students. A recent study of the occupational interests of adolescents found that both African-American male and female students, in general, were more interested in music and music production than in computer programing [16]. EarSketch seeks to increase and broaden participation in computing by creating engaging and culturally relevant learning experiences using a STEAM approach [23].

EarSketch fosters a learning environment that is both personally meaningful and industry relevant in terms of its STEM component (computing) and its artistic domain (music remixing) [18] [33]. It includes a programming environment, digital audio workstation, curriculum, audio loop library, and social sharing site that enables students to write Python or JavaScript code to create and share musical remixes. EarSketch students write code to creatively manipulate musical samples while learning computing fundamentals such as loops, lists, and functions. The theory underlying the EarSketch project posits that incorporating EarSketch into high school computer science courses will increase and broaden participation in high school computer science by increasing content knowledge, positive engagement, and perceived creativity among students, particularly student populations traditionally under-represented in computer science. The EarSketch curriculum is specifically tailored to support CS Principles (CSP), an emerging curricular framework for an introductory computer science course intended to help broaden participation in the discipline.

Building on previous preliminary studies, this paper contends that EarSketch is an effective approach to enhancing students' attitudes, creative expression, intentions to persist, and content knowledge in computing. Specifically, EarSketch enables students to a) create music that is personally- and culturally-relevant; b) learn to code and produce music that is industry-relevant; c) use music and computing paradigms that are specific to music and coding disciplines; and d) engage in graded projects in which they write code to creatively remix music. By testing a theory of change model, this project seeks to uncover the underlying mechanisms driving students' motivations to persist in computing with a focus on student creativity. Qualitative data from student

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focus groups provide contextual information for future programmatic improvements.

2. CREATIVITY AND AUTHENTICITY IN STEAM EDUCATION

One reason that STEAM education may be effective is that it creates opportunities for students to be creative in STEM disciplines [15]. In this light, STEAM education marks a paradigm shift for infusing teaching and learning of STEM domains with creative and artistic practice. Traditional STEM teaching often involves little opportunity for creativity and self-expression; EarSketch, however, ensures that students build something of their own design, as opposed to following prescribed recipes as in a lab experiment. Previous research has found that STEAM education leads to more motivated, engaged, and effective learning [15]. Indeed, the importance of personal expression and creativity has been found to play an important role in student engagement [13].

According to previous research, creativity has been discussed from four perspectives: Creativity as process, person, press or place, and product [1] [31] [24]. In this paper, we focus on creativity from the perspective of the *person* (or student) and the *place* (or learning environment). Person refers to the traits, tendencies and characteristics of the individual who creates something or engages in a creative endeavor. Place refers to the environmental factors that encourage creativity.

At the person level, previous researchers have measured creativity by using Creativity Support Tools (CSTs) that were developed from interviews and focus groups [5]. The Creativity Support Index (CSI) [5] measures creativity in terms of feelings of exploration, expressiveness, and immersion. This scale has a high test-retest validity and is a useful way to measure creativity, though does not explicitly consider tools used in learning contexts. Our current work builds on this scale by modifying the items to fit within a STEAM, specifically computing and music, context.

At the place level, researchers offer many different teaching approaches that are designed to promote creativity among students. One constructionist theory contends that learning is most effective when students are actively engaged in their learning environment [14]. Shaffer and Resnick [33] assert that learning material that is personally-relevant and situated in the real world promotes engagement. This kind of authenticity is considered to be "thick" authenticity [33]. Thus, in the context of this study, we operationally define a creative place as being one that promotes a thickly authentic learning environment [33]. At the environmental level, according to Shaffer and Resnick, authentic learning is marked by four identifiable components:

1. Personal: Learning that is personally meaningful for the learner
2. Real World: Learning that relates to the real-world outside of school
3. Disciplinary: Learning that provides an opportunity to think in the modes of a particular discipline
4. Assessment: Learning where the means of assessment reflect the learning process.

Using this theoretical framework, we developed a survey which assesses these dimensions in students' learning environments. We argue that the EarSketch platform and curriculum embodies a thickly authentic approach to engaging students via STEAM education.

2.1 Theory of Change

The following theory of change outlines how students may be affected by a thickly authentic learning environment like EarSketch. A theory of change is a method to illustrate how and why a desired change is expected to happen in a particular context. A theory of change provides a picture of the conditions, or early and intermediate outcomes, that are needed to achieve an ultimate goal [2]. We posit that EarSketch, as an authentically creative learning environment, fosters students' creativity and internal positive attitudes. By enhancing students' internal psychosocial attitudes, EarSketch will, in turn, motivate students to persist in computing. In this way, we describe the psychological processes or mechanisms that fuel students' persistence in STEM education using an authentic STEAM curriculum. This model is couched in the attitude-behavior theory that provides the overall structure for the theoretical model.

According to Fishbein and Ajzen [12], attitudes lead to intentions which, in turn, give rise to behaviors. The flow of our model indicates that a student who is immersed in a creative and thickly authentic learning environment will develop more positive attitudes towards the domain (i.e., computing). Specifically, they will show more confidence or self-efficacy in computing, enjoy computing, perceive computing as more useful in their own lives and in the real world, express more motivation to succeed, feel a sense of identity and belonging, and be able to engage in expressive, creative thinking skills [36]. Gains in these areas will drive the student to persist towards additional education and/or a career in computing.

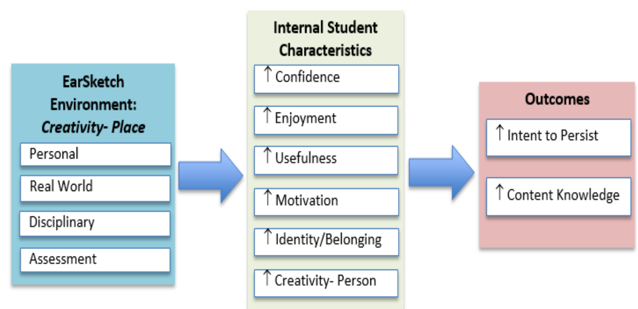


Figure 1. Theory of Change Model for EarSketch

3. METHODS

3.1 Procedure

Seven high school CSP classrooms were recruited to participate in the project. Three classrooms were assigned to the treatment group and used the lesson plans and teaching materials for an EarSketch programming module. The remaining classrooms were assigned to the comparison group and used CodeAcademy and/or Scratch to teach the programming module.

Treatment teachers attended a summer professional development workshop and received on-going support during the academic semester when implementing the EarSketch curriculum. The professional development workshop was intended to prepare teachers to teach the CSP course using EarSketch. In total, there were 74 students in the treatment group and 29 students in the comparison group. Only students who returned both parent consent and student assent forms were included in the study which may partly explain the disproportionate numbers of comparison and treatment students. Due to the small number of comparison students (n=29) and violations of assumptions of normality and homogeneity of variance, we were unable to employ robust statistical analytical methods (e.g., propensity score matching) to compare growth between comparison and treatment students [32]. As a result, this paper will focus primarily on the attitudinal and computing outcomes among treatment classrooms, and the role that creativity plays in fostering engagement in computing.

3.2 Assessment Instruments

To assess the efficacy of EarSketch on students' outcomes, an attitudinal survey (Student Engagement Survey), creativity survey, and content knowledge assessment (CKA) were administered to both treatment and comparison students. The Student Engagement Survey was administered as a retrospective pre-post survey. This instrument draws scales from Wiebe et al. [36] and Knezek & Christensen [17] measuring computing confidence, computing enjoyment, computing importance and perceived usefulness, motivation to succeed, and computing identity and belongingness as predictor variables and intention to persist in computing as an outcome variable. Previous research [36] indicates that these psychosocial constructs contribute to increasing the number of under-represented students who persist in STEM field.

In conjunction with the student engagement survey, the researchers also measured creativity at both the level of the person and the environment. Creativity at the level of the person is defined as the traits, tendencies and characteristics of the individual who creates something or engages in a creative endeavor (*Creativity-Person*). The survey items used to measure *Creativity-Person* were derived from other measures of creativity that assess creative expressiveness, exploration, immersion or flow, and creative thinking skills [1] [5] [31]. These items were administered as a pre/post survey in order to gauge whether EarSketch had a measurable impact on students' creativity. To assess the extent to which the learning environment was perceived as creative or set the conditions for creativity to flourish, we developed a set of *Creativity-Place* items [8]. The *Creativity-Place* scale explores creativity as a thickly authentic learning environment, and taps into the four aspects of authentic learning—Personal, Real World, Disciplinary, Assessment—described by Shaffer and Resnick [33]. These components, or subconstructs, of a thickly authentic learning environment are inherent in the design of the EarSketch computation learning platform and curriculum. The *Creativity-Place* scale was administered as a post measure only, and included such items as "This unit allows me to work on projects that are meaningful to me" and "This unit allows me to work on projects that are based in the real world."

To assess gains in programming content knowledge, the EarSketch team developed an assessment with support from an Advanced Placement Computer Science teacher. We deployed the assessment as a traditional pre- and post-test to students. This assessment is aligned to the College Board's AP Computer Science Principles Curriculum Framework (2016-2017) [7]. This instrument was designed to assess learning objectives 5.1.1-5.4.1 (Big Idea 5: Programming), addressing all essential knowledge areas appropriate for a multiple choice format. The items were classified according to Webb's Depth of Knowledge [35], which categorized the items by the level of complexity and thinking required to provide a successful response (level 1, Recall and Reproduction to level 4, Extended Thinking). The assessment was developed through multiple iterations in conjunction with a team of subject matter experts and think-aloud interviews with high school computer science students. In addition to collecting quantitative data, we also conducted three focus groups with 26 treatment students to add contextual data to our findings.

3.3 Survey Reliability

In the theory of change model, constructs derived from the Student Engagement Survey and Creativity Survey are used as both predictor and outcome variables. Given this, it is important to know the reliability of each construct, whether the same set of items for each construct would elicit the same responses if recast and re-administered to the same respondents. To assess reliability, Cronbach's alphas were calculated for each of the 8 constructs in the Student Engagement Survey. Alpha coefficients range in value from 0 to 1; the higher the score, the more reliable the scale. Nunnally [29] recommends .70 and higher as acceptable reliability. The Cronbach's alphas for each of the 8 psychosocial constructs are displayed in Table 1. Overall, all scale reliabilities fell within the acceptable range [29].

Table 1. Reliabilities of Student Engagement Survey and Creativity Survey constructs

Constructs	Cronbach's alpha	
	Pre	Post
Confidence	.876	.803
Enjoyment	.719	.750
Importance	.768	.732
Motivation	.847	.786
Identity	.785	.743
Intent to Persist	.954	.946
Creativity-Person	.930	.901
Creativity-Place	--	.907

4. RESULTS AND DISCUSSION

4.1 Attitudinal and Creativity Gains

As a first step, we used paired samples t-tests to assess whether gains in computing attitudes and content knowledge were significant. In the case of our attitudinal constructs, paired samples t-tests were used on scale scores following the guidelines set forth by previous researchers [3] [4] [26] [28]. Table 2 shows statistically significant increases across all attitudinal and creativity constructs. As a next step, we calculated Cohen's effect sizes (*d*) across all constructs. Cohen's effect sizes reveal the magnitude of differences between pre and post measures. According to Cohen [6], effect sizes are classified as being small at .20, medium at .50, and large at .80. The effect sizes displayed in Table 2 suggest that all attitudinal constructs yielded medium or large effect sizes (e.g., d>.50). EarSketch was most robust in increasing students' confidence in computing (d=.99). Qualitative data from student focus groups reveal what some students may be pondering when reporting changes in computing self-efficacy. For example, one student said,

> "Before [EarSketch], I wasn't really into any of this stuff… Programming especially. I was like…I'm probably never going to understand this. Now, I actually enjoy it. I'm thinking big about trying to get into a college to go and learn this and get a degree on it, because I'm actually enjoying this, because I'm making something new. I usually just wait until someone does it….. I'm that person who just waits. But now, after making more and more music, I'm like, this could all be changed, my future in education. Hopefully, I'll get a college degree on this."

Other students mentioned their ability to create a personally meaningful project as an important factor in developing their confidence in computing and motivation to persist in computing. For instance, one student described the internal satisfaction gained by creating music, expressing a sense of pride akin to an artist's signature on a painting: "When I started doing EarSketch…it's kind of that beauty of making, creating something yourself…You made it. You get this feeling…hey, I actually made this…it's pretty good."

Table 2. Attitudinal and Creativity Statistics

	Pre/ **Post**	p-value	Effect size (*d*)
Confidence	3.06/ **3.86**	p<.001	0.99
Enjoyment	3.54/ **3.91**	p<.001	0.55
Importance	4.03/ **4.35**	p<.001	0.54
Motivation	3.53/ **3.87**	p<.001	0.56
Identity	3.52/ **3.90**	p<.001	0.63
Intent to Persist	3.65/ **3.94**	p<.001	0.53
Creativity-Person	3.46/ **3.89**	p<.001	0.74
Creativity-Place	**--/ 3.73**	--	--

Scale: 1, strongly disagree to 5, strongly agree.

While we were unable to compare attitudinal gains between treatment and comparison groups due to statistical assumption violations, preliminary results indicate that attitudinal gains were expressed even among comparison students who did not utilize EarSketch during the programming unit. However, it is encouraging that the magnitude of the effect (i.e., effect sizes) was smaller, in many instances, among comparison students than treatment students. While this provides us with some evidence to suggest that EarSketch may be a more effective tool at enhancing computing attitudes, additional research is still needed given the lack of equivalence between the treatment and comparison groups. For instance, a larger percentage of comparison students than treatment students identified as White; likewise, comparison students had more advanced computing experiences, like writing their own code, than students in the treatment groups.).

4.2 Content Knowledge Gains

Paired samples t-tests suggest statistically significant gains in treatment students' programming knowledge. See Table 3. The computed effect size further indicates that students gains in content knowledge are large at d = 1.33. Interestingly, students, on average, scored less than 35% correct on the assessment after receiving EarSketch. This suggests that the assessment was very difficult for students. An ideal assessment using a multiple choice format with five response options should yield, on average, 70 to 74% correct [20]. Using item response analysis, discrimination was calculated for each item. Discrimination refers to how well an item distinguishes between examinees who are knowledgeable and those who are not. A highly discriminating item (e.g., "good") indicates that examinees who responded to that item correctly also did well on the test; a poorly discriminating item suggests that the least knowledgeable examinees are getting the item right while the most knowledgeable examinees are getting the item wrong. The majority of the items were considered good discriminators, which lends validity to the assessment on top of the face validity check from the AP CS teachers. Given how difficult the assessment was for students, the research team subsequently made significant changes, with input from CSP experts and student think-alouds, to improve the CKA for future studies.

Table 3. Content Knowledge Statistics

	Pre/ **Post**	p-value	Effect size (*d*)
Content Knowledge-Overall	14%/ **34%**	p<.001	1.33

Scale: 0% to 100% correct.

4.3 Testing the Theory of Change Model

The theory of change model describes the hypothesized conditions or pathways that might predict students' persistence in computing. For instance, as the learning environment is perceived as being more creative (*Creativity-Place* or Environment), students' psychosocial attitudes should increase; in turn, intent to persist in computing should increase. Each directional path in the model was tested in a series of multiple regression analyses. The multiple regression analyses sough to answer the following research questions: 1) To what extent do changes in students attitudes from pre to post predict changes in students' intent to persist?; 2) To what extent does *Creativity-Place* predict changes in students' attitudes? To answer the first research question, the changes in attitudes from pre to post, delta (Δ), were used as predictors; the change in intent to persist and content knowledge from pre to post, Δ, were used as outcome variables. Controlling for other variables in the model, the results indicate that two variables predicted intent to persist at p<.05: 1) Perceived Importance, β=.37, p=.003; and 2) Identity and Belongingness, β=.25, p=.041. See Figure 2. The standardized coefficient (β) tells us how increases in the predictor variables affect the outcome variable. The larger the standardized coefficient, the larger the impact on the outcome variable [11]. This suggests that students' motivations to pursue additional computing education and/or a career in computing is partly contingent on gains in the following: Perceptions that computing is important and useful for their futures (Importance), and feelings of belongingness in the computing domain (Identity). See Figure 2. Interestingly, none of the predictor variables predicted students' gains on the CKA. It is also important to note that gains in intent to persist were not statistically significantly correlated with gains in content knowledge, r=.107. Together, this suggests that there may have been issues with the content validity of the CKA, and additional modifications are needed.

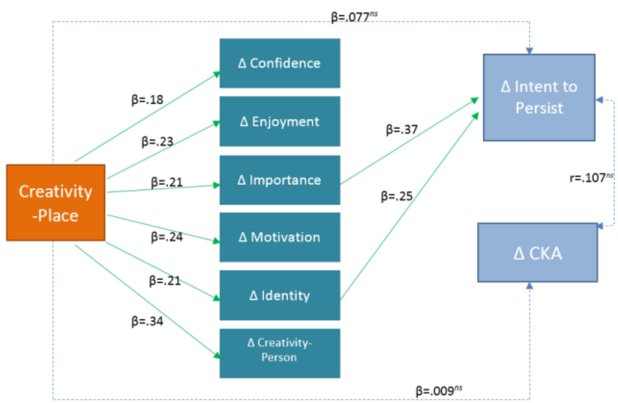
To address the second research question— To what extent does Creativity-Place predict changes in students' attitudes?—multiple regression analyses were also employed; *Creativity-Place* was the predictor variable and students' attitudinal gains from pre to post, Δ, were the outcome variables. The results suggest that *Creativity-Place* statistically significantly predicted gains in all attitudinal constructs. See Figure 2. This indicates that authentic learning environments and activities, that are industry- and discipline-relevant and personally meaningful to students, play an important role in increasing students' attitudes towards computing. It is important to note that *Creativity-Place* did not predict changes in intent to persist (β=.077, p=.520, not significant *ns*) or content knowledge (β=.009, p=.940, not significant *ns*). In other words, *Creativity-Place* did not have a direct effect on persistence or content knowledge. However, it may have had an indirect effect. In other words, *Creativity-Place* may lead to increases in intent to persist by enhancing students' enjoyment, confidence, importance, motivation, identity and creativity-person. To explore this mediational model, additional analyses are needed. Specifically, increasing the sample size of students will allow researchers to generate a path model to test direct and indirect effects of *Creativity-Place* on students' internal characteristics (e.g., identity) and behavioral outcomes or intentions (e.g., intent to persist). Figure 2 provides preliminary evidence to suggest that a mediational relationship exists.

Qualitative data gleaned from focus groups with students corroborates the importance of a creative learning environment in driving attitudinal gains. For example, one student reported a sense of freedom when creating music in EarSketch that was vastly different from the strict boundaries set in other classes:

> "I think in our other classes, if you have like a project or something to do, the thing is it has to be this, this, this, and that. You hear your rules and regulations. But here, the only rules are…you don't have any… So, there aren't really any rules to how to do it. Me, being creative like I am, I like it."

This student voices an appreciation for an authentic learning environment that allows for maximum personal expression and creativity. Another student echoes similar sentiments by describing the EarSketch platform as encouraging novel expressions of self:

> "I think EarSketch is where you can make your own style of whatever you want to do. I think it's a place where you can open up and show like what you like and what you don't like in a song. You can make your own (like) way."



Note. Solid green lines signify significance at p<.05. ns=not significant.

Figure 2. Regression analyses

5. CONCLUSIONS AND LIMITATIONS

Overall, this study tests the underlying mechanisms that affect students' motivations to persist in STEM and, therefore, encourages other researchers to test the model or recommend alternative models. It also contributes to computer science education by demonstrating a significant relationship between an authentic, creative STEAM learning environment and a set of psychosocial constructs that have been used to predict persistence in computing. The results of our study indicate that when programming and music remixing are combined to provide an authentic and creative learning experience, students' attitudes and intent to persist increase. In fact, the magnitude of the effect of EarSketch on students' attitudes and content knowledge were considered medium to large. Furthermore, a series of multiple regression analyses found that a creative learning environment, fueled by a meaningful and personally relevant curriculum, drives improvements in students' attitudes and intent to persist in computing. Finally, a creativity survey that assesses creativity at both the level of the person and the learning environment was developed and showed good reliability. This survey is freely available for use upon request.

Moving forward, one important area for improvement is to acquire a larger sample size of both treatment and comparison students, allowing for a robust statistical comparison. Currently, our comparison and treatment groups were different in terms of size, demographic composition (e.g., the comparison group was composed of primarily White students whereas the treatment group was composed of primarily underrepresented minority students), and computing background (e.g., comparison students had significantly more advanced computing experiences, like writing their own code, than treatment students). Without controlling for these disparities, the effect of EarSketch could not be distinguished from the effect of race/ethnicity and previous computing experience. By increasing the sample size, we will be able to employ propensity score matching (PSM), which adjusts for selection bias in quasi-experimental designs. This technique uses a matching algorithm to match students from the treatment and comparison groups on important variables (e.g., demographic characteristics) in order to isolate the effect of the intervention on students' outcomes [25]. Also, boosting the sample size enables us to use more advanced statistical techniques like structural equation modeling to test the proposed theory of change model. Structural equation modeling would test both direct and indirect pathways, and may support a mediational model [34].

We are currently scaling up our research efforts over the next two years to expand the study of EarSketch to approximately 30 high schools across the state of Georgia. The current paper provides promising findings and a theoretical model that will serve as the foundation for future work in authentic STEAM education.

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