Creativity, Customization, and Ownership: Game Design in Bootstrap:Algebra

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ABSTRACT

Game programming projects are concrete and motivational for students, especially when used to teach more abstract concepts such as algebra. These projects must have open-ended elements to allow for creativity, but too much freedom makes it hard to reach specific learning outcomes. How many degrees of freedom do students need to make a game feel like one they genuinely designed? What kinds of personalization do they undertake of their games? And how do these factors correlate with their prior game-playing experience or with their identified gender?

This paper studies these questions in the concrete setting of the Bootstrap:Algebra curriculum. In this curriculum, students are only given four parameters they can customize and only a few minutes in which to do so. Our study shows that despite this very limited personalization, students still feel a strong sense of ownership, originality, and pride in their creations. We also find that females find videogame creation just as satisfying as males, which contradicts some prior research but may also reflect the nature of games created in this curriculum and the opportunities it offers for self-expression.

KEYWORDS

K-12 education; videogames; design; ownership; motivation; gender

1 INTRODUCTION

Many authors [3, 7, 11] emphasize the creative benefits of computing. A game or physics simulation author can design novel characters or means of input, experiment (or do away) with gravity, and so on. Many are attracted to computing precisely because of this creative power, and constructionism [8] embraces this kind of power as a central part of its pedagogy.

When discussing K-12 CS curricula, "creativity" is often used colloquially (as opposed to formally, as in psychology [15]), referring to a combination of student engagement, motivation, or flexibility for students to choose their learning tasks. In a traditional curricular setting, too much flexibility can be problematic. If a course has concrete topics to cover—especially in the context of an externally administered exam—then teachers may not have the flexibility to engage in free-form exploration. Here, we do not go into the question of whether this is a reasonable attitude or not. We take it as a given and important constraint of many teachers and schools, and note that curriculum designers that want to succeed in a large number of schools—thereby bringing computing to *all*—must take into account such constraints.

Three factors amplify these costs:

- Some attempts at bringing computing to all take it to non-computing subjects. Their instructors may be ill-equipped to aid students in unstructured explorations.
- These problems as exacerbated when computing is embedded into topics like algebra, which are subjected to high-stakes testing. These tests often push teachers to stick to a regimen likely to meet their testing goals, and create anxiety about too much deviation. Thus, a curriculum that wishes to embed itself into such a topic must minimize variance.
- Finally, not all students themselves necessarily appreciate a lack of fetters. As research has shown [6], too much choice can negatively impact motivation and engagement.

Thus, curriculum design has many constraints to balance, rather than blindly embracing "creativity" at any cost.

In this paper, we examine these issues in the context of a specific curriculum, Bootstrap:Algebra[1] (henceforth BS:A). In BS:A, students build a videogame that is purportedly "of their own design", but in actuality is highly constrained. The benefit of this curriculum for math transfer has been studied before [14], but does it come at a cost of hurting computing satisfaction? Indeed, many CS teachers balk at how little "creative control" students are given over their games, especially in relationship to free-form curricula that build on tools like Scratch [12]. In response to those teachers, we investigate the impact of the small amount of customization BS:A provides. Is this enough for students to feel a sense of satisfaction or ownership over their product? Do they view this as an authentic game-building experience? Along the way, we also consider the impact of identified gender, providing new data on how female students relate to game design.

2 CREATIVE EXPRESSION IN BOOTSTRAP:ALGEBRA

BS:A is a 20–25 hour module embedded into math classes in US grades 7–10, and is designed to teach students the essence of functions. To motivate learning, students approach this topic by creating a videogame. Concretely, students write several functions to define the behavior of various game elements: the movement of characters,

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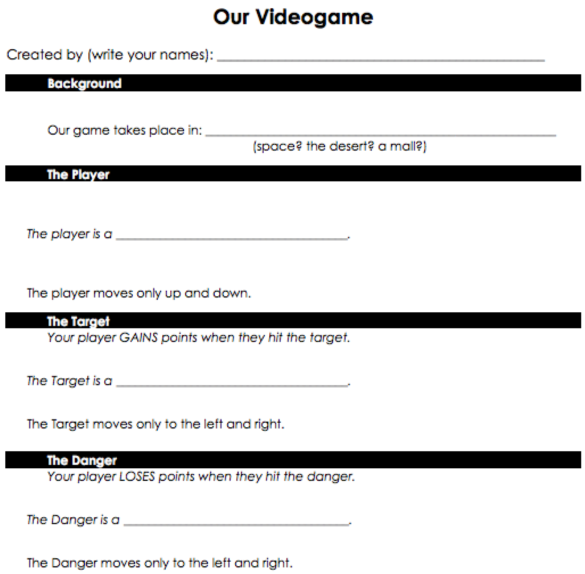
[1] Bootstrap is the umbrella name for a family of four curricula. The Algebra curriculum is the oldest of these, and referred to simply as "Bootstrap" in older publications.



Our Videogame

Created by (write your names): ______________________________

Background

Our game takes place in: ______________________________
(space? the desert? a mall?)

The Player

The player is a ______________________.

The player moves only up and down.

The Target

Your player GAINS points when they hit the target.

The Target is a ______________________.

The Target moves only to the left and right.

The Danger

Your player LOSES points when they hit the danger.

The Danger is a ______________________.

The Danger moves only to the left and right.

Figure 1: Game Design Worksheet

the detection of walls (to implement "side-scrolling"), the calculation of distances (to check for collisions), and the production of game visuals. To meet its math curricular needs, the game design obeys a careful progression to motivate every next needed mathematics topic, in close alignment with math standards, and with significant scaffolds [13] to stage the math/game progression.

To motivate students, teachers tell them that they will *create their own videogame*. This is followed by a discussion about the importance of teamwork and pair-programming[2], and setting student expectations.

Students are then shown a simple game with four components:

- *background* (static image over which the game takes place)
- *player* (avatar, moves along y-axis via keypresses)
- *danger* (moves along x-axis; player wishes to avoid)
- *target* (moves along x-axis; player wishes to catch)

The game score increases when the player collides with the target, and decreases when it collides with the danger.

At this point, students are given time to design their game. In fact, the only "design" they can perform is to customize these four elements. Furthermore, they are then given merely *five minutes* to (in pairs) come up with the design elements. Their design is written down on the worksheet shown in fig. 1. Having come up with this design, they are given a few minutes on Google Images [images.google.com] to find images corresponding to these choices.[3]

In principle, there is still ample room for creative expression. One team might use an underwater background, a diver for a player, a treasure chest for the target, and a shark for the danger. Another might use a mall as the setting, a teenager as the player, jewelry as the target, and a mall cop as the danger. Some games borrow from existing narratives (a *Twilight*-themed game, for example, might use characters from the well-known franchise), while others have a social mission (a student avoids drugs and gangs while collecting As and Bs that fly across the screen). Two sample screenshots are shown in fig. 2.[4] On the left, the heart tries to catch the cap and avoid the monster. On the right, the net tries to catch space junk while avoiding asteroids. The BS:A infrastructure maintains the score (initial value of 100, +20 for catching the target, -50 for colliding with the danger) and automatically overlays it atop the game.

Because there is an enormous gap between the popular commercial games they have named and what they are being allowed to design for themselves, students may not find this an authentic experience. Furthermore, the movement of characters is also fairly scripted (they can only move in certain dimensions; thus, the only flexibility they have is in how far they move, which is usually a function of the sizes of images). To a mathematically-minded viewer, then, the games might seem essentially isomorphic. Do students also view them that way?

Note that working in pairs further affects these issues. When grouped, student are forced to come to an agreement. While this may lead to more creative options, it also requires a degree of compromise, which may further reduce the sense of personalization and hence ownership. Nevertheless, studying the effect of working in pairs is a broad topic outside the scope of this paper, so we leave this question for future study.

Concretely, in this paper we ask the following questions:

- Do the students play videogames themselves? Their frequency of play may impact how they perceive the (lack of) flexibility they are given.
- Do students feel excitement about building a game? If they felt overly constrained or scripted, that is likely to reflect in a lack of excitement.
- Do students feel pride in the game they built? The closer they associate with the game, the more pride they are likely to feel; the small degrees of freedom they are given may result in a lack of pride in the result.
- Do students feel their game is "real"? It is quite possible that choosing four parameters with limited motion greatly impacts their sense of realism, especially when compared to the blockbuster games they have played.
- Do students feel their games are different from each others'? Given the high degree of behavioral similarity between the games, is the small amount of customization they perform sufficient for them to feel like their games are distinctive?

We also study the impact of gender on these questions.

3 STUDENT SURVEY

We conducted a survey across students who had just completed BS:A. We had a choice of a small-scale, in-depth study or a large-scale one with fewer details. While the former would and will be instructive, we wanted results with sufficient numbers to arrive at statistically significant conclusions. Therefore, we opted for a lighter-weight study to encourage participation and completion.

[2]Though the BS:A curriculum strongly recommends that teachers have students work in pairs, some teachers permit some or all students to work individually.

[3]Teachers are instructed about Google Images filters to enable students to search for images with suitable usage rights [support.google.com/websearch/answer/29508].

[4]These images were obtained from programs voluntarily provided by students.

Figure 2: Sample Student Game Screenshots

Our goal was to examine whether there was even preliminary evidence in favor of personalization and ownership before conducting a richer study. In this paper, we use $\Longrightarrow$ to indicate some of the issues we either explicitly left out of our study (to keep it short) or that have arisen as a result of seeing the data we obtained.

In response to our request on the primary BS:A mailing list, we received responses from 21 schools. These spanned both middle- and high-schools. All but one were public middle and high schools in the USA, with one international school in Nigeria. The survey was administered using a Google Form, which teachers forwarded to their classes; no personally-identifying information was collected.

A total of 225 students responded, evenly distributed across the schools. Of the respondents,[5] 94 identified as female, 104 as male, and 11 marked Other or preferred to not answer. (The ratio of about 43% female is consistent with the overall BS:A student demographic.) While it is impossible to check that students were taking the study seriously, we felt any lack of seriousness would be manifest in the free-form textual answers. As we did not find instances of this, we used all survey responses in our analysis.

4 STUDENT BACKGROUND

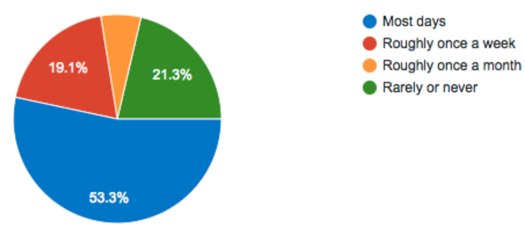
We now analyze student responses to answer the questions raised in section 2. We begin by exploring the student population.

Game Playing. We first determine to what extent students themselves play videogames.

As we can see, roughly half are avid game players. We did not ask them for specific styles of games, allowing their self-definition of games to suffice for this purpose. $\Longrightarrow$This is an example of a question a richer study could include, e.g., as a free-form textual box where students could name the games they play, and the research team or outside experts could classify these by styles of games.

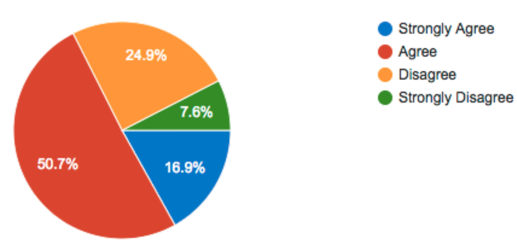
[5]Due to a form error, this question was missing from the survey that the first few students saw. Therefore, these data alone are for 209, not 225, respondents.

How often do you play videogames?



Game Creation Confidence. We also asked students whether, before they started, they felt confident they could create a game. Note that this question was posed at the end of the class, so their recall may not be perfect. Nevertheless, student confidence in completing the task was high. This could be attributed to having had some prior experience with tools like Scratch [2]; $\Longrightarrow$additional research is needed to understand why students have this confidence.

Before I started this project, I was confident I could make a game

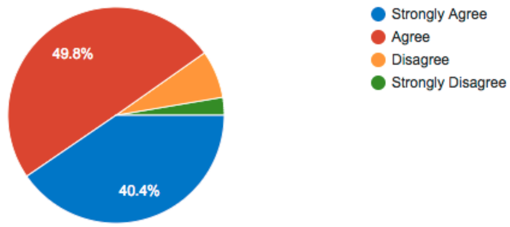


5 AUTHENTICITY AND OWNERSHIP

Now we focus on student responses that help us understand their perception of the games they created.

Excitement. In light of the previous data, it is conceivable that many students, being confident about their ability to create a game and being game habituants, did not feel much excitement from their accomplishment. However, we find that that is not true:

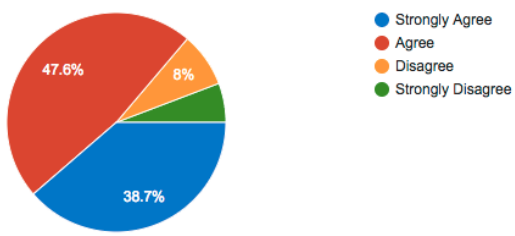
I am excited that I made a game



In particular, only six students are in the strong disagreement group.

Pride. Beyond excitement, we were interested in a more subtle emotion: pride in their product. It is conceivable that students were excited by the activity but did not feel a deeper sense of pride, which would result in a more lasting positive impact [5].

I am proud of the game I made



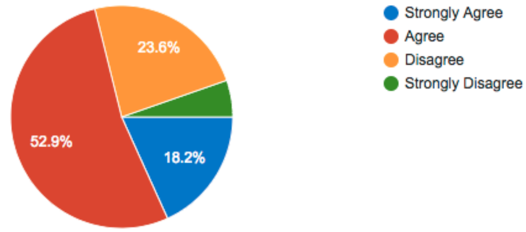
We note that students feel pride to essentially the same extent as they feel excitement. (Indeed, student ratings for the two questions are essentially identical.) ⟹It is possible students interpreted the two questions in essentially the same way; in-depth studies would be needed to determine their perceptions.

Having established a baseline sense of accomplishment, now we get to the two most important questions relevant to this paper: does the small degree of customization they were able to perform (a) result in authentic-feeling games and (b) help differentiate their games from those of others?

Realism. First, we asked students how *real* they felt their game was. It is easy to see that a simple game with just three entities and highly constrained movement might not feel real. In that case, students might view their activity as no more than a disguised math task and might not feel they have done any computer programming. However, the data (shown in the next chart) do not bear this out.

It is noteworthy that about a quarter of students slightly or strongly disagreed with the realism of their games. Indeed, we would have been surprised, and been suspicious about the attention students were paying to the questions, had this not been so: given the very artificial nature of the games, a significant number of students should have felt this way. In light of that, we find it interesting that nearly three-quarters (71.1%) somewhat or strongly felt their game was realistic. In section 6 we analyze these data further,

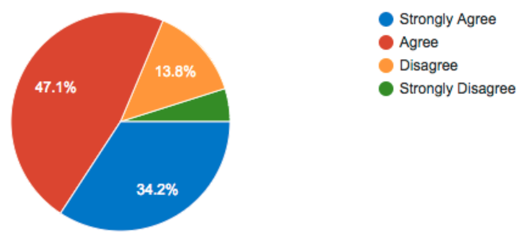
I feel like I made a real game



in particular comparing the perception of realism with students' gaming activity and with gender.

⟹A natural follow-up is to determine what factors of the games felt realistic. For instance, if scoring were removed, would that impact realism? Did students want more freedom in choosing components? Was the restriction to one-dimensional motion for each moving object to blame? (This is a restriction that many students want to remove; the Bootstrap:Reactive [www.bootstrapworld.org/materials/spring2017/courses/reactive] curriculum was created as a follow-up to Bootstrap:Algebra precisely to provide this power.)

My game is different from the ones other students made



Difference. Another important question is whether the similarities that are clear from a mathematical perspective are evident to the students, or at least whether they *matter*. We asked students this directly. A total of 18.7% feel that their game is *not* different from those of others, with only 4.9% feeling *strongly* this way. What this indicates is that even the small amounts of customization permitted by BS:A are sufficient to get students to view their games as different from those of others; indeed, over a third feel *strongly* that their games are different, nearly double the disagreement groups put together.

⟹It would be useful to understand the students who do *not* perceive differences. We conjecture several hypotheses. Some might be procedural:

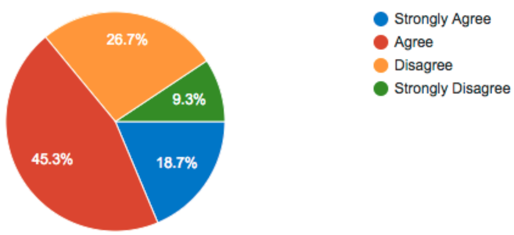
- All games started by customizing the same worksheet.
- All games were produced in lock-step in a class setting.

More intriguingly, however, students might have perceived the underlying mathematical similarity between the games, and might thus have looked past the visual and narrative differences.

Equally interesting is why students *did* view the games as different: did they understand the underlying mathematical similarity and consciously choose to overlook it, or did the visual and narrative differences occlude that similarity?

Visibility. One other measure is how students feel about sharing these games with people outside their class. Here we find that 64% would like others to see their game.

I want people from outside my class to see my game



⟹Of course, there are many reasons why a student might *not* want others to see their game. They may not feel sufficient pride in their product; they may be nervous about criticism or even just calling attention to themselves; they may be embarrassed about how their parents might distribute their work. In addition, we have to also consider social factors, such as students not wanting to be seen by their friends and peers as overly academic [4]. These factors demand significantly more study.

Design Inspiration. Finally, we ask students for the inspirations for their game designs: both how they chose the characters in their game, and whether they got interesting ideas from seeing or playing other students' games. Students cited numerous influences on the former: a quarter chose "They remind me of a book, movie or TV show that I like"; another 14% chose "They remind me of something I like to do"; 7.6% chose it because of their partner. 20% had no particular reason for their choice.

Because we permitted free-form answers, we received many that evinced personalization in one of the above categories. Some chose to write in specific TV shows (e.g., The Simpsons) or bands (e.g., Migos). Several mentioned either specific videogames that inspired their design (e.g., Minecraft, Clash Royale), genres ("who doesn't like a good zombie game!"), or a generic desire to mimic a videogame. We also received some other categories of responses, such as [all quotes are verbatim, including typos]:

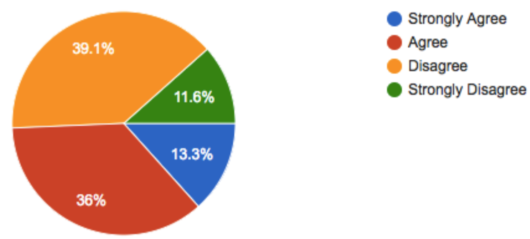
- "They represented something I was extremely passionate about; the enviorement and environmental protection."
- "we thought it was funny and we like dogs"
- "it has a good meaning: to always pick up trash"
- "Sloths are cute. Zombie marshmallows are a necessity of life."
- "i chose batman as my them because my sister oves batman and she kind of wonted me to make the about that so i chose to make her happy"
- "To raise animal endangerment"
- "it's a true story. Me and my partner just changed it a little bit though."

Some of these responses represent recurrent themes: animals they like or animal rights in general, social goals (such as reducing littering or protecting the environment), or humor.

We also see some conflict. Two students commented that they were forced to change their choices by their teacher. Both students, one male and one female, who may have been partners (both were taught by the same teacher), strongly disagreed on most of the questions above (e.g., on excitement and pride). The teacher's comment on this intervention was: "After some experience with poor decisions made by my 8th grade students, I had to restrict any racial stereotypes and political figures. I had a couple of groups over the years make some games that were very offensive to the parents and staff that the students were presenting to." These issues are not widely reported by BS:A teachers, but are nevertheless something to consider when students have freedom to choose from the unlimited palette of the Web, as opposed to highly restricted characters provided by some systems.

We also see evidence of inspiration from one another:

I got some interesting ideas from seeing or playing other students' games



Observe that over 40% of students claimed to get interesting ideas. Surely this could not happen if they all considered their games to be the same, so this is further evidence that students did not do so, even to the point of getting new ideas from each other.

6 ANALYSIS

Finally, we examine some correlations of interest.[6] We abbreviate question names and give responses ordinal values (Strong Agree = 4 down to Strong Disagree = 1) to summarize responses.

- *Does the frequency with which a student plays games impact how they feel about their games?*
  PlayFrequency has a positive, weak relationship with OutsiderSee (0.16), but the relationship is somewhat significant ($p = 0.01645$). No other factor shows significance.
- *Does students' confidence going into Bootstrap impact how they feel about their games?*
  Yes! PreConfidence has a positive, weak relationship (0.17–0.26) with PostPride, PostExcitement, OutsiderSee, and PostAuthentic ($p < 0.001$ to 0.11).
- *Does the frequency with which a student plays games impact their amount of confidence about being able to make one?*
  PlayFrequency has a positive, weak relationship with PreConfidence (0.26), and the relationship is significant ($p < 0.001$). This is noteworthy given the previous two.

We also performed an ordered logistic regression [1] to identify which effects might have been significant in arriving at our key outcomes. When factoring in *frequency of playing videogames*, *confidence in being able to make a game*, and *gender*, the only effect to

[6]We use correlations rather than ANOVA as the variables are not independent.

show true significance (t = 2.223) is that identifying male leads to a feeling the videogame is not real. No other factors are significant.

The Impact of Gender

The following table summarizes the responses by gender for the 198 students who self-identified as one of male or female (section 3).

Measure	*Males*	*Females*	$p < \cdots$	*Significant?*
PlayFrequency	3.56	2.41	**0.001**	yes
PreConfidence	2.87	2.56	*0.011*	somewhat
PostPride	3.16	3.26	0.2248	**no**
PostExcitement	3.23	3.19	0.39	**no**
PostAuthentic	2.72	2.89	0.11	**no**
PostUnique	3.09	3.18	0.4033	**no**
OutsiderSee	2.75	2.65	0.4049	**no**
GotIdeasFromOthers	2.5	2.54	0.7322	**no**

The data show that there *is* a difference between the extent to which males and females play games, *but* these do not translate into other measurable differences. Females seem to get every bit as much excitement, pride, and sense of authenticity out of this educational experience. These results are consistent with prior research on gender and games that distinguish game *play* from game *design*. Lucas and Sherry [10] found that male adolescents were more likely to play games, to play them for longer, and to enjoy different qualities of gameplay, but Kafai [9] reports on multiple studies (some from other researchers) showing that gender differences are much smaller when looking at game design. In Kafai's design studies, gender differences manifest in the *nature* of games (i.e., themes and characters) that students choose. Examining whether similar differences arise in Bootstrap games would be an interesting question for future work.

7 DISCUSSION AND CONCLUSION

Our study offers several important lessons. First, it questions how much creativity is really needed for students to feel proud and have a sense of ownership of their work, showing that very small amounts can have large impact, even when the subsequent programming is largely identical. Second, it fails to find any significant outcome differences between male and female students, indicating that a videogame programming curriculum can be just as effective with female students. Finally, it demonstrates that BS:A students feel a sense of accomplishment over their computing artifact, which is independent of any math learning outcomes achieved.

A few details are worth noting. Once students have designed their scenario, they are allowed to get images from the Web. This means they have access to the "entire world" of images. It is possible that students' sense of realism comes from this array of choices, in contrast to the curated selection found in tools from Code.org, Scratch, and Alice.

Is more room for creative expression better? Perhaps not! A previous version of BS:A had one more opportunity for customization: a projectile. When this was given to students, most games ended up looking like "shooter" or "shoot 'em up" games. Concerned about the negative connotations of a projectile, the BS:A team removed this option from the standard curriculum in 2009. Yet this effectively liberated students, as a result of which the games now produced are much harder to classify. We believe this shows that there is a great deal more study needed to understand what constitutes creativity and freedom in computing.

How lasting is the impact of our findings? Will students' sense of pride dissipate quickly? Would they feel less pride if they were to see a friend's game written in a more free-form setting? These issues may not be relevant for the original purpose—of invigorating their math learning—but would matter in a broader CS setting.

Finally, we note that some of the games have very strong social and personal components. Their student designers are essentially using games for self-expression. To what extent does this happen in other game-based programming curricula, and what are the curricular design factors that enable or inhibit it? And how can we draw on these experiences to create a more socially meaningful form of computing?

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REFERENCES

[1] A. Agresti and M. Kateri. 2003. Categorical Data Analysis. 482 (2003).

[2] M Armoni, O Meerbaum-Salant, and M Ben-Ari. 2015. From Scratch to "real" programming. *ACM Transactions on Computing Education* 14, 4 (2015), 25.

[3] D. Clements. 1991. Enhancement of creativity in computer environments. *American Educational Research Journal* 28, 1 (1991), 173–187.

[4] B DiSalvo. 2012. *Glitch game testers: the design and study of a learning environment for computational production with young African American males.* Ph.D. Dissertation. Georgia Institute of Technology.

[5] C. Ingleton and K. O'Regan. 2002. Recounting mathematical experiences: Emotions in mathematical learning. *Literacy and Numeracy Journal* 11, 2 (2002), 95–107.

[6] S.S. Iyengar and M.R. Lepper. 2000. When choice is demotivating: Can one desire too much of a good thing? *Journal of Personality and Social Psychology* 79, 6 (2000), 995.

[7] Y. Kafai and K. Peppler. 2011. Youth, Technology, and DIY: Developing Participatory Competencies in Creative Media Production. *Review of Research in Education* 34 (2011), 89–119.

[8] Y. B Kafai, K. A Peppler, , and R. N. Chapman. 2009. *The Computer Clubhouse: Constructionism and Creativity in Youth Communities.* Teachers College Press.

[9] Yasmin V. Kafai. 1998. Video game designs by girls and boys: variability and consistency of gender differences. In *From Barbie to Mortal Kombat: gender and computer games.* MIT Press, 90–114.

[10] Kristen Lucas and John L. Sherry. 2004. Sex Differences in Video Game Play: A Communication-Based Explanation. *Papers in Communication Studies* 20 (2004).

[11] A. Repenning, D.C. Webb, C. Brand, F Gluck, R Grover, S Miller, H. Nickerson, and M. Song. 2014. Beyond Minecraft: Facilitating computational thinking through modeling and programming in 3D. *IEEE Computer Graphics and Applications* 34, 3 (2014), 68–71.

[12] M. Resnick, J. Maloney, A. Monroy-Hernández, N. Rusk, E. Eastmond, K. Brennan, A. Millner, E. Rosenbaum, J. Silver, B. Silverman, and Y. Kafai. 2009. Scratch: programming for all. *Commun. ACM* 52, 11 (2009), 60–67.

[13] E Schanzer, K. Fisler, and S. Krishnamurthi. 2013. Bootstrap: Going beyond programming in after-school computer science. In *SPLASH Education Symposium.*

[14] E Schanzer, K Fisler, S Krishnamurthi, and M. Felleisen. 2015. Transferring skills at solving word problems from computing to algebra through Bootstrap. In *Symposium on Computer Science Education.* 616–621.

[15] Robert J. Sternberg. 2006. The Nature of Creativity. *Creativity Research Journal* 1 (2006), 87–98.