BeadLoom Game: Using Game Elements to Increase Motivation and Learning

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ABSTRACT

The Virtual Bead Loom (VBL) was designed to teach mathematical concepts such as Cartesian coordinates, symmetry, and iteration to middle and high school math students through the design of Native American-inspired bead loom art. In our outreach programs using the VBL, we noted that the students avoid using complex functions such as iteration, instead creating designs one point or line at a time. To motivate students to learn the advanced concepts, we created the BeadLoom Game by adding game elements to the VBL. We have tested the BeadLoom Game with two summer camps and found that the game motivates students, exposes them to more complex computing-related math concepts, and increases the chance that students will continue using the tool beyond assigned class time.

Categories and Subject Descriptors

K.3.2 [**Computers and education**]: Computer and information science education. – computer science education.

General Terms

Design, Human Factors

Keywords

Game development, education, motivation, evaluation.

1. INTRODUCTION

Motivation is extremely important to effective learning. Although teachers and classes often provide extrinsic motivation for students to learn, researchers know that intrinsic motivation is what can keep students pursuing learning beyond the classroom and the school day [Gee, Garris]. Intrinsic motivation can also help a student delve deeper into a topic, learning more complex concepts and linking learning to their personal experiences, which can lead to long-term learning effects. Often, without this self motivation, users will neglect exploring the available options in educational software and miss out on some potentially exciting and important concepts. This is especially important for work done outside of the classroom environment where a teacher cannot monitor and guide the students.

In our outreach with the STARS (Students & Technology in Academia, Research & Service) Alliance [starsalliance.org] we have used a series of tools known as Culturally Situated Design Tools (CSDTs) [rpi.edu] to help middle school students learn mathematics while learning more about cultures and computing. In particular, we have used the Virtual Bead Loom (VBL) many times for teaching elementary, middle, high school basic math such as Cartesian coordinates and introductory computer science concepts such as iteration. In the VBL, students replicate traditional patterns or create their own bead designs by entering parameters into bead-creating functions, including ones that make points, lines, rectangles, triangles, linear iterations, and triangle iterations. We observed that most students learned plotting points in a Cartesian plane but neglected to use other functions that would teach them about iteration. Since our focus is on preparing students to be successful in computing, we are interested in promoting understanding of iteration, which is a core concept in computer science.

In order to increase student motivation to use and learn the advanced functions of the VBL, we have developed the BeadLoom Game. The objective of the game is to create a target pattern using the fewest number of functions in the VBL. We consider finding the shortest sequence of functions for a target pattern a "puzzle". Each puzzle has one ideal solution but there are many non-ideal solutions. The game rewards the player for using the fewest number of functions in the creation of a goal pattern. In order to get the best scores, the player must use and master all of the VBL functions. However, the game allows players to solve puzzles using simpler functions they are comfortable with, and earn more points when they learn to use the harder functions.

We used the game in two summer camps for middle and high school students. Through the use of the game, the students showed significant gains in both iteration and layering comprehension. Additionally, they showed clear signs of increased motivation to use the advanced tools both in their own original designs and in puzzle solving.

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2. PREVIOUS RESEARCH

Culturally Situated Design Tools (CSDTs), developed by Dr. Ron Eglash at Rensselear Polytechnic Institute, are a suite of educational tools which aim to teach students math and computer science through the creation of cultural artifacts. CSDTs help people discover that mathematics and computing are cross-cultural activities that manifest naturally in the creation of culturally meaningful artifacts. They have shown to be very effective at teaching basic mathematic principles and motivating students to use the basic functions of the tools [Eglash et al. 2006]. There are a variety of CSDTs that each explore different cultural artifacts and mathematic principles. Each of the CSDTs was developed to honor and preserve native cultures and better understand how math and computing naturally occur, while engaging young people with their own and other cultures in a creative way. This is particularly important for under-represented minorities who may feel that mathematics and computing are western concepts that do not relate to their own cultures. Although the tools were first conceived of to help these under-represented minorities, they have been found to be effective for all students.

One of the most successful CSDTs is the Virtual Bead Loom [Bert et al. 2009]. With it, students learn Cartesian coordinates, symmetry, geometry, and iteration through the use of functions that place virtual beads on a grid to create their very own Native American bead art in a free-play environment. It has shown positive results in teaching basic mathematical principles and students reported more enjoyment from using the tool as opposed to more traditional assignments [Eglash et al. 2006]. However, our own experience with the tool showed us that students tended to over-use simpler functions and avoid more advanced functions, particularly iteration. Since we are interested in preparing students to be more successful later in computing, we needed a way to motivate students to fully utilize all features of the VBL.

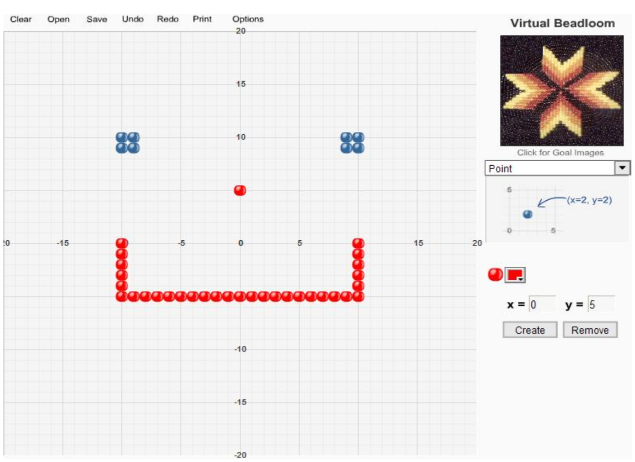


Figure 1: Virtual Bead Loom Screenshot

Games have been consistently shown to have inherent motivational properties, allowing them to be used for improving educational applications [Barnes et al. 2008; Garris et al. 2002]. We therefore decided to develop an educational game component to be incorporated into the framework of the VBL in order to increase the motivation to use and learn the advanced functions. We also had to make sure our game was fun for the students. One of the most important factors in the fun of an educational game is the challenge, or the balance between easy and difficult [Lepper et al. 1987]. Thus, our game needed to be challenging enough to engage the user, but not so hard that it discourages them. Finally the motivation to replay the game is a key feature in the most successful educational video games [Garris et al. 2002]. In order to make the game as successful as possible we needed to design it to internally motivate students to play and replay the game, and to motivate them to use the all the functions in the VBL.

3. SOFTWARE DESIGN

3.1 Original Virtual Bead Loom

The original VBL is a free-play tool that allows users to create their own Native American bead art by placing colored dots (beads) onto a 41 by 41 Cartesian grid. The tool provides six different functions: point, line, rectangle, triangle, linear iteration, and triangle iteration, that create patterns traditionally found in authentic Native American designs. The first function in the VBL is the Point Function which takes an x and y value and places a bead of the chosen color on the grid. Obviously, all potential designs could be done with just this function; however doing so would require one point function call for each of the 1681 cells of the grid. Students can speed up this process with the other functions which can place multiple beads per function. For example, the Line and Rectangle Functions each take two points and create a line or rectangle of beads of the given color. Similarly, the Triangle Function creates a triangle of beads by taking three points from the user. These functions are more complex than the point function but students tend to quickly learn how they work and use them in conjunction with the Point Function to make their own art. Ideally, the students would segue into using the more advanced Iteration Functions.

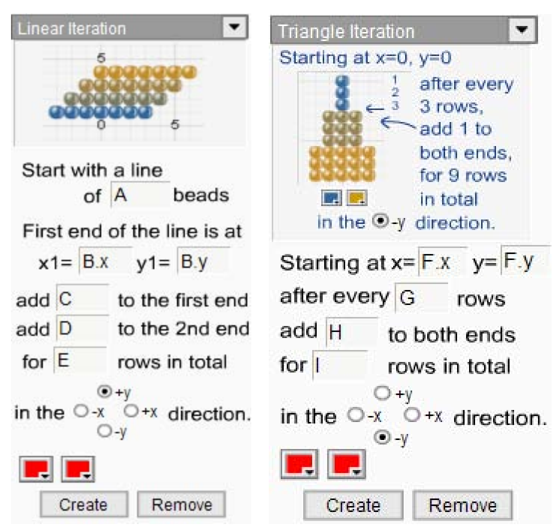


Figure 2: Linear and Triangle Iteration in the Virtual Bead Loom

As the name suggests, the Iteration Functions use iteration to place beads in complex patterns onto the grid. The first is the Linear Iteration Function (Figure 2). This function begins with a straight line of beads of a given length (A) at a given point (B). It then moves to an adjacent space in a given direction and redraws the line adding or subtracting a given number of beads from each side of the line (C and D) for the given number of lines total (E). The next function is the Triangle Iteration Function (Figure 2).

This function begins with a single bead at a given point (F). Then, for every given number of rows (G), the tool adds a given number of beads to each side (H). It does this for a given number of rows (I) and in a given direction.

It is important to note that the VBL uses layering with all the functions. For example, if a user places a black bead at a particular point and then later places a white bead at the same point, the user will see the white bead and not the black one. As the tool is not designed to handle anything other than bead placement, blending of the bead colors does not occur. This can be seen as a simple implementation of the Painter's Algorithm, a key concept in computer graphics which calls for drawing objects in the distance before drawing closer ones. In other words if a user wanted to create a background for their bead art, it would be much easier and efficient to start with a single rectangle function call covering the entire grid. If the user starts with foreground design elements they will be forced to use multiple functions to place the background around the rest of the image.

3.2 Pilot Study of Original Tool

Through our outreach with the STARS Alliance we regularly used the Virtual Bead Loom tool in classroom setting with groups of elementary and middle school students. Our own experiences with the tool matched those of previous research; in other words the tool is very effective at teaching basic math concepts including symmetry, geometry, and Cartesian coordinates. However, due to its free-play nature, students tended to use only the simplest functions when creating their art. They would primarily use the rectangle and line functions and rarely, if ever, use the iteration functions. Even though using these functions would produce the same image in fewer steps, we consistently noted that students did not use the advanced functions. To encourage students to use the advanced functions we would often provide external motivation and require students to make some art using the iteration functions. This pressured the students, and thus, they would report enjoying these more directed activities less than the free-play ones.

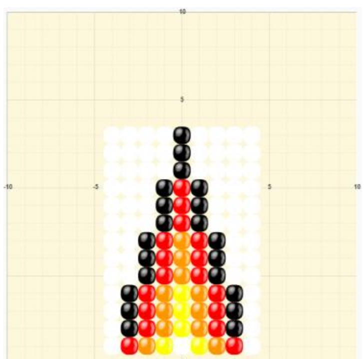


Figure 3: An Easy Difficulty Iteration Puzzle

Admittedly, the Iteration Functions are complex, especially for middle school students, many of whom have not yet been exposed to this style of algorithmic reasoning. Since the VBL provides no internal motivation to use the various functions, students would almost always revert to using the basic functions when creating their designs. This natural tendency prevents students from learning more about iteration and how to use it to create authentic bead art. Avoidance of the iterative functions also increases the time for students to create their target designs. This is an issue since many programs that use the VBL are limited to short after-school or in-class sessions, where saving time might allow students to be more creative or explore more complex math and computing concepts. The students believe the first four functions are the best and result in the quickest production of designs, which is not always the case. For example, if the student wanted to create the design in Figure 3 a completely novice user might make the image relying solely on the point function, which results in 117 function calls. A typical student with a basic understanding of the tool is likely to do the same design with the line function, creating a series of lines, which results in 24 or more function calls. Even an advanced user can, at best, accomplish this design with 15 moves, using only layering and the four basic functions. However, with the use of the Triangle Iteration Function and layering, this design can be made in only six function calls. In order to provide internal motivation to explore and learn the advanced functions as well as expose the students to the concepts of layering and efficiency, we developed and present the BeadLoom Game.

3.3 BeadLoom Game

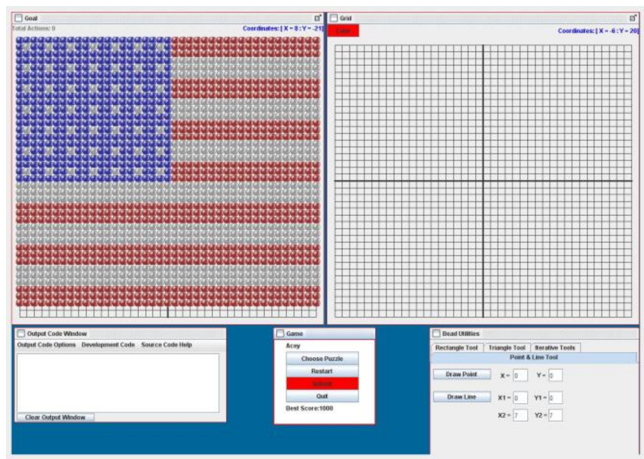


Figure 4: The BeadLoom Game

The core game mechanic of the BeadLoom Game is the creation of the given goal image. Each puzzle asks the student to recreate a given image using the six functions from the original VBL. When the student uses one of the functions, it is counted as a move. The goal is to complete the puzzle using the fewest number of moves possible. Every puzzle has an ideal move count: the lowest number of moves to complete the puzzle. The game is able to compare the user's design to that of the goal image and pinpoint the locations of differences. When the student matches the goal image, they are awarded a medal based on their performance. If the student completes the puzzle with the ideal move count, they receive a platinum medal. Gold is awarded for solving it in up to two times the ideal solution, silver is awarded for up to three times, and for just completing it, they receive a bronze medal. For example, if a puzzle can be finished in 10 moves, gold means the student finished in 20 or less moves and silver means the student finished in 30 moves or less.

After much deliberation, we decided to give all the students who completed the puzzle, in less than optimal moves, a bronze because we do not want students to lose interest in the game. This also provides students with positive reinforcement and incentive to replay each puzzle until an ideal solution is found. Although it is possible to complete each puzzle in the game with only the basic functions, many puzzles require using and understanding the iterative functions in order to earn the platinum medal. Unlike the original tool which offers no reward or incentive for creating the same picture with the more advanced functions, the BeadLoom Game encourages competition and reflection about how to use iteration in order to achieve the best scores.

In addition to providing an incentive to explore and use iteration in creating designs, the BeadLoom Game also emphasizes two other computer science concepts that the original tool does not: layering and optimization. Although the original goal of our project was to increase the motivation to use the iteration tool, a primary goal driving the development of all CSDTs is teaching math and computer science so these additions were an added benefit to our game. A majority of the puzzles have a strong emphasis on layering; a fundamental property of the Painter's Algorithm. To create the Triforce, a design inspired by Nintendo's The Legend of Zelda series shown in Figure 5, most users create a white rectangle background and then create three dark triangles on top of the background. However, by using more layers, this design can be made by layering a large white rectangle, a large dark triangle, and a small inverted white triangle in the middle, for three total moves. The game rewards the student for optimizing their design "algorithm." Although they can do it point by point to win the bronze medal, they must find faster ways to create the image to achieve the best scores.

During our process of game development, we faced this optimization challenge many times. After designing a puzzle and a solution, we often later devised faster ways to solve the puzzle. Occasionally students piloting the game would find better solutions than our initial ones! This reflects the exploratory nature of the puzzles, and that even experienced university students can continue to learn and grow in problem solving. This is an exciting feature that makes the puzzles fun for all ages.

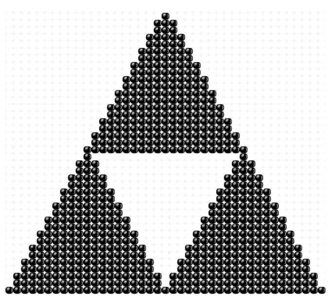


Figure 5: An Easy Difficulty Layering Puzzle

The game stores each puzzle as a series of moves associated with the ideal solution. This was a surprisingly simplistic solution to the originally complex problem of how to measure the validity of the designs the students create. Since each picture is a 41 by 41 grid of colored dots, each solution is represented by 1681 points of Red Green Blue (RGB) color data. Our initial plan was to simply store all this data in arrays and compare it to the user's design. We quickly realized that storing these arrays for each of the puzzles would have been a very large waste of space and that hand coding all the values would have taken an unreasonable amount of time on the developers' part. By storing and coding each puzzle as the series of function calls used in the ideal solution (between 2 and 27 depending on the puzzle) rather than 1681 RGB color points, we were able to save a great deal of storage space and development time. This solution illustrated one of the concepts students are exposed to by the game: do not do things point by point, rather use broader functions that take care of many points at once.

The game was developed in and integrated with the Java version of the original Virtual Bead Loom. One new menu was added to the original tool so that players can enter their names into the game world (for the purposes of tracking records and unlocking more difficult puzzles) and a selection to start the game. Inside the game, the layout is nearly identical to that of the VBL. All six functions are available to the player and presented in the same fashion as the VBL. This allows the skills gained in either the game or original tool to be directly translatable to the other. The only differences between the game and the VBL are the addition of a game menu, for seeing scores, puzzle selection, checking the students work, and a second graph for displaying the selected puzzle. The game tracks the users' high scores on each puzzle and has puzzle difficulties that are unlockable. The locked puzzles are to prevent students from starting on puzzles that are too difficult for them without them learning the required skills. Easy puzzles feature the use of minimal layering and iteration; medium ones require a good deal of iteration and layering, and hard puzzles demand strong mastery of iteration and clever use of layering. Figure 6 shows hard puzzles that take over 26 moves each. These difficulty levels keep the user engaged at an appropriate level of challenge and act as a reward for progression.

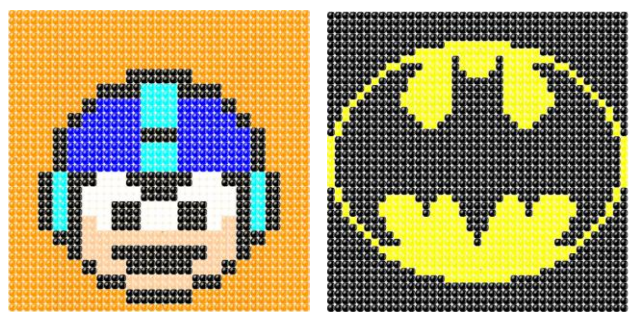


Figure 6: Two Hard Difficulty Puzzles

4. EXPERIMENTAL METHOD AND RESULTS

In order to test the effectiveness of the BeadLoom Game, we used it at two summer camps held at the University of North Carolina at Charlotte. The first summer camp was a group of 18 middle school students: 14 male and 4 female. While the version of the game at this point was not the final version, we wanted to test to make sure the students were enjoying the game concept and gauge to make sure the puzzle difficulty was appropriate for the age and skill level of the target audience. The camp was 5 days long and focused on CSDTs. On the first day, we held a one hour introduction to the BeadLoom Game. During the introduction, we walked the students through the tutorial puzzles, each of which utilize one of the six functions. In addition, each day we had a 30 minute to one hour session devoted to a BeadLoom Game contest. During this activity, we selected one puzzle and the students would race to see who could complete the puzzle in the fewest moves and in the shortest amount of time. The students who found a solution would get to write their names on the board along with their score. The winner would be whichever student(s) found the ideal solution and, if no one found the ideal solution before time was called, the student(s) who found the best solution the fastest would be the winner. In addition, students were allowed 30 minutes a day to design their own bead art using the original VBL tool. At the end of the week, we surveyed the students to gauge their enjoyment of the BeadLoom Game. Additionally, we observed the art created during the free play time for complexity and use of layering and iteration.

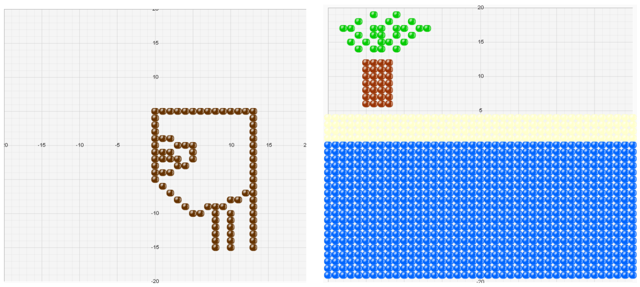


Figure 7: Middle school student art from early in the CSDTs camp, showing use of points, lines, and rectangles

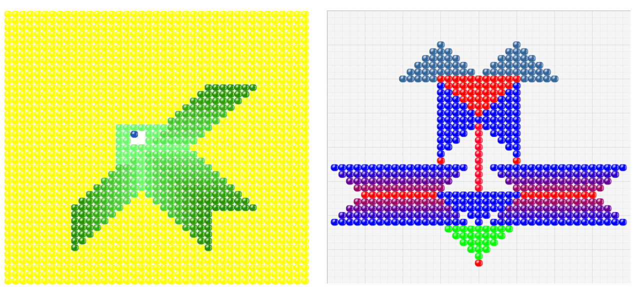
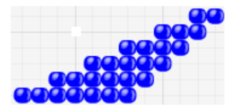


Figure 8: Middle school student art from the end of the CSDTs camp, showing more use of iterative functions and layering

The students in the middle school group gave the BeadLoom Game an average enjoyment rating of 3.7 out of 5. This is partially attributable to the fact the game at this stage was not finished and, during some of the competitions, we had to stop and troubleshoot the game before the students could continue. Regardless of the game's problems, the students provided us with a lot of good feedback on ways to make the interface and structure more user-friendly and enjoyable. We implemented most of their suggestions into the later version of the game. Two observers trained in the use of the VBL independently noted a higher use of iteration and increased complexity of design at the end of the week as compared to the beginning. For example, at the beginning of the week only one student was using a background layer and by the end of the week all the students had adapted this principle in some of their designs. At the beginning students also used primarily points, lines, and rectangles to make images like those in Figure 7. As the week progressed, many students also began using the iteration functions in their free-play designs such as those in Figure 8.

The second camp we ran at UNC Charlotte, had 18 high school students: 16 male and 2 female. Although this was a games and computer forensics camp, the use of the BeadLoom game was similar to that of the middle school student camp: a 5 day long summer camp with an original 1 hour guided tutorial and daily 30 minute to one hour BeadLoom Game time. Contests for these students used the same rules as the first camp. The focus of this camp was on game making, which meant the students did not get the additional 30 minutes time for free-play with the original tool, although some students did request and were allowed additional time with the BeadLoom Game. At the beginning of the week, before seeing the game, we had the students take a short pre test to gauge their understanding of Cartesian coordinates, iteration, and layering.



This shape was created using iteration.
It can be described by the iteration pattern:
Start with 7 beads

Every line add _____ bead(s) to the right and

add _____ bead(s) to the left

for _____ lines in total.

Figure 9: An example iteration question

The pre test consisted of eight questions each with a singular right answer. Each question was worth one point and some questions had multiple parts. For example, the iteration questions provided the student with an example iterative design and asked the students to fill in the missing numbers from the iteration function, as shown in Figure 9. If the student got part of a question correct and part of it wrong they were awarded partial credit with each part of a question being weighted equally. At the end of the week the students were given an isomorphic post test to reevaluate their understanding of these topics as well as an attitude survey asking them to rate the BeadLoom Game with three affective measures: how fun they felt the game was, how educational they felt the game was, and how they liked the game overall. They gave the game an average of 4.28 out of 5 on fun and educational content and a 4.33 out of 5 overall.

The pre and post test was designed to evaluate the students' understanding of the three main areas the BeadLoom Game teaches: Cartesian coordinates, iteration, and layering. However, the summer camp's main focus was on the teaching of game design through the Game Maker software [yoyogames.com]. Game Maker utilizes a modified Cartesian coordinate system with the origin in the top left corner and not in the center or bottom left like the traditional system. Since the students had been using both all week we decided to throw out the Cartesian coordinate questions since they did not differentiate between the two systems. With the remaining questions we submitted the student's pretest and post test scores, shown in Figure 10, to a 2-tailed matched paired t-test. Students performed significantly better, $t(17) = 3.29$, $p = .005$, $d = .77$, on the post test ($M = 3.57$, $SD = 1.14$) than on the pretest ($M = 2.98$, $SD = 1$). Cohen's d indicates that students improved from pretest to post test by .77 of a standard deviation. We do not believe that Game Maker contributed to this performance increase, because none of the activities we did using it dealt in any way with iteration or layering. We do plan to run further experiments with the game and without Game Maker, to further substantiate this belief.

In addition to the post-test scores, the high school group also provided other indications of their level of enjoyment and motivation. During the free programming time when students were allowed to work on their games 3-5 students would typically ask for permission to play more BeadLoom Game. Also during many of the contests the students would start trying to solve the puzzle with the iteration functions. This was the right way to go with some puzzles but not for all of them. It was often necessary to inform them that although they can find a good solution with iteration it is not the ideal for a particular puzzle. Finally at the end of the week two students asked for copies of the game to take home to play and show their friends. They were also determined to win platinum medals for the most difficult puzzles, Mega Man and Batman (shown in Figure 6), which take 26 and 27 moves respectively.

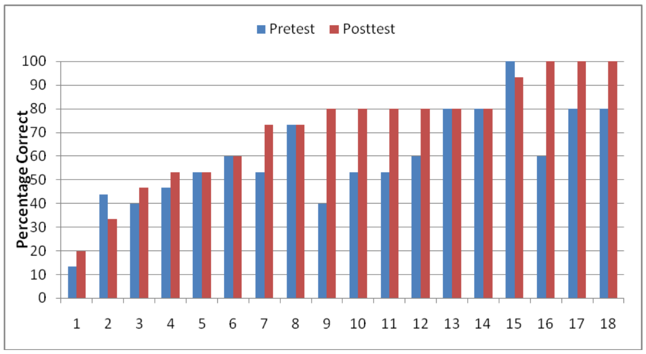


Figure 10: Pre and Posttest Scores per Participant

5. DISCUSSION AND FUTURE WORK

This study demonstrated how game elements can be added to the VBL tool with positive results on student learning and self-reported measures of enjoyment and liking. In particular, results suggest that the game encouraged students to increase their use of the iteration functions in the original tool. This could be seen by the middle school students' increased use of these functions in their own art as well as the high school students' immediate use of iteration in the puzzles. These findings suggest that game elements introduce fun, challenge, and competition which can build internal motivation that increases time on task and use of advanced functions, thereby enhancing learning.

We began with the strong basis of the original VBL. Although it did not meet all the learning goals it was originally designed to, it did provide an excellent base idea and educational benefit. By combining it with the inherent motivation of games we were able to create a game that motivated students to use the more challenging iteration functions on their own. Additionally, through the use of the scaling and unlockable difficulties we managed to create a game that is challenging while growing with the player's skill level. This challenge is key to the BeadLoom Game's, and all games', fun [Lepper et al. 1987]. Finally through the use of medals that reward the player for improved performance we increase the games replayability, which is a key component of successful educational tools [Garris et al. 2002].

There is still a great deal of research to be done on the BeadLoom Game and on adding game elements to educational systems. We would like to run additional controlled studies to avoid confounds like what occurred with the Cartesian coordinates questions. We are also interested in seeing the differences in performance when used by underrepresented students and differences from middle to high school groups. Most importantly we would like to directly compare the effects on learning and motivation between the game and the original tool.

Additionally, we hope to repeat the success of this game through the conversion of other CSDTs into games. Since a majority of the tools feature free-play similar to that of the VBL, they have some functionality that is used less than others. Through the use of game elements we can provide internal motivation to explore the tools fully and make the CSDTs an even more effective suite of software. Potentially we can extend this system to other educational tools to help educational software as a whole.

6. CONCLUSION

The results of the study showed that the BeadLoom Game was fun and taught the intended concepts. The students responded on the survey and showed clear indications that they enjoyed the game. Additionally the game showed statistically significant learning gains in both iteration, which the original tool was lacking in, and layering, which the original tool did not directly teach. This process of adding game elements to supplement lacking areas as well as increase motivation has worked for this CSDT. The data shows support for the premise of extending the Eglash model of CSDTs with gaming elements. The addition of game elements to these and other tools may make it possible to have students fully explore all the learning materials present in them as well as motivate these students to use the tools outside of the classroom setting. This can result in students having fun and learning both in and potentially out of the classroom.

7. ACKNOWLEDGMENTS

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