Integrating Computing into Middle School Disciplines Through Projects *

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ABSTRACT

For four years we have been integrating computing into a variety of middle school disciplines via the Alice programing language. Early on we focused on creating curriculum materials for teachers to use in teaching the basic programming and animation concepts. This paper describes our efforts over the past two years in creating model projects for students to build in all disciplines, and our most recent focus on science and mathematics projects. For science we have introduced experiments in Alice and the tools needed for them. In mathematics we have created projects to increase their understanding of programming and to use the projects to increase their understanding of mathematics. We also discuss our efforts in workshops to teach K-12 teachers Alice and an analysis of the teachers' lesson plans and worlds developed in the most recent workshop.

Categories and Subject Descriptors

K.3.2 [**Computing Milieux**]: Computers and Education-Computer and Information Science Education

General Terms

Human Factors

Keywords

Alice, virtual worlds, K-12 education, middle school, introductory computer science

1. INTRODUCTION

A report conducted by the Association for Computing Machinery (ACM) and the Computer Science Teachers Association (CSTA) revealed that computer science education in the United States K-12 classrooms is at a crisis[1]. Although middle school students (grades 6-8) use computers for many tasks at home and at school, the majority of them never quite understand what computer science is and how it relates to problem solving. Their exposure to computers in school is most likely with spreadsheets, word processors and media presentation tools. Few high schools have a computer science course and even fewer middle schools offer a computer science course, a crucial time when students are starting to think about careers.

One difficulty in the adoption of computer science is the lack of standards. The CSTA and ACM have developed a model curriculum for K-12 computer science [20] that is now under revision in addition to several model curriculum documents such as the Level I course which is recommended for students in grades K-8 [10].

The lack of exposure to computer science at the K-12 level leads to few students choosing computer science as a career in college. The NCWIT scorecard[14] mentions future problems in the United States, that the U.S. Bureau of Labor Statistics predicts that the U.S. will only be able to fill about one-third of technology jobs in 2018 with U.S. Citizens. There are efforts to increase the number of K-12 students exposed to computing such as the 10,000 teachers project [7], and a new proposed AP CS Principles Course[4]. Many projects targeting middle school include CS Unplugged [5], Alice [2, 3, 8], Scratch [19] and Greenfoot [11].

Our project focuses on using Alice, a 3D virtual worlds programming environment, to integrate computing into K-12. A study using Alice with college students[13] showed improvement in students' performance in CS 1, retention within computer science and attitudes towards computer science. We have been teaching Alice, since 2002 at Duke University in several courses and in outreach programs to K-12 students and have seen first hand the excitement Alice brings to students. Based on our success in outreach programs, we began teaching Alice programming to middle school teachers in all disciplines. Alice is attractive to middle and high school students because they can easily create interactive animated games and stories. As it is difficult to insert a new course into a middle school curriculum, we are

integrating computing into middle schools by training teachers to use Alice for student projects in their disciplines.

This paper describes our efforts over the past two years to create sample projects for specific disciplines to show teachers how students can use Alice for projects in middle school. Most of these projects include tutorials for students to build them as a sample project in learning Alice. The majority of these projects are in math and science, but we also describe projects for other disciplines and general projects. We also include an analysis of the teachers lesson plans and worlds developed in our 2011 workshop.

2. BACKGROUND

We have run Alice workshops since 2005 and specifically targeting middle school and high school teachers since 2008 training over 150 teachers. In 2008 and 2009 we developed a wide range of Alice tutorials on both computer science topics and animation topics [18, 17, 6]. The computer science topic tutorials included if statements, events, variables, functions, random numbers, lists, and inheritance. The animation tutorials included moving the camera, creating lighting effects, creating scene changes, modifying objects with textures, and creating people you know using pictures. Working with the teachers led to creating template worlds and objects they could use. In particular we created a series of quiz template worlds to make it easier for teachers to create a quiz world.

The main feedback from teachers in our 2009 and 2010 one-week summer workshops were a need for a large number of sample Alice projects and longer workshops. Thus in summers 2010 and 2011 we developed a large number of model projects for many disciplines, with the largest number for mathematics and science. The majority of the projects include a tutorial. In Summer 2011 we ran a two-week Alice workshop for teachers and spent the extra week in helping them to develop lesson plans.

3. SCIENCE PROJECTS

Alice can play a helpful role in the middle school science classroom. The link between the physical and life sciences and computing is already acknowledged in the curriculum objectives for middle school science. For example, units in the 8th grade North Carolina Standard Course of Study (NCSCS)[16] for Science include "Using Technology to Study our World" and "Technology for a better tomorrow". A goal common to both units is to learn how to use software to view and process data for communication. Many of the other units have sections where Alice can fill in as a model.

An interactive model can also be used to collect data. Many times the concept being presented has no experiment that can easily be done in a classroom; Alice can provide an interactive alternative for collecting data. Beyond teaching concrete facts, science curriculums aim to develop skills in students that will help them in understanding the scientific data. In fact, the NCSCS in science states that the achievement of "scientific literacy" is the primary goal of the science curriculum. Being able to create and read the visualizations of data used in scientific articles is a core part of their mission. Being able to analyze data using visualizations is an important skill that Alice allows students to learn easily.

One challenge to producing models, especially scientific, in Alice is the need for accurate objects. There are a lack of objects in the Alice gallery that are suited for teaching some
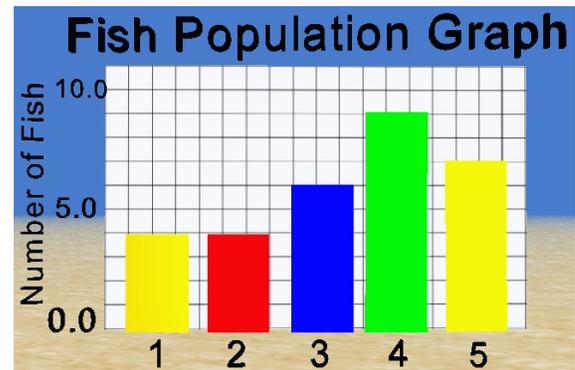

Figure 1: BarChart of Fish Rounds

areas of science. Earth science and ecosystems are easier because these types of objects are well represented in the Alice library. Other subjects such as genetics need objects made before one can easily create a model. We had to repurpose ordinary geometric shapes in some of our science worlds.

3.1 Experiments

We surveyed science teachers on how to integrate Alice into science classes. From their responses we focused on examples in earth science.

To visualize the data, we created a bar chart in Alice. The bar chart uses rectangles that resize height to indicate value. The bars can be put together in a list to form a bar chart that animates changing values by increasing or decreasing the height of the rectangles. The list can be created with data a user already has or by collecting the data in an experiment.

The motivation for our first example world came from a biology teacher and focuses on population change. There is an activity where students simulate and record the changing population of fish in the pond originally using goldfish crackers. Alice provides a way to simulate the population of fish, but also will allow the data to be collected and visualized in the same program. By changing the numbers of fish that are taken from the pond, students can see how populations change. Instead of recording the numbers by hand, the numbers are saved into a growing list in Alice. When more and more fish are taken, eventually the population stops increasing and begans to quickly subside - a model for unsustainable fishing - that they can quickly see both visually but also in the bar chart that is automatically created in the end. Figure 1 shows a resulting bar chart after 5 rounds of collection.

This bar chart became the model for a more general bar chart object. We created a tutorial to show how to create a bar chart in any world as well as a template world that one can start with that already contains a bar chart.

For another example, we created an atmosphere world that uses two animating bars, one for temperature and one for pressure. We chose the atmosphere primarily because it was a topic that multiple teachers in the survey mentioned. It is also a topic that would be greatly enhanced by data visualization. Since the layers are differentiated by how temperature behaves in relation to altitude, it is important to differentiate how pressure and temperature behave differently. As the scientist advances through the different layers of earth's atmosphere, students are able to learn about each

layer as well as visually appreciate how the two variables of interest change.

The data for the world is stored in three different lists in the world-temperature, pressure, and altitude. We obtained the data for the world by combining NASA, UK's Discovering Antarctic Organization, and Portland State University models. Ideally, special charting objects would be in the Alice library. The Alice team has plans to create a 3D Bar-Chart Object to add to the Alice library.

We sent these worlds to the teachers for feedback. In general, the feedback from the five teachers that responded was positive. One of the teachers suggested expanding the atmosphere world to include the different layers of the earth so that it could be used for two different units.

3.2 Models of Tiny Objects

There is a need for interactive models in the science classroom to help conceptualize objects that are either too small or too large to be practically demonstrated in the classroom. Alice's ability to easily produce interactive animations means that with the right mix of objects from Alice's library and creativity, these models can be created using Alice.

An example to help visualize concepts that are too small to see physically in a classroom is an interactive Alice world for a lac operon model. Many middle school and high school biology textbooks classically use the lac operon as an example for gene regulation. Our world uses differently colored geometric shapes to represent enzymes and molecules inside the cell. Two sliders marked "Lactose" and "Glucose" allow students to experiment with the lactose and glucose levels independently and observe how that changes the interaction of molecules in the cell and ultimately affect the rate the lactase gene is transcribed.

4. MATH PROJECTS

We describe several interactive Alice projects for middle school math. Students use them to practice a math concept. We built tutorials for each of these to encourage students to build the worlds. Then students will be integrating mathematics while learning programming concepts.

4.1 Algebra/Function

Danica McKeller writes books for girls to better understand math concepts. She uses examples that girls can relate to. One of the ideas we took from her book [12] was her functions factory. She describes it as putting a food product into a factory and it comes out differently. She relates this to how one would plug in x into an algebraic expression and get a different answer.

We integrated this concept into a world. We used ice cream as the x value that goes into the factory or algebraic expression, and comes out the factory with a different ice cream flavor. In the world, the x value, coefficient, constant, and the wrong answer choices are generated randomly. Ten rounds are played. If all ten rounds are correct the reward is a life time supply of ice cream.

In building the world one can modify the number of questions the player must answer and the amount of questions they need to get correct. They can change the type of equation; instead of doing algebraic expressions they could do something simpler. Another change is to add negative numbers to the world. Changing x-value, coefficient, and con-

stant to generate random numbers that can be negative will make the world more difficult and once they play they can get practice working with negative numbers. According to the NCSCS, this tutorial fulfills grade 8 learning object 5.01 which includes developing and understanding the concept of a function.

4.2 Energizer Exercises

Energizers for middle school address the high rise of obesity in America. More teachers are trying to implement exercise and learning at the same time. One of our teachers uses Math Middle-School Energizers [15] in her classes. At our workshop she was able to recreate one of the energizers in Alice and we recreated one as well that we describe here.

An operations computations Alice world teaches NCSCS grade 6 learning objective 1.04 and grade 7 1.02. Both include fluency in addition, subtraction, multiplication, and division of numbers. The student/teacher can choose which operation they want by clicking on the symbol. Then random numbers are generated and the problem is displayed. For 10 seconds you must complete the physical activity that corresponds with the operation. Then the player will be prompted to answer the question. For addition the physical activity associated with it is hitting the drums, subtraction is knee lifts, multiplication is twist, and division is running in place.

4.3 Plotting Points

We created a math world for plotting points based on an idea from a teacher. The player has to click and drag points onto the graph at the correct coordinate. There is one invisible object in the world, a pair of axes, which are aligned with the axes on the grid. To check what coordinates the points are at, they are compared to their relation to the axes. The program uses a formula to convert the units in Alice to units on the graph. The coordinates which the player is required to plot are stored as variables. This makes it very easy if a teacher wanted to change the points or make them random.

We created two additional worlds to expand on checking the coordinates of a point. The first world, shows the student how to plot a line. First, they are given an equation for the line in slope-intercept form. The teacher in the world gives a short explanation of how to use an equation to plot a point, and then asks what the y-intercept of the line should be. If they answer correctly, they must click on the first point and move it to the y-intercept and click ok. Then the teacher asks what the slope is and the player must type it in. The player then has to plot what the next point should be using the slope. If both points are plotted correctly, the line is drawn, which goes through the two points. The world can be modified to plot as many lines as the teacher chooses. They can also easily change the equations which are stored using variables. This automatically changes the equation that is displayed, what numbers must be typed in, and what points must be plotted. They can also change how much instruction is given for each equation. If fewer instructions are wanted, the teacher does not explain how slope intercept form works at the beginning, and instead of having to type in the numbers, the player is only required to plot the two points of each line.

Another example world we created teaches students how to use a scatter plot to predict future data. It starts out

Figure 2: Collecting Data for Bike Plot

Figure 3: Percentage Discounts

Figure 4: Scientific Notation

with a biker riding down the street. The player clicks on the clock four times during the ride to collect data as shown in Figure 2. Each time the clock is clicked, the time and the biker's current position are recorded and displayed on the screen. Then a graph is displayed, on which the player is required to plot each of the four points. Once all four of the points have been correctly plotted, the player has to use a best fit line to figure out how far the biker could travel in other amounts of time. In this problem, the student gets to see and interact with the bike ride as opposed to just reading the story problem in a textbook.

4.4 Percentages

The Alice world in Figure 3 teaches students how to apply percentage discounts to whole numbers. In this world, there are about eight toys either on a table, hanging on the wall, or under the table. One at a time each toy tells the player, what their original price is and what their percent discount is. The player must calculate the new price and enter it in when prompted to. Each toy's original price is random and the discount starts at 10% and increases with each new toy.

4.5 Distributive Property

A world on the distributive property allows students to practice expanding simple expressions and corresponds to Competency Goal 5: Objective 5.01 of the NCSCS for grade 6 mathematics. A factored expression in the form a(bx+c) is displayed, where a, b, and c are random integers ranging from -10 to 10 (although these specific minimum and maximum values can be easily changed). The student must de-
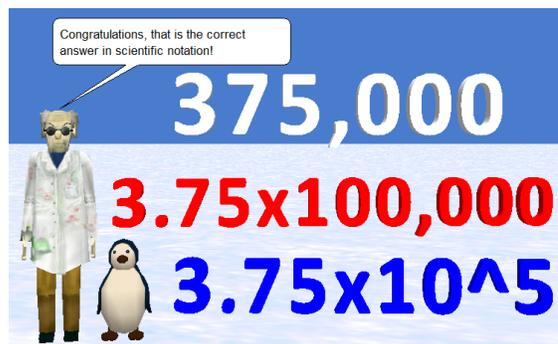
termine whether another displayed expression is the correct expansion of a(bx+c); the correct answer is (a*b)x+(a*c). However, by changing the sign (positive or negative) of a*b and a*c, the student must also be careful with signs when multiplying numbers.

4.6 Reducing Fractions

This world helps students practice reducing fractions to lowest common terms. A fraction is displayed and the student must fully reduce this fraction; the fraction is guaranteed to always have a reduced form with a denominator not equal to 1 (final answer is not an integer). To input the answer, the student clicks the numerator or denominator of an adjacently displayed fraction to increment its value by 1 (for example, 1 becomes 2 when clicked, 8 becomes 9, and 9 becomes 1 again) and checks the answer when ready. The numerator and denominator are both single-digit random integers, but the range can be changed.

4.7 Scientific Notation

The world in Figure /refscinotation both explains and provides a chance to practice writing numbers in scientific notation. A mad scientist and penguin review the definition and format of scientific notation and demonstrate using an example. During the practice portion, the student is shown a number in standard form and is prompted to convert it to scientific notation, but can get a hint where the number is displayed in product form.

4.8 Multiplication Table

This world is an interactive (0-10)x(0-10) multiplication table in Alice. The world starts with an empty table and repeatedly asks multiplication problems. When a user enters a correct answer it is entered into the table. Every time a player plays the game, the questions are asked in a different random order. When a player gets the question right the first guess, the number turns green and red if it's wrong. The player is prompted for the answer until he gets it right, types "answer" to skip to see the answer, or "end" to end the game.

4.9 Balancing the Scales

This world tests a player's knowledge of inequalities. Two types of arithmetic expressions (addition, subtraction, multiplication, division, negative numbers, fractions, etc.) are placed onto the scale and asked for evaluation. The player
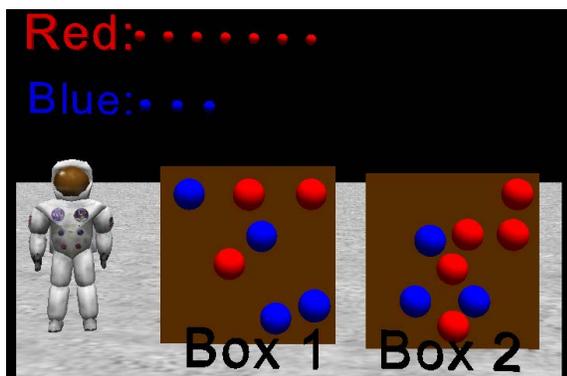
Figure 5: Random Sampling

has to decide if the first expression is greater than, less than or equal to the second expression.

4.10 Sampling

By using the classic red and blue marble approach, this world shown in Figure 5 demonstrates two important types of sampling introduced in a statistics class: simple random sampling and stratified random sampling. The player can choose which type of sampling he wants to see, and the red and blue balls are collected at the top of a screen in a sort of bar graph. Extensions for this in this exercises inquire about many of the associated probabilities.

4.11 Card Game Set

We created an Alice world on the classic SET game. There are 27 cards in the game, each with 3 attributes: color (red, green, or blue), number (1, 2, or 3) and shape (oval, squiggle, or rectangle). A SET is a collection of 3 of these cards such that all 3 cards are all the same or all different in each of the 3 categories. This game can be used as an early introduction to set theory, combinatorics, randomness, and probability.

4.12 Card Game War

We created an Alice world on the classic card game of War. Players 1 and 2 press the 1 and 2 buttons, respectively, to draw their card, and the player with the higher card wins both. If the two players draw cards of the same value, then there is a war. This game can be used for probability purposes in the classroom.

4.13 Choosing Randomly

An Alice world created to help teachers randomly choose students from a class. The students are displayed with girl and boy bodies with photos of their heads instead of the ones given in Alice. A player can either choose to sample a specified number of people all at once, or he can choose to sample them one at a time and pressing the "+1" button in corner to add another student to the sample. One can insert pictures of people they know for the students.

5. OTHER PROJECT WORLDS

We describe worlds helpful for other disciplines. For history, we created a sample world on the history of the Brooklyn Bridge. A student could use the tutorial of the world as a guideline to build a world on a different topic. Similarly for language arts we created a sample tutorial to show students how to create an interactive book report. For Spanish we created a sample world to to make banana bread. Instructions are given in Spanish to ask the user to put specific ingredients in a certain order into a mixing bowl. These items must be clicked and dragged into the bowl in that order.

Several of our tutorials are sample games. One is an adventure game in which the user has several items they need to find and cannot advance until they have found a specific item. One game to catch a ball in mitt shows how to build a score and integrate it in. One game is a boat racing against time that shows how to build a timer and to integrate it in.

6. MASTERY LEVEL OF TEACHERS

In the summer of 2011 we held a two-week Alice workshop attended by 26 K-12 teachers. The first part was Alice instruction and the second part was working with them to develop Alice worlds and Alice lesson plans. The teachers produced 32 different Alice example worlds and corresponding lesson plans. After the workshop their worlds were analyzed by examining the concepts they used in their worlds and examining their lesson plans for their planned usage of the world.

The teachers managed to pick up a significant number of Alice concepts. Of the 98 total basic Alice features determined by us, 69 different Alice features were used by the attendees in their worlds. These concepts include events, properties, methods, functions, programming logic, dummy objects and sound recording. On average, 20.78 features were used in each of the Alice worlds built, though advanced interactive worlds contain as many as 46 different Alice features and basic Alice worlds contain as few as 7 total concepts.

The worlds and corresponding lesson plans, were tallied based on academic subject area, the corresponding lesson type, and the number of Alice concepts used. The subject areas of the teachers were Business Technology, Computer Applications, English, ESL, Fine Art, Foreign Language, Math, Physical Education, Science, and Social Studies.

Here are the results. Of the 32 example worlds tallied, 12 Alice lesson plans state that their world will be an example for a future project or part of a technology course. 11 worlds created are for interactive games. These come with lesson plans that either express some interest in letting students build their own Alice worlds, or only plan to let students play one of the teachers Alice pre-built games. The final 9 Alice worlds built by the attendees use primarily animation elements and either come with a lesson plan that specifies using Alice only as an informative presentation, or includes a lesson plan that does not provide any coherent academic purpose.

Nearly one-third of the Alice worlds built by attendees were designed for technology and multimedia classes. Of the lesson plans counted, those from Business Technology and Computer Applications show the most interest in using Alice as a primary teaching tool. Despite this interest, however, those teacher's worlds use some of the fewest Alice features. In the Business Technology category, the average number of feature used per world was 16, whereas the average number of features used across the board was 20.78. Within the group of Business Technology teachers who plan on building Alice worlds, the average number of features used per world

was 13.67. Amongst the Computer Applications teachers, the average number of features used per world was 17.

Among attendees from different subject areas, math teachers showed the greatest knack for using Alice programming features. Of the 10 Alice worlds built in the math subject area, the average number of features used per world was 25.8. This was the highest average amongst worlds from all the different subject areas. However, out of these 10 Alice worlds, only 1 includes a lesson plan that involves having students build their own Alice game. 6 out of 10 math worlds were advanced Alice games built for students to play. A close analysis of the coding from the interactive game math worlds show that many teachers who created worlds in math were able to use more programming concepts. In addition, math teachers were able to apply Alice features to a number of different math concepts. These concepts include using a number line, division, systems of equations, and finding number subsets.

Other teaching areas that showed interest in teaching Alice are language arts, ESL, foreign language, and science. Teachers from these subject areas are primarily interested in using Alice as a supplementary tool to generate interest in an existing course topic.

Overall, teachers who built interactive games used the highest total number of Alice Concepts per world. The average features used in this category is 29.33 out of the total average 20.78. Worlds that teach students to build their own Alice worlds averaged 20.81 features per world. The remaining 8 teachers who built presentation-only worlds show the least likelihood of continuing to use Alice extensively in the classroom except as a lecture tool.

7. CONCLUSIONS

Using feedback from teachers we have created over sixty Alice tutorials and projects to integrate computing into middle school. They are available on our web site [9]. Every attendee in our 2011 workshop created a functioning Alice world and lesson plan, with most creating a world advanced enough to successfully convey an academic topic relevant to their field of teaching. Teachers expressed positive feedback on continuing to use Alice in the coming school year. From our experience, the best way to integrate computing into middle school is through technology teachers, getting them to work with teachers in other disciplines. Involving math teachers with technology teachers would likely lead to a deeper experience in programming.

8. ADDITIONAL AUTHORS

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