Code Control: Developing a Serious Game to Reinforce Introductory Programming Concepts
SIGCSE Final Report

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Summary: We developed a 3D game to teach and reinforce fundamental programming concepts. An innovative feature allows instructors to create customized programming challenges that students solve in the context of the game. The game was designed to engage and motivate all students, with a special focus on women and other underrepresented students.

1 Background

Majoring in computer science fields offers a number of benefits to students, including a growing and lucrative job market [30]. However, many students are unable to progress past the first introductory programming course. Introductory programming courses frequently suffer from high drop-out and failure rates of over 30% – 50% [5, 28, 16]. The attrition rate is often significantly higher for female students.

It is commonly observed that learning to program is difficult and that difficulty may account for the poor retention rates in the introductory class [12, 24, 17]. Our experience with our computing students is that learning to program demands significant practice time. Students learn how to program by programming, and the more students program, the easier it is for them to master the material and become successful in the course. However, many introductory courses do not include sufficient programming practice [4].

The literature on *serious games* discusses strategies to motivate students to practice programming. Researchers report that the long-standing formal lecture teaching mode is the least popular with students [27] and less effective than more interactive modes of learning [18]. *Serious games* describes those games that accomplish a goal in addition to entertainment. Research on *serious games for education* shows that, compared to traditional methods of instructor, game-based learning is superior at teaching subject matter [26, 15, 23, 31, 29] and increases both long-term retention and student motivation [26, 23, 13, 29]. Students who learn through games have increased feeling of alertness, activity, and involvement in contrast to standard lectures [11].

We therefore developed a serious educational game to help engage, motivate and improve the learning experience for students taking the introductory programming courses at our institutions and elsewhere. Our game, *Code Control*, is a game that helps reinforce programming concepts. An innovative feature is that instructors can create customized programming challenges that students solve in the context of the game. An automated compiler and testing environment gives students instant feedback, and completing successful programming challenges advances students in the gameplay.

2 Game Design

Code Control is a digital game developed using the Unity 3D platform, that teaches and assesses programming concepts. Instructors can optionally create customized programming challenges for their students as well as provide correct solutions. The programming challenges are then posed to the players in the context of the game.

While a number of serious games for computer science have been created, including some to teach introductory programming (e.g., [1, 2, 3, 8, 10, 9, 22, 19, 20, 21]), all of these games involve fixed programming challenges. In contrast, our approach allows instructors to specify their own challenges that best reinforce what is being taught in class. Additionally, many of these games (e.g. *Gidget* [19]) use a simplified programming language that was created for the game, and are designed to teach abstract programming concepts. In contrast, our game uses standard programming languages and is designed to augment existing programming courses. It is targeted to students who are learning the basics and want practice to solidify their skills.

The game's storyline involves a woman looking for endangered animals who are missing from an animal rescue. The digital name tags contain code that was broken by enemies. The player needs to find the lost roaming pets by solving the code to fix their name tags, to save the pets. The short programming challenges act as mini quizzes based on research of the "testing effect" that indicates that tests actually improve learning [6, 7, 14, 25].

The game currently has two levels, which take place in different areas in the city, to allow players to progress in solving the problems. In addition to solving programming challenges, players can explore the city, engage with non-player characters (NPCs) who offer advice and hints, and take part in recreational activities such as yoga on the street and hopping on the carousel in the park. A map of the area (situated in the bottom-right corner of the screen) allows the player to find their bearings and spot animals; a panel on the upper-left corner keeps track of the progress to date.

In designing our game, we consulted with students, both gamers and non-gamers, men and women, and varied races to appeal to a broad audience. It has been particularly designed for a female audience, featuring a (default) female lead character, avoiding violence and focusing on social goals. The avatar's appearance is fully customizable, including gender, skin color, and outfit, to give players co-ownership and to be able to represent a diverse group of players.

3 Programming Challenges

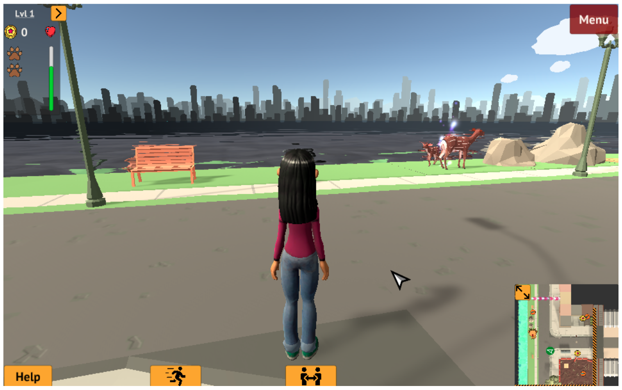
Instructors use our instructor portal to enter programming problems and their solutions. We use the Judge0 API[1], which is a free open-source API for code compilation and execution.

Code windows give players code snippets with missing sections to complete; once the players fill in the missing code, the code is compiled. The students' solutions are then checked for correctness by comparing them to the instructor's solution to see if the output matches. Compiler errors, execution errors, or positive feedback are are also provided. Customized scripts provide syntax highlighting. Judge0 supports 42 programming languages; so that any introductory language will most likely have support in our game. Furthermore, with Judge0 support for multi-file programs, *Code Control* can be used in coding courses at all levels.

CodeControl allows for several types of problems: coding, find and fix the error(s) and tracing problems (e.g. "What is the output of this code?").

A database connection allows us to collect detailed analytics of all users' gameplay (e.g. time spent per challenge, successes and mistakes made, levels completed, score, etc.) This provides a

[1] https://api.judge0.com/



(a) Player approaching an animal in Level 1

(b) Player exploring Level 2

(c) Player near the park in Level 2

(d) Customization of avatar

Figure 1: Gameplay pictures

wealth of information to instructors as to how this game is being played and what students are struggling with and succeeding at. Instructors who adopt this game as a course material are able to use the game as an informal evaluation mechanism to see which concepts their students are successful with and with which they need additional practice.

4 *Code Control:*

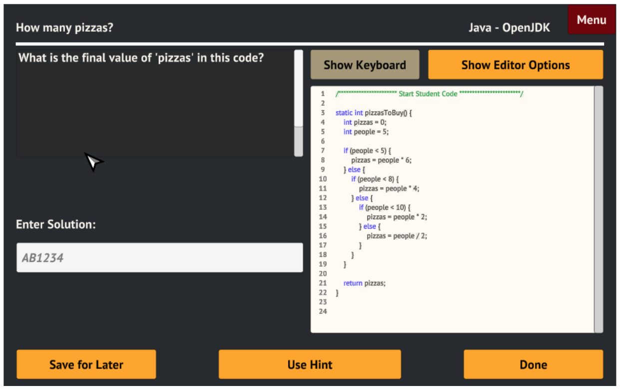
Pictures of *CodeControl* are given in Figures 1 and 2. Figure 1 depicts the gameplay; Figure 2 shows various types of problems as well as the instructor view of a problem.

Code Control is deployed as a WebGL and can be played in a browser without requiring installation. It is available at https://codecontrol.app/. If you are an instructor who is interested in using the game in your course, please contact us for a free instructor's account.

Future work on the game includes the development of more levels and integrating Parson's problems in addition to the coding and tracing problems. An evaluation of the success of *Code Control* in engaging and motivating the students is the topic of an ongoing Master's thesis project.

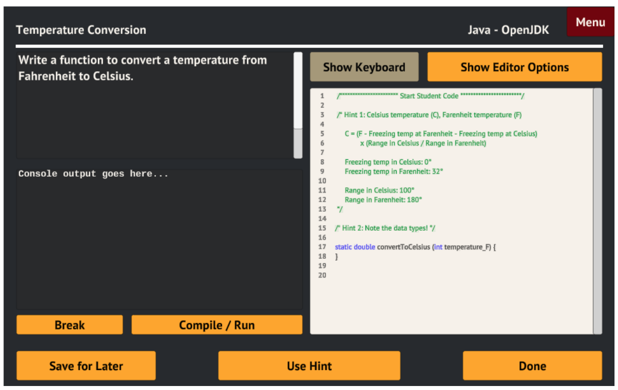
5 Conclusion

The SIGCSE Special Projects funding of $5,000 was used to support the work of an undergraduate student who developed the game.

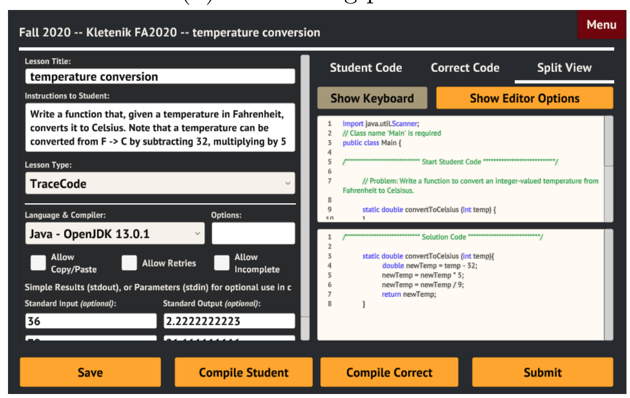


(a) Code tracing problem

(b) Code fixing problem



(c) Code writing problem



(d) Instructor view of a problem

Figure 2: Programming challenges

We are grateful to the SIGCSE Board for supporting our work. We anticipate *CodeControl* having an impact on students taking the introductory programming course at CUNY as well as at other institutions.

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