# Engaging Young Learners with Testing Using the Code Critters Mutation Game

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Abstract—Everyone learns to code nowadays. Writing code, however, does not go without testing, which unfortunately rarely seems to be taught explicitly. Testing is often not deemed important enough or is just not perceived as sufficiently exciting. Testing can be exciting: In this paper, we introduce Code Critters, a serious game designed to teach testing concepts engagingly. In the style of popular tower defense games, players strategically position magical "portals" that need to distinguish between creatures exhibiting the behavior described by correct code from those that are "mutated", and thus faulty. When placing portals, players are implicitly testing: They choose test inputs (i.e., where to place portals), as well as test oracles (i.e., what behavior to expect), and they observe test executions as the creatures wander across the landscape passing the players' portals. An empirical study involving 40 children demonstrates that they actively engage with Code Critters. Their positive feedback provides evidence that they enjoyed playing the game, and some of the children even continued to play Code Critters at home, outside the educational setting of our study.

Index Terms—Gamification, Mutation, Block-based, Software Testing, Education, Serious Game

# I. INTRODUCTION

Programming is not only a useful and desirable skill in industry [1], [2], but it is also considered a core aspect of computational thinking [3]. Consequently, programming has become an essential aspect of education, both at schools [4] and in higher education. Writing code is inseparably linked to testing, which often plays an insignificant role in education [5], despite growing awareness of its importance in higher education and proposals to integrate testing into school curricula [6]–[8]. This neglect is often due to a lack of teaching resources and skills for testing, along with the perception among learners and programmers that testing is dull and tedious [2]. Without a more engaging and accessible approach to teaching testing, this situation is unlikely to change.

To bridge this educational gap and foster a more engaging approach to teaching testing, we introduce *Code Critters*, a serious game inspired by the Tower Defense game genre (see Fig. 1). *Code Critters* is set in a scenario where a disease threatens humanoid creatures, forcing them to migrate. To help these creatures, the players are tasked to strategically place magic portals along the routes taken by them, thereby protecting healthy creatures from mutated ones, with the ultimate goal of rescuing the healthy humans and to identify as many mutants while using as few portals as possible.



Fig. 1: Gameboard during active gameplay

This competitive process hides an educational aspect: As the creatures move around the game field, their behavior is determined by small snippets of simple code, written in an easily understandable block-based programming language. Mutant creatures are not only mutated in their appearance but also use mutated, erroneous code. Thus, distinguishing healthy from mutated creatures resembles the task of testing programs: By selecting where to place portals, players implicitly select test data in terms of coordinates or terrain. Magic portals distinguish healthy critters from mutants using simple block-based test assertions, thus letting players create test oracles. By incorporating various software concepts across different levels and mutant behaviors, *Code Critters* provides an immersive learning journey for testing concepts.

The game-like nature of *Code Critters* and its use of a simple block-based representation of code targets younger learners specifically. To evaluate whether *Code Critters* is indeed suitable for younger audiences, we conducted an empirical study involving 40 children aged 11 to 16. In particular, we aim to study how children interact with the game elements, whether their gameplay leads to meaningful testing, and whether they enjoy the experience. Overall, the contributions of this paper therefore are as follows:

- We introduce the Code Critters serious game and its content, the idea of which was briefly described in a previous short paper [9].
- We present the results of an empirical study with 40 children in a school context, tasked to play the game.

Our experiment shows that the majority of children are actively engaged with *Code Critters*, revealing either a deep interest in understanding each level thoroughly, or aiming to swiftly progress to the final stage. A subsequent exit survey confirms that the children enjoyed playing *Code Critters*, with some even choosing to continue playing during their free time.

#### II. BACKGROUND

Despite its significance and the increasing recognition in higher education, software testing remains inadequately addressed in programming instruction [10]. One promising strategy to encourage developers to write tests is gamification, which involves integrating game elements such as leaderboards, points, or challenges into non-game contexts [11]–[13]. Serious games take this a step further, as they are explicitly designed for training, education, or simulation, such that players learn about a topic through embedded information without feeling like they are learning or working [14]. Despite this potential, only a few serious games have been proposed for software testing [15]–[17].

Mutation testing, exemplified by its integration into the Code Defenders [18] or Code Immunity Boost games [19], stands out as a testing concept well-suited for gamification and serious games. In mutation testing, artificial defects are introduced into the code under test to reveal weaknesses in existing tests [20]. Small variations of the code under test, known as mutants, are created, and the available tests are run against them. If a test fails, it signifies that the mutant has been detected (i.e., killed), while mutants remain alive if there are no failing tests, indicating potential deficiencies in the test suite. In Code Defenders [18], this process is gamified: attackers create artificial defects (mutants), and defenders attempt to detect them by writing tests. However, a significant drawback of Code Defenders and similar gamified testing approaches is that they demand reasonably advanced programming skills, making them more suitable for higher education. To engage less experienced learners, testing needs to be introduced earlier in programming education and in a more accessible way.

A common strategy for making programming accessible to younger learners is using block-based languages like Scratch [21]. Instead of typing textual code, learners piece together predefined code blocks by dragging and dropping them, quickly creating games and programs. Given the success of block-based programming [22], this paper explores the idea of similarly lowering the entry barrier for software testing by employing a block-based programming approach.

### III. CODE CRITTERS

Code Critters is a web application available as open source, and also accessible openly at https://code-critters.org, designed to be played directly in the web browser.

## A. Game Scenario

The inhabitants of the mysterious forest, known as the *Code Critters* [9], have enjoyed peaceful coexistence in their secluded land for an extended period. However, their tranquility is disrupted when a sudden outbreak of disease afflicts the *Code Critters* colony. The infected mutants undergo a disturbing transformation, deviating from their usual behavior and posing a threat to the colony. Faced with this crisis, the remaining healthy critters must seek safety by evacuating their city and making their way to a secure tower located across the expansive forests. The game board (see Fig. 1)



Fig. 2: Scoreboard after finishing the current level

illustrates this dire scenario, which follows the classic Tower Defense format. In this strategic game, players are tasked with defending the tower against infected critters, ensuring that only the uninfected ones successfully reach safety.

# B. Game Concept

Code Critters includes different levels, where each level consists of a playing field made of 16 by 16 tiles with different types of terrain and textures: grass, dirt, ice, water, or wood. Critters can traverse only on grass, dirt, and ice fields. Two tiles on the board designate the colony's village (spawn point) and the tower as their destination, connected by at least one path for the critters to walk on. The game starts with a playing field consisting only of the terrain and devoid of portals, with critters stationed in their village.

As the critters traverse the playing field from village to tower, healthy critters have a humanoid appearance, whereas some of the critters are infected and can be easily identified by their mutated appearance. To succeed in the game, players need to strategically place magical portals along the possible routes to prevent mutants from reaching the tower, while ensuring that healthy critters arrive safely. With a target audience of younger learners, the notion of enemies and elimination common in tower defense games is reframed as collecting infected critters with a portal and transporting them to a safe place until a cure for the disease is found.

Once the player is done positioning portals, the game can commence, and critters start their journey from the village, navigating slightly randomized routes toward the tower while passing through player-placed portals. The game allows for pausing, speeding up, and resetting at any time. A correctly configured portal efficiently beams away mutants while permitting healthy critters to pass without interference.

A level is completed once all critters have left the village and have either arrived in the tower or have been collected by portals. The player then receives a score that is calculated based on how many healthy critters made it safely and how many mutant critters were collected, for a maximum of 1000 points, given 20 critters per level. Each level has a predefined number of portals that is required to identify all mutants and for each additional portal required by the player there is a penalty of 25 points. Finally, the overall score is also rated with 1–3 stars depending on the point range. Figure 2 illustrates the score popup after completing level one. Achieving the maximum score of 1000 for this level involves placing two portals, one on grass and one on the dirt trail.

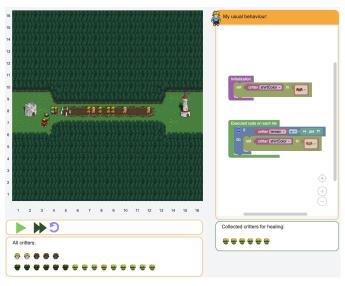


Fig. 3: Game screen of Code Critters

#### C. Critter Behavior

The game interface, as depicted in Fig. 3, features the main gameboard on the left and game control buttons at the bottom. The initially empty green box on the right gradually fills up with collected critters throughout the game. To the right of the gameboard the appearance and behavior of this level's critters is described as the Critter Under Test (CUT), which serves as a concise set of instructions in the form of code that is invoked continuously as critters traverse the landscape. To make the game more accessible, *Code Critters* uses the Blockly¹ library to visually represent code as blocks rather than text.

Conceptually, a CUT can be likened to functions within an object-oriented class, outlining both the attributes and behavior of a critter. Figure 4 shows a closer view of the CUT corresponding to the game in Fig. 3. The *Initialization* section establishes initial values for attributes such as shirt or hair color. The *Executed code on each tile* represents a looping mechanism executed repeatedly on each tile. For instance, the CUT in Fig. 4 initializes the critter with a red shirt, and the color changes when the critter steps on a dirt field.

Mutant critters execute code that deviates from the CUT's code, similar to the artificial defects used in mutation testing. As a point of comparison, Fig. 5 illustrates the CUT of an infected critter: A mutant deviates in one or more attributes from the correct CUT, indicating the presence of at least one code mutation. Various versions of mutants exist within the game. In the example of Fig. 5, the mutant begins with a red shirt (correct) but subsequently changes to a blue shirt upon reaching a dirt field.

## D. Portals as Critter Tests

The overarching objective is to ensure that only critters exhibiting correct behavior reach the tower while capturing



Fig. 4: Critter under test

```
Initialization

Set critter shirtColor to fit critter terrain for dirt 22

do set critter shirtColor to fit critter shirtColor to fit critter shirtColor for fit critter shirtColor for
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Fig. 5: A mutant of the CUT in Fig. 4

mutants along the way. This can be accomplished by strategically placing portals along the critters' path. Figure 3 shows an example portal positioned at the start of the dirt trail, resembling the depiction in Fig. 6 when opened. Each portal occupies a single tile and functions as a test, with the tile properties (coordinates and texture) serving as test inputs. The test specified in the portal is executed during gameplay whenever a critter steps onto it.

To set up a test case, players can click on any walkable field on the board, prompting a dialog to appear with a toolbox of programming blocks. Constructing a test case involves initiating the process with the *only critters with ... can pass* block, akin to a familiar assert statement. Through judicious combination with other blocks and asserting the appropriate attributes, the portal becomes instrumental in safeguarding the tower. The cumulative effect of all placed portals constitutes the comprehensive test suite for the CUT, serving as the tools the player employs to thwart the enemies.

As an example, consider the mutant in Fig. 4, transitioning from a red to a blue shirt on dirt. Placing a portal on the first dirt tile aligns with the if-condition of the correct CUT, where the shirt color mutation occurs. As healthy critters turn orange at this tile, the portal's code, exemplified in Fig. 6, should assert the expected shirt color as orange. This ensures that only orange-dressed critters pass, successfully collecting blue-shirted mutants. The visualization consists of the portal emitting a beaming light, and the captured mutant soaring across the screen into the designated collection space.

# E. Systematic Testing with Portals

The portal in Fig. 6 on its own is not sufficient to thwart *all* mutants from reaching the tower in Fig. 3. Since the disease induces varying mutations, testing all behaviors and attributes becomes crucial. Considering Fig. 4, another statement remains uncovered by the portal in Fig. 6: the Initialization. Placing an additional portal at the beginning of the grass path, asserting the expected red shirt color, completes the test suite. Although there is no limit on the number of portals, minimizing the test suite is encouraged, with unnecessary and redundant portals resulting in deducted points from the score.

<sup>1</sup> https://developers.google.com/blockly

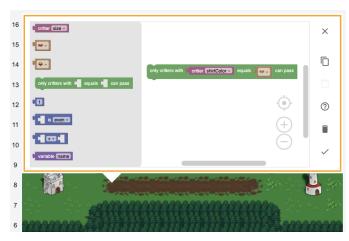


Fig. 6: Gameboard of *Code Critters* with an open portal

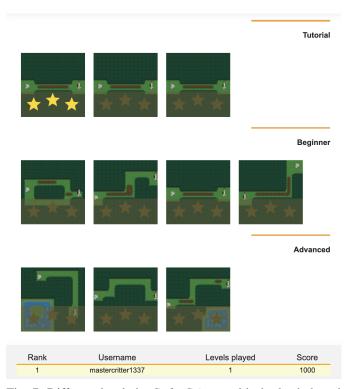


Fig. 7: Different levels in Code Critters with the leaderboard

Since players need to systematically test the code of CUT, each level can be used to exercise different testing concepts, such as statement or branch coverage. Currently, *Code Critters* incorporates a total of ten levels, categorized into three groups: three tutorial, four beginner, and three advanced levels (refer to Fig. 7). The progression in difficulty is marked by the introduction of more intricate CUTs and the introduction of new concepts, including the use of named variables. The complexity is further enhanced by altering the design of the gameboard itself, such as incorporating additional and varied terrain fields or creating multiple possible routes to the tower. Cumulative scores from all played levels are tallied and ranked in the score leaderboard, visible at the bottom in Fig. 7.

#### IV. EVALUATION

To evaluate the usefulness of *Code Critters*, we conducted a controlled experiment, aimed at answering the following research questions:

- RQ 1: How do children play *Code Critters*?
- RQ 2: How much testing do players of Code Critters do?
- RQ 3: Do children enjoy playing Code Critters?

## A. Experiment setup

The controlled experiment was carried out at the Maristengymnasium Fürstenzell in two sessions in January 2024.

1) Experiment Environment: Thanks to a collaboration with Maristengymnasium Fürstenzell, a secondary school that prepares students for higher education at universities, we conducted our experiment within their academic setting. Specifically, we were granted access to two slots within their elective subject centered on robotics. Each slot entailed 90 minutes of teaching, with approximately 20 students participating in each session. Given that this course is an elective subject, all participating students had expressed an interest in programming robots. Before the experiment, these students had three months of experience programming robots using a block-based language developed by Lego,<sup>2</sup> making them already familiar with the foundational concept of block-based programming, which forms the foundation of *Code Critters*.

None of the students had engaged in any explicit form of testing before the experiment, relying primarily on trial and error [23]. In total, 40 students took part in our experiment across the two slots, with the majority being male and only a single female participant. Most participants were in the 5th to 7th grade (11–13 years old), with only four students in the 8th to 10th grade (14–16 years) classes.

- 2) Experiment Procedure: In the initial ten minutes, we provided an introduction to Code Critters, elucidating its storyline and game mechanics. Subsequently, participants were assigned the task of independently playing Code Critters, without specific instructions on which level to tackle or whether to accumulate all points before progressing to the next level. This gameplay phase extended for 60 minutes, concluding with the cessation of the experiment, allowing ample time for participants to respond to our exit survey.
- 3) Experiment Analysis: Our analysis primarily focuses on presenting results for all participants and groups of them. To assess the significance of measurements between different groups we use the exact Wilcoxon-Mann-Whitney test [24] to calculate p-values with  $\alpha=0.05$ . When visualizing trends, we display the 84.6% confidence intervals for mean calculations [25]. If the intervals overlap, indicating no statistically significant difference [26], it is equivalent to confirming non-significance using an exact Wilcoxon-Mann-Whitney test with  $\alpha=0.05$ .

<sup>&</sup>lt;sup>2</sup>https://education.lego.com/en-gb/lessons/ev3-robot-trainer/

- 4) RQ 1: How do children play Code Critters: To address this research question, we examine the data collected throughout the experiment. Firstly, we analyze the average number of (1) completed and (2) attempted levels, along with the corresponding achieved (3) scores and (4) stars. Secondly, we investigate the participants' activity during the experiment, searching for differences in their behavior. This includes identifying the levels they played at different times during the experiment and the number of games played within specific time intervals during the experiment.
- 5) RQ 2: How much testing do players of Code Critters do: To address this research question, we conduct a comparative analysis of the total number of (1) generated test cases (i.e., portals), (2) identified bugs (i.e., mutants), and (3) recognized correct code (i.e., healthy critters) across the participants. Additionally, we examine these metrics during specific time intervals, precisely every minute of the experiment, to gain insights into the development of participants' testing skills over time. Our comparison does not involve absolute values; rather, we focus on the ratios between (1) utilized and required portals, (2) killed and total mutants, and (3) finished and total healthy critters. Furthermore, we conduct these ratio comparisons on a per-level basis rather than per player to uncover differences in the difficulty levels. To ascertain statistical significance, we employ the exact Wilcoxon-Mann-Whitney test with  $\alpha = 0.05$  to compare between groups of participants.
- 6) RQ 3: Do children enjoy playing Code Critters: This question is answered by comparing the answers to the exit survey. The survey encompasses general inquiries about gender and grade, followed by a section with seven five-point Likert scale questions asking participants' enjoyment of different aspects of Code Critters, along with open-ended prompts inviting them to share additional thoughts or feedback. For better visualization, the data is presented in stacked bar charts including the questions and percentages.

## B. Threats to Validity

- a) Threats to Internal Validity: Participants' prior experience with block-based programming could potentially bias the experiment's outcomes. However, introducing Code Critters without prior exposure to block-based programming might overwhelm the children. Additionally, participants may feel inclined to provide socially desirable responses in the exit survey, potentially skewing the data. To counter this threat, we instructed them to respond honestly and without hesitation.
- b) Threats to External Validity: The small sample size and lack of diversity in terms of gender and grade levels limit the generalizability of our findings to broader populations of children. Moreover, since the children were part of a robotics course and already had an interest in programming, the results may not fully represent the experiences of children in a more general context. Furthermore, the short duration of the experiment may not capture the long-term effects or usage patterns of Code Critters, potentially impacting how interactions with the tool develop over time.

#### V. RESULTS

## A. RQ 1: How do children play Code Critters?

During the experiment, the children altogether played 824 games, with an average of 20.6 games per child. They explored around 6.42 distinct levels, finishing approximately 6.12 levels each with at least one star. Achieving at least one star constituted completing a level, prompting some participants to proceed to the next level, aiming to finish it. On average, they scored 5153 points, accumulating a total of 12.68 stars. It took them about 7 minutes, on average, to complete a level. During the levels, the players placed a mean of about 50 portals in total, while identifying more than 200 mutants and saving more than 40 healthy critters.

Considering performance over time, especially achieved levels, reveals substantial discrepancies and variations between players. Figure 8a shows the progression in terms of levels over time for all participants and reveals a wide range of maximum achieved levels from two to ten. The number of games played over time (Fig. 8b) similarly shows discernible differences among the children, suggesting the presence of three distinct groups. This observation aligns with our observations during the experiment, where we noticed three distinct groups of children exhibiting different behaviors while playing *Code Critters*:

- Group 1: These children demonstrated minimal participation in the experiment, often placing random portals without deliberate strategy, and observing the behavior of mutants and healthy critters.
- Group 2: These children displayed a meticulous approach, striving to comprehend the intricacies of *Code Critters* and consistently aiming for 100% completion of each level before progressing.
- Group 3: These children prioritized speed, seeking to complete all levels, advancing to the next level as soon as they achieved at least one star in the previous one.

Each of these approaches leads to a different number of levels completed, and we can therefore categorize the children into groups by the number of different levels completed: 1–3 for Group 1 (6 children), 4–7 for Group 2 (20 children), and 8–10 for Group 3 (14 children). Analyzing the average current level played during the experiment (Fig. 8c), we observe significant differences between these groups, with non-overlapping intervals in the latter third of the experiment. Group 1 shows minimal progress throughout the experiment, indicating limited achievement. In contrast, Group 2 demonstrates consistent progress, steadily completing one level after another. Group 3 exhibits rapid advancement, reaching their maximum level by minute 51. Subsequently, many of them progress to level 10 before revisiting lower levels to improve their scores.

**Summary (RQ 1):** We observed three main types of behavior: A few children disengaged from the game, most children tried to progress as quickly as possible, and many others also focused on maximizing their scores.

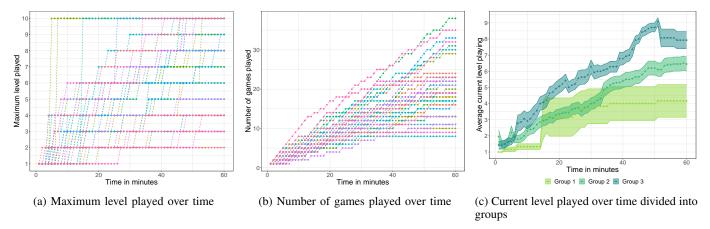


Fig. 8: Differences between the players over time

## B. RQ 2: How much testing do players of Code Critters do?

Figure 9a shows the number of portals created by each group identified in RQ1. Participants of Group 1 seem substantially less ambitious (avg. 24.00): Both Groups 2 (54.35) and 3 (50.57) significantly outperform Group 1 in the number of created portals (p < 0.001 for both). However, there is no significant difference between Groups 2 and 3.

To understand how effective the portals the players created are, we can consider how many mutants were detected, shown per group in Fig. 9b. The result resembles that of portal creation, with a notable difference between Group 1 and both Groups 2 (p=0.002) and 3 (p<0.001). This underscores the lower participation level of Group 1, while the outcomes of the other two groups are comparable.

A complementary data point is whether the portals successfully let healthy critters pass, or falsely identified them as mutants. Figure 9c again shows that both Group 2 (p=0.002) and 3 (p<0.001) significantly outperform Group 1. However, in this comparison, there is a more pronounced difference between Group 2 and 3, with a p-value of 0.061, close to  $\alpha=0.05$ . This can be explained by children in Group 3 aiming to maximize their scores at individual levels, thus focusing more on portal placement to recognize correct behavior.

Figure 10a compares the number of portals used with the number of portals required to solve a level as an indicator of effectiveness. Participants of Group 1 used insufficiently many portals, suggesting that they struggled to identify all the relevant cases they needed to check for in the CUT's behavior. The behavior of Groups 2 and 3 is generally similar in that they used more portals than actually necessary to win a level, resulting in a ratio greater than 1, but thus also higher coverage of the CUT's behaviors. However, towards the end, Group 3's ratio noticeably begins to decline towards the desired ratio of 1, suggesting an improved performance. We conjecture that this is influenced by the score penalty for redundant portals.

Clear differences in behavior can also be identified by considering the ratio of eliminated mutants to the total number of mutants (Fig. 10b) and the ratio of completed healthy critters to their total number (Fig. 10c). The average ratio

of detected mutants does not surpass 90%, which can be attributed to various factors, primarily stemming from misplaced or erroneous portals. For instance, consider Fig. 11a, which illustrates such a scenario. As per the CUT, the healthy critter changes its shirt color to orange at x coordinates of 8 and above. Placing the portal on the tile with x coordinate 9 renders the code susceptible to mutants incorrectly altering their shirt color at an x coordinate of 8, consequently evading detection.

Similarly, the average ratio of surviving healthy critters does not surpass 70%, such that more than 30% were erroneously eliminated on a portal. This could stem from various factors, primarily arising from misinterpretation of conditions or misunderstanding of how assertions function. For instance, consider Fig. 11b, which depicts such a scenario. Here, an if-condition with two branches is presented. The children mistakenly believed that the shirt color changed from orange to blue on the dirt instead of the opposite. Consequently, they placed portals allowing only blue shirts to pass on grass instead of dirt, resulting in incorrect elimination of healthy critters.

Overall, while Group 3 excels in terms of mutants identified, Fig. 10b as well as Fig. 10c both show a small but steady decline over time. This is likely due to these players progress to more challenging levels quicker (Fig. 8c). In contrast, players in Group 2 focused more on perfecting each level, progressing slowly, and repeatedly placing similar portals until correctly positioned, often resulting in healthy critters casualties, but also exhibiting a steady increase in both ratios. Group 1 members were initially motivated but eventually resorted to randomly placing portals, which may explain the initially good and later deteriorating ratios. The differences between groups are significant for the ratio of eliminated mutants (Fig. 10b) Towards the end, particularly the disparities between Group 1 and both Groups 2 (p = 0.001) and 3 (p < 0.001) are significant, while the difference between Groups 2 and 3 diminishes, nearing significance (p = 0.051). Around two-thirds into the experiment, significant differences emerge between all groups in terms of the ratio of completed healthy critters (Fig. 10c), with p < 0.031 between Group 1 and 2, and (p = 0.024) between Groups 2 and 3.

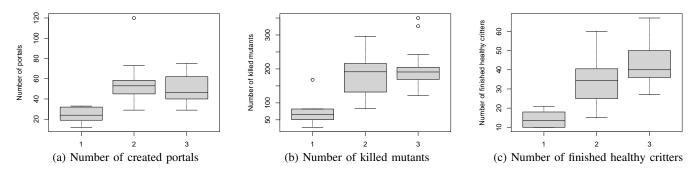


Fig. 9: Statistics on the use of Code Critters divided into groups

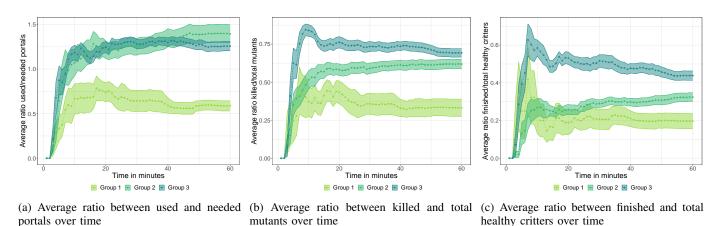


Fig. 10: Differences in correctness between the groups over time

The influence of individual levels can also be seen in Fig. 12, which compares the ratios of portals, mutants, and healthy critters per level. The ratio of detected mutants and surviving healthy critters remain relatively consistent across levels 1 through 8, while there is an increase in the portal ratio for levels 4, 5, and 7. In the case of level 4, one possible factor of influence may be that there are multiple possible paths to the tower; in addition levels 4 and 5 use a disjunction of two conditions in an if-statement, which likely also contributes to uncertainty concerning necessary tests. Level 7 is the first one to include an if-if/else construct, which also seems to cause some uncertainty about necessary tests with players. Level 6 adds complexity by introducing variables, resulting in a slight decrease in the mutation score and surviving healthy critters, but since it only uses a simple if-condition without an elsebranch and the level offers only one path, it seems to be more obvious to players how many portals are needed.

A clear outlier is represented by level 9 (Fig. 13), where all ratios drop to nearly 0.0, identifying it as the most challenging level. In this level, the terrain does not influence the behavior of the critters, but there is a nested if-if-else construct that changes a variable. The code does not affect the behavior or properties of the critters at all, and assertions would be necessary purely on the value of the variable. Although the

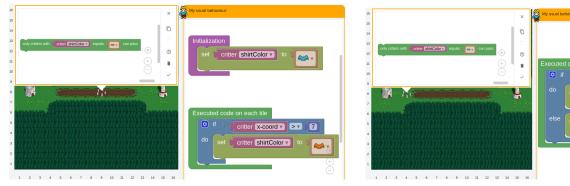
code in level 10 is similarly complex, there is no variable and this time the critters change their appearance, thus allowing assertions on critter attributes rather than variables; this seems to be slightly easier to comprehend for children.

**Summary (RQ 2):** The children engaged well with testing actions in our experiment, creating effective tests (portals) that detected an average of 90% of mutants and 70% of healthy critters. Complexities in level design as well as code lead to variation in accuracy as well as redundant tests.

### C. RQ 3: Do children enjoy playing Code Critters?

Figure 14 summarizes the results of the exit survey. According to the responses, 63% of the children found *Code Critters* enjoyable. They particularly enjoyed the healthy critters and levels, while feeling more neutral towards portals and code blocks. Interestingly, no specific aspects of the game were disliked by a significant portion of the children, as at least half of them expressed enjoyment for every question and therefore every part of the game. Notably, 17.5% of the children continued playing *Code Critters* at home in their free time, indicating its overall appeal as an enjoyable game.

**Summary (RQ 3):** The children enjoyed playing *Code Critters*, even continuing to play it in their free time.



(a) Misplaced portal in level 2

(b) Misplaced portal in level 3

Fig. 11: Two examples of misplaced mines

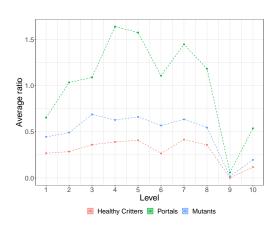


Fig. 12: Correctness per level

```
Initialization

Set variable count to 0
```

```
Executed code on each tile

of f critter x-coord x x 4 and x critter y-coord x x 13

do set variable count to variable count + x 2

else if critter x-coord x x 4

do set variable count to variable count + x 1

else set variable count to 0
```

Fig. 13: CUT of level 9

## VI. CONCLUSIONS

Code Critters is a serious game designed to teach children software testing concepts through block-based mutation testing in an enjoyable manner. Our study involving 40 children demonstrates their active engagement with Code Critters, as they successfully identified numerous bugs and often correctly identified the behavior of the correct code. Feedback from the exit survey indicates that the children thoroughly enjoyed

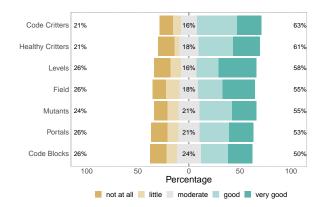


Fig. 14: Survey responses to "How much did you enjoy..."

playing *Code Critters*, with many continuing to play even after the experiment concluded.

Moving forward, we aim to expand the game by incorporating additional programming concepts such as loops to enhance their understanding of testing. Furthermore, we plan to implement a hint system to assist children struggling to progress in the game. In addition, our goal is to bridge the gap between block-based programming languages and more sophisticated ones such as Python. We are considering to achieve this by introducing additional levels in which block-based code is gradually replaced by another programming language while maintaining consistent gameplay.

The source code of Code Critters is available at:

https://github.com/se2p/code-critters

You can try out Code Critters online at:

https://code-critters.org

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