

Development of an Enjoyable Educational Game on Fundamental Programming: Designing for Inclusion and Learning Analytics

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Abstract: A well-discussed problem is how to attract a new public to computer programming, and especially how to reach girls and women. At the same time research reports on that children spend considerable amounts of time playing different types of games, where educational games today are part of formal, informal and non-formal learning. However, many educational games still have a design that appeals more to boys than to girls. Another problem addressed in this paper is how to measure the learning outcomes of an education game. It is a challenge per se to design for joyful gaming, but to assess the learning outcomes is important if the game should be accepted by teachers and a part of teaching and learning activities. The aim of this study was to describe and discuss the design and development of an educational game where girls would like to play together and at the same time learn fundamental programming. The research question that guided this study was: "How could a motivating and inclusive educational game on fundamental programming be designed and developed, with minimal prerequisites for students and teachers?". The overall strategy for the design and development of the was the Design Science Research (DSR) approach. This work was carried out according to the recognised DSR process with the five phases of: 1) Explicating the problem, 2) Defining the requirements, 3) Designing and developing the artefact, 4) Demonstrating the artefact, and 5) Evaluating the artefact. Phase one was based on a minor literature study, while Phase 2 was a combination of a larger and more systematic literature study combined with game testing. Phase 3 was conducted with brain storming sessions for design followed by implementation in the Unity game development tool. Finally, the game has been demonstrated for, and tested by, a group of academic game developers. Results from the formative evaluation look promising, but the important next step in this project is a more formal evaluation using game-based learning analytics with a larger and more diverse test audience.

Keywords: Game-based learning, Game design, Inclusive design, Game-based learning analytics, Programming education

1. Introduction

Previous research shows that students' interests in Computer Science (CS) and programming courses have been increasing (Zweben & Bizot, 2016; Sax, Lehman & Zavala, 2017). However, the larger number of potential students have put strains on CS faculty and personal to find strategies for course execution and logistics that do not negatively impact underrepresented groups in CS courses, such as women and students of colour (Camp et al., 2015; Kaczmarczyk et al., 2015; Sax, Lehman & Zavala, 2017). Today, games are part of everyday life for both children and adults. According to a report, 6 out of 10 Swedish internet users play games on either mobile devices, computers, or gaming consoles (Internetstiftelsen [The Swedish Internet Foundation], 2022). Games are also widely used for learning, both formal (Pan, Ke & Xu, 2022; Humble & Mozelius, 2022), informal (Koutromanos & Avraamidou, 2014; Humble, Mozelius & Sällvin, 2021), and non-formal (Pienimäki, Kinnula & Iivari, 2021).

Although games have been used for educational purposes for a long time (Hellerstedt & Mozelius, 2019; Mozelius & Humble, 2023), research show that girls and women does not engage in games with the same passion as boys and men (Cassell & Jenkins, 2000; Carr, 2005; Lima & Gouveia, 2020; Mozelius et al., 2022). Previous research has also noted that although games are popular for educational purposes, their effectiveness for learning have been insufficiently studied (Yu, Gao & Wang, 2021). That the games used in educational context have positive impact on students' learning outcomes is of course important if games are to be accepted as teaching and learning tools by teachers and other educational stakeholders. The aim of this study was to describe and discuss the design and development of an educational game where girls would like to play together and at the same time learn fundamental programming. The research question that guided this study was:

How could a motivating and inclusive educational game on fundamental programming be designed and developed, with minimal prerequisites for students and teachers?

2. Method

This study used a Design Science approach involves the second and the third phases of the five-phase process that has been outlined by Johannesson and Perjons (2014). The two phases that were conducted and described in this paper were 2) Defining the requirements and 3) Designing and developing the artefact. All the ingoing phases in the Design Science process are depicted in Figure 1 below. The first phase of explicating the problem, and a beginning of phase 2 has been conducted earlier and was published in Mozelius et al. (2022).

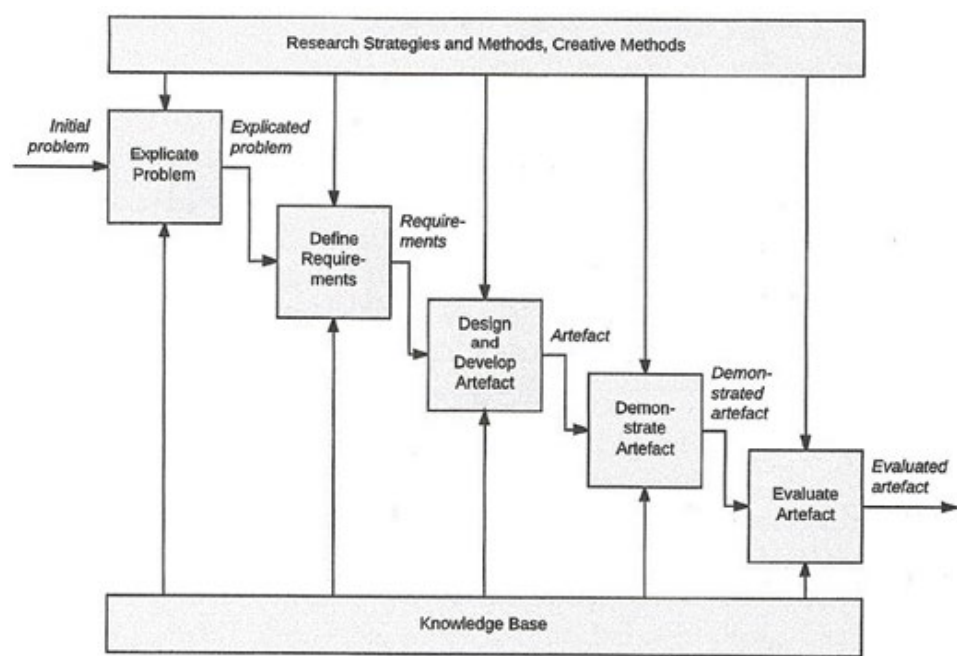


Figure 1: The five phased Design science framework (Johannesson & Perjons, 2014, p. 82)

Phase 2 was carried out in a combination of a larger and more systematic literature study that has been combined with testing of other educational games on fundamental programming (Sällvin, Mozelius & Humble, 2023). Phase 3 was conducted by project members in brain storming sessions on appropriate and creative game design. Later the design ideas were implemented with use of the Unity game development tool. A start of phase 4 and phase 5 was initiated when the game was demonstrated for, and tested by, a group of academic game developers. What remains, in a longer journal article, is to describe and analyse all the five phases in Figure 1. This should be done when phase 4 and phase 5 have been completed with demonstration and more formal testing by the presumptive target audience.

3. Requirements

The second phase of the design science research process involved defining the requirements. This was accomplished through a systematic literature review, which aimed to identify important game design concepts for engaging both girls and boys in serious gaming (Mozelius et al., 2022). Those results are in line with other literature reviews such as (Sharma et al, 2021). Additionally, three existing educational programming games were tested by girls between the ages of 10 and 15 (Sällvin, Mozelius & Humble, 2023). The findings from the literature review and the testing phase can be summarized as the game design recommendations presented below. The literature review was conducted during the spring of 2022, and the game was tested in a Maker movement girl group during the autumn of 2022.

3.1 Creativity, Customisation and Character diversity

Examples of this include providing players with the ability to create items for use within the game and incorporating functionality that allows customization of game environment components, such as modifying game characters. Games featuring a mix of male and female characters or non-gender-specific characters are preferable.

3.2 Exploration Without Violence and Collaborative Interaction

The literature review showed that while boys are often drawn to games involving combat and violence, girls tend to prefer indirect competition without violence. An educational game targeting both girls and boys should strive to incorporate explorative gameplay with a compelling narrative or diverse activities, engaging characters, and opportunities for collaboration and social interaction.

3.3 Flow and Mastery

The sense of flow and of being in control is important not to lack motivation. Challenges and tasks in the game should therefore be aligned with the player's competence level to achieve an optimal level of engagement and motivation.

3.4 Reward and Feedback

Rewards, such as virtual currency, unlocking new levels or abilities to customize the avatar, for accomplishing specific goals keep players engaged and motivated. Feedback and guidance in the form of messages and hints are important in educational contexts, as it provides valuable information to learners and facilitate the enhancement of their programming skills. The possibility to fail and try again is also highly valued.

In addition to these motivating and inclusive design recommendations, there are also two other requirements that should be considered. Firstly, the game should include mechanisms to measure learning outcomes. Secondly, it is essential for the game to be easily adaptable for use by teachers and students, with minimal prerequisites or technical barriers.

All the above recommendations served as the requirements and the foundation for the next step in the design process, where the game design was developed through brainstorming sessions with the project members.

4. Game development

The theoretical thoughts explained above resulted in the creation of an initial game concept which was later expanded iteratively during the autumn and winter in 2022 and 2023. The declared goal of the game was to help students learn computational thinking skills and fundamental coding skills in Python. Another decision was to focus on the age group of 10–16-year-old students without earlier programming experience. Furthermore, it was a requirement that the game would be attractive enough to make people want to play it and not just see it as a learning tool and, most importantly, that it should use a girl-inclusive design. These requirements and intentions shaped the idea of focusing on a few essential game elements that are proven to work well from a game design perspective and that are addressing the outlined requirements.

The core idea of the game is that players collect cute fantasy creatures called 'critters' which can be trained by giving them instruction scripts. The training is purposefully not called programming in order to give the game less of a technical feeling. The main gameplay consists of collecting interesting critters, training them for racing and entering them into a race against other players. Races are held on different obstacle courses. The critters compete either against bots, or against other players. Four proven elements are implemented at the heart of the game:

4.1 Collecting

The activity of collecting things has a large appeal as a game element, especially when the player can collect creatures. The most prominent example of this is the Pokémon GO game. Since new creatures are awarded for winning races or for other achievements the interest in collecting critters has a strong impact on the motivation of the players to get better at coding, leading to that collecting new critters becomes easier.

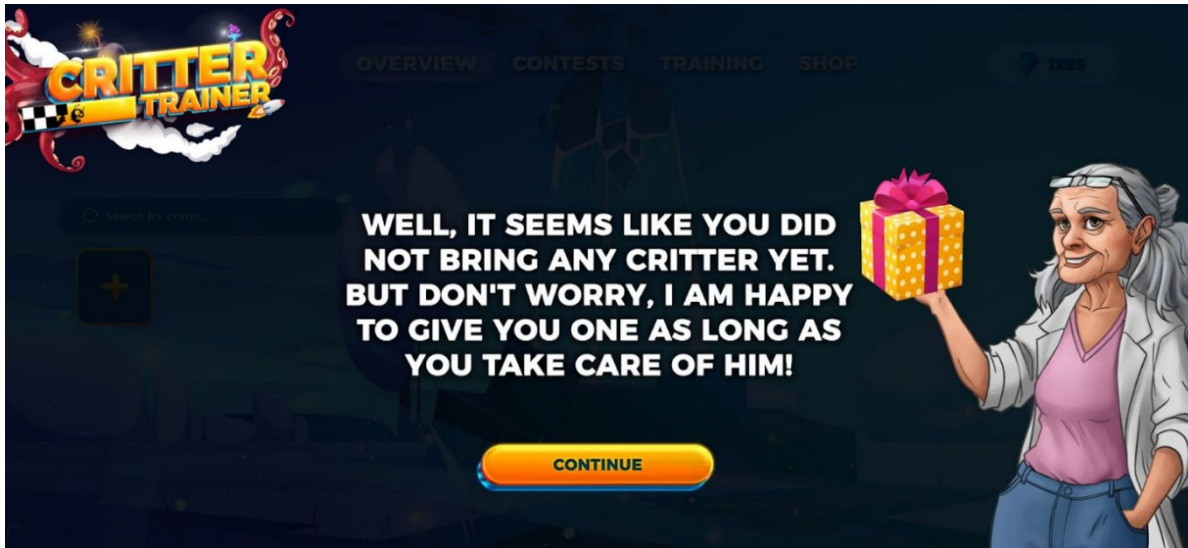


Figure 2: A critter to take care of and to train

Competition

The competition element is a well-established way to challenge a player to become better. The game uses a mixture of players and bots as competitors so that the player always has the opportunity to win against someone, even if it is too hard to win first place. Competition should also give players an opportunity to learn from others.

Rewards

Rewards are very important for player motivation. The game rewards victories in races so that players get something out of having created well-working training scripts for their critters. However, the game also rewards personal achievements, even if the player doesn't end up winning the race. Thus, rewards play an important role in keeping the motivation high for any learning and gaining of experience. The biggest rewards are new collectable critters, smaller rewards are special items for the critters and trophies.

Difficulty matching

The game uses a smart algorithm to assign competence levels to players in order to match them with other players or bots that are performing at comparable levels. This avoids having a beginner crushed by a very advanced player.

Python syntax was chosen for the coding elements since Python is one of the most popular programming languages which is also widely recommended for school environments in Europe. It is also a programming language with high readability and high writability that is easy to learn. In the actual game the players first learn how to give critters commands in order to guide them through an obstacle course. Commands correspond to functions in Python but the players will be using predefined functions from the beginning (such as run, dodgeLeft, dodgeRight, and jump) before learning how to create their own functions. The game starts with tutorials which challenge the player to solve a situation, so they are essentially little puzzles that help the player acquire the skills needed. The tutorials gradually introduce the player to the competitive racing game in which more critters can be unlocked and rewards can be won.

Of course, the tutorials can be skipped and the players can immediately start training their critters and enter them into races. In a race the player only has limited control over the critters as they are mainly in the role of a spectator. Winning or losing a race has a lot to do with which critter is selected for the race track and which commands are given to the critter in a 'training script'. When training a critter, a player writes down a sequence of commands which the critter will execute in the race. This could start in a very simple way (' run ', ' run", ' run ', 'jump') as in Figure 2 below, and then move to more advanced coding structures with while loops and conditionals.

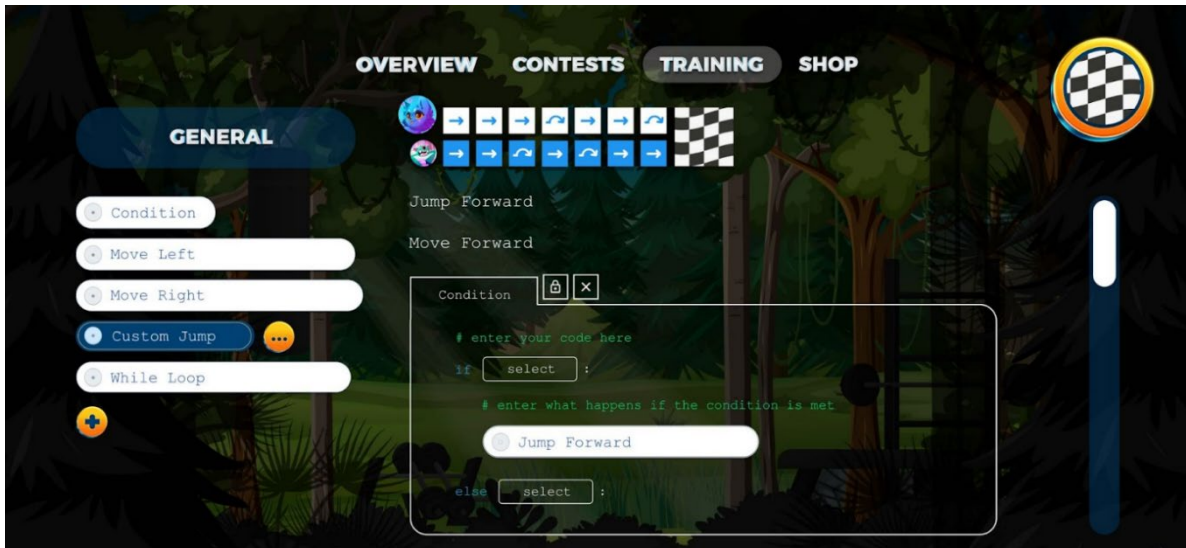


Figure 3: Creating code scripts for training and contest

The game never pushes the player to advance in the coding skills, however the competitive aspect and the rewards for winning races are a huge motivation to improve the performance of the critters, thus leading to players trying out more advanced code. As a framework for the development, Unity was chosen since it has become a standard for game app development. The advantage of using a framework like Unity is that a lot of the movement of objects on the screen (in essence the interaction between critters and race track) can be implemented fairly easily and without days of programming work. A first alpha version has been tested by a group of academics with experience of game design and game development. The testing was carried out, at two universities during April and May 2023. Several bugs were discovered and there is a need for a revision before the game meets a wider audience. At the same time the graphics and the general game idea got positive feedback.

5. Game-Based Learning Analytics

The use of games to enhance the learning of programming in schools is something that has already started to be used, and where different examples can be found. There is a wide variety of games and approaches ranging from promoting the teaching of computational thinking concepts to learning a specific programming language (both board games and videogames), or even relating programming to physical robots (Malliarakis et al, 2014; Jordaan, 2018). However, as with other serious games, it is not so often that the results have been scientifically validated and it is even very rare that such evaluation has been done in a systematic way with a large number of students and supported by evidence of the results obtained (i.e., based on usage data and not only on self-assessments or student perception and acceptance) (Sharma et al, 2021).

Game learning analytics (GLA) comprise the collection, analysis, and visualization of player/student interactions with serious games. The information gathered from these analytics can benefit all the stakeholders in the game development helping us to improve serious games design and implementation and improving their educational use by better understanding player actions and strategies, as well as improve player assessment (Alonso-Fernandez et al, 2022). However, to obtain significant GLA results, it is necessary to have a learning analytics model that can relate the interaction data obtained to the educational design of the game. This model allows that a more comprehensive analysis can be made to identify potential game design problems and gain insight how actual student learning develops with the game (Perez-Colado et al, 2018). We also consider that it is necessary to systematize the GLA processes as this will allow to scale up GLA use and to have data from a significant number of students. One way to achieve this systematization is through standards and open software. In our case, we use the new standard eXperience API (xAPI) as it has an application profile for serious games (xAPI-SG) which simplifies both the collection and analysis of data. GLA will be compliant with European regulations for data privacy (e.g., EU GDPR) informing students that data is being collected and that will be used only in an aggregated way to improve the game and the educational experience. All the data captured will be

pseudo-anonymized at the origin so that it cannot be traced back to any specific student (students will play with a code without providing their personal details).

In this project, we are currently carrying out a formative evaluation of the game with the aim of improving it for testing with end users (i.e. learners). In addition to the usual testing with game experts (e.g. beta testing), we are incorporating GLA. For a game to be effective, testing with experts is not enough and early formative evaluation based on data about learners' behaviour and progress in the game is necessary. To this end, we want to start early testing that will allow us to improve both the game and the GLA process applied to this programming learning game. Specifically, we want to:

- Compare and improve the instructional design: GLA can be used to check whether the game is well designed from both a gameplay and pedagogical point of view. The aim is to identify areas where learners have difficulties (e.g. non-progressive gameplay situations) and to be able to correct them by improving the user experience.
- Evaluate the effectiveness of the game as a learning tool: GLA can be used to evaluate the effectiveness of the game as a learning tool by measuring student progress and learning outcomes (e.g. related programming concepts). This information can be used to make improvements to the game or to make informed decisions about whether to use the game in future learning experiences.

Thus, the purpose of the GLA is to improve the overall quality of the game, but it requires a thoughtful and responsible approach to implementation to be effective. By providing information about learner behaviour and progress, and at the same time having a model that attempts to relate this data to the instructional design of the game, it is possible to test whether the initial assumptions are being met. All this analysis should be driven by and related to the educational design of the game. Only with this approach, GLA can help to ensure that serious games are effective and engaging learning tools that meet learners' needs. A project meeting was held in March 2023 to discuss how the game-based learning analytics should be implemented in the game.

6. Discussion

The first results from the formative evaluation look promising, but what is of greater importance is the next step, to carry out a more formal evaluation for the intended target group. An evaluation where the game will be tested both in girl groups, and in groups that are as heterogeneous as possible, but within the aimed age group. Moreover, the described GLA will be implemented to provide data that could improve the user-friendliness and the instructional design in the Critter trainer game. Test results that later will be used as input for the next five Design science phase iteration, before the game should be made public and downloadable from the project's web portal.

Using video games in classrooms can provide a different and more active way to build and explore their learning and help break down stereotypes. It also allows children to explore and enhance their digital, creative, and problem-solving skills, which can change perceptions and help girls become more interested in STEM disciplines in general and in programming in particular (Sharma et al, 2021). While GLA analytics can be powerful, it is not a magic solution that will automatically lead to improved learning outcomes. The data collected through GLA must be carefully analysed and interpreted to draw meaningful conclusions about learner progress and areas of difficulty. In addition, the data must be correlated with the instructional game design to provide relevant insights into the learning experience.

7. Conclusion

Although the use of games to increase students' motivation is not new, it seems clear that there is still a need for more systematic projects to better understand the relationship between girls' gaming behaviour, game design and their perception of programming and computer science careers (Sharma et al, 2021). However, game-based learning analytics must be implemented with careful consideration for learner privacy and data security (e.g., EU GDPR compliance). Learners must be informed that interaction data is being collected to improve both the game and the educational experience (as previously mentioned, all the data captured will be pseudo-anonymized at the origin so that it ca not be traced back to any specific student).

8. Future Work

The work presented here in this paper is a part of a two-year European project with the aim of developing, testing and disseminating the described educational game. As the next important step in the project, the game

should be demonstrated and evaluated in different test groups. Some test groups will consist of girls only, while other test groups should be as heterogeneous as possible, but with participants from the intended age group.

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This study was made possible by funding from the Erasmus+ project Gaming4Coding. This is a two-year project, with the overall purpose of designing and developing a game where secondary school students should learn text-based programming. Moreover, the game should be a joyful experience for players, and it must be a game where girls should feel welcome to play and learn together with boys. The project builds on the idea that the highly motivating features of game-based learning could be used to promote the learning of programming in a younger audience, and especially among girls.

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