The Eurasia Proceedings of
Educational & Social Sciences (EPESS)
ISSN: 2587-1730

The Eurasia Proceedings of Educational & Social Sciences (EPESS), 2023

Volume 31, Pages 171-179

ICRESS 2023: International Conference on Research in Education and Social Sciences

Game Development-Based Learning Approach to Teaching Programming in Upper Secondary Education: A Case Study

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Abstract: The CODING4GIRLS (C4G) initiative aims to prepare young learners, especially girls, for careers in computer science by promoting a game development-based learning approach to teaching programming. Using the C4G approach, students learn programming concepts through the development of serious games. After the effectiveness of the C4G methodology has been confirmed at the lower secondary level, the aim is to examine whether the application of this approach is also effective at the upper secondary level. This paper presents the results of a study that represents the beginning of research in this direction. The study involved a mixed-gender class of 15- to 16-year-old students from a school in Croatia who participated in learning activities based on C4G learning scenarios. They were expected to develop games using the programming language Snap!. The scenarios aimed to engage both boys and girls by addressing interesting topics and promoting problem-solving skills in real-world contexts. According to the results, the students accepted the process of developing games to solve real-world problems and were motivated to learn programming using this approach. Their teacher also commented positively on the effectiveness of the approach in achieving the learning objectives related to programming and its suitability for upper secondary students.

Keywords: CODING4GIRLS, Game development-based learning, Programming skills, Upper secondary education, Snap!

Introduction

Teaching programming is often challenging because it can be difficult for students to understand abstract concepts, terminology, or syntax, especially if they are beginners (Tuparova, 2019). Therefore, teachers try to incorporate various innovative methodological approaches in their teaching practices to help students learn programming concepts and to increase their learning motivation and engagement during classes. These approaches include teaching programming concepts through game-based learning (GBL) (Shabalina et al., 2017; Topalli & Cagiltay, 2018). GBL activities usually gradually introduce programming concepts and require students to solve interactive programming tasks that represent game levels. There are many games and tools that can be used to support the learning basic and advanced concepts using GBL approach that provide students with immediate feedback to learn from mistakes (Bauer et al., 2015; Holenko Dlab et al., 2019).

Another innovative approach based on games is game development-based learning (GDBL), which involves creating games (Papadakis, 2020; Rugelj & Lapina, 2019). GDBL activities can range from developing or modifying existing small games or missions for younger learners to developing games or even apps for phones and tablets where students apply all the programming concepts they have learned. It is important that complexity of the games should match the learning outcomes that students are expected to achieve. Since GDBL approach is application-oriented, students are more engaged in the learning process (Bewer & Gladkaya, 2022). To promote the acquisition of programming skills at an early stage, specific visual tools and programming languages such as Alice (Alice, 2020), App Inventor (App Inventor, 2023), Scratch (Scratch, 2023), Snap! (*Snap!*, 2023), Thinker (*Thinker*, 2023) have been developed. With these tools, students can easily create interactive stories and games, which positively affects their motivation for programming-related learning

activities (Holenko Dlab et al., 2019; Lau, 2018; Papadakis, 2020). Instead of writing text-based commands, students manipulate graphical elements (blocks) to create programs. Visual and game components have positive effects on learners' interest in computer science (Bewer & Gladkaya, 2022).

To facilitate the implementation of programming tools and the organization of GDBL learning activities, it is important to provide teachers with learning scenarios or educational sheets. GDBL scenarios can be inspired by real-world situations and promote critical thinking. Gender can affect student engagement in GBL activities, with girls preferring games that involve puzzles, fantasy, role-playing, stories, exploration, challenges, and problem-solving (Hosein, 2019), but are not fond of direct competition (Alserri et al., 2018).

CODING4GIRLS (C4G) (*CODING4GIRLS*, 2018) is a European initiative that encourages young students to acquire programming knowledge through GDBL and develop games that address real-world problems. CODING4GIRLS methodological framework for learing programming was developed within the project CODING4GIRLS, funded by the Erasmus+ Programme of the European Union under the Key Action 2: Cooperation for innovation and the exchange of good practices. The main aim of the development of the methodological learning framework was to make the computer science education and careers attractive to young students and thereby address the gap between male and female participation in this field (Hoić Božić et al., 2020). The fields of computer science and ICT have historically been dominated by men, both within the European Union (EU) and globally. According to (Wong et al., 2016), introducing programming in primary and secondary education is seen as a crucial factor in encouraging students to pursue further education in these fields. Therefore, the main objective of the project was to engage girls by increasing their understanding of the potential for professional and personal development that computer science provides. Additionally, the project aimed to advocate for gender equality and equip both boys and girls with programming skills, preparing them for future careers in computer science.

According to C4G methodological learning framework, students are motivated to create game-based solutions that tackle real-world challenges within the visual programming environment of Snap!. The C4G project also empowered educators with guidance on integrating the designed methodology and tools into their teaching practices and a set of learning scenarios and supporting instructional resources designed to emphasize the C4G approach, which promotes the acquisition of programming skills among girls. Using C4G learning scenarios, students begin by solving simpler problems and gradually progress to more complex ones, which ensures ongoing engagement and interest. Furthermore, students are presented with partially developed games that they must complete by implementing smaller modules, resulting in a meaningful product. This approach enables acquisition of necessary knowledge and skills to design and develop their own games for both, girls and boys, while fostering a constructivist approach to learning.

CODING4GIRLS approach has been shown to be effective for acquiring programming skills among 11- to 14-year-old students attending lower secondary school (Holenko Dlab & Hoic-Bozic, 2021) so the aim is to examine whether the application of the approach is also effective at the upper secondary level. To begin with research in this direction, the CODING4GIRLS approach was applied in one secondary school, with a group of 18 students aged 15 and 16 years, comprising both male and female participants who engaged in learning activities based on C4G learning scenarios. Paper presents the results obtained from the study and plans for further research.

Method

Following the CODING4GIRLS validation methodology (CODING4GIRLS, 2020) and the research methodology applied at lower secondary level (Holenko Dlab & Hoic-Bozic, 2021), the study described in this paper explores the effectiveness of the C4G approach to learning programming in upper secondary education in Croatia. As descriptive case study research (Yin, 2003), the presented research includes implementation of learning activities based on the C4G approach in one upper secondary school in Croatia. A combination of quantitative and qualitative methods was used to answer the following research questions:

RQ1) Do students consider the C4G methodology effective and appropriate for building programming skills?
RQ2) What is the difference in the students' perceptions regarding the level of their programming skills before and after C4G activities?
RQ3) Does teacher consider the C4G methodology relevant, effective, and appropriate for building programming skills among students aged 15-16 and why?

Participants

Participants in the study were teacher of informatics (NT =1) and her students (NS =18). This teacher has extensive experience in informatics and serves as a mentor for preschool teachers who are studying informatics at the University of Rijeka (UNIRI), guiding and supporting them during their teaching practice in informatics. She applied the C4G approach to building programming skills in a mixed-gender class with students aged 15 and 16 (N=18, 16 male, 2 female). The mean age of the participants was 15.11 years (SD =0.314).

In Croatia, there are two types of upper secondary schools: high schools, including gymnasiums where students acquire competencies (knowledge and skills) from general knowledge as a basis for further education at universities, and vocational schools, where the focus is on acquiring competencies needed in the labor market. In this case study, the focus was on gymnasiums. After successfully completing lower secondary education, students who choose to continue their education at a gymnasium can select the type of gymnasium that matches their interests, talents, and educational goals (e.g. general gymnasium, natural sciences and mathematics gymnasium, classical gymnasium, sports gymnasium).

The participants of this study were first grade students of natural sciences and mathematics gymnasium "Gimnazija Andrije Mohorovičića Rijeka" from Rijeka, Croatia. This type of gymnasium is enrolled by students who have an inclination or are even gifted in mathematics and computer science (especially programming) and was chosen to examine whether these students find it motivating to learn programming using the game development-based approach in Snap!. Moreover, this type of gymnasiums in Croatia are facing the problem of enrolling girls (the majority of students are male) which is an additional reason to investigate approaches that can contribute to greater motivation of girls to acquire knowledge in mathematics and computer science.

Study Procedure and Instruments

Activities for teaching programming using the C4G approach were organized during April and May 2022 as part of regular Informatics classes. The teacher was provided with learning scenarios based on the game development approach, developed by the project consortium (CODING4GIRLS 2020) and translated into the Croatian language. At the beginning of the study, students were familiarized with the C4G project and the GDBL approach to acquiring programming skills. They were asked to complete a preliminary questionnaire to determine their motivation for learning programming.

After completing the preliminary questionnaire, the GDBL activities were conducted. The teacher began each lesson with an introduction to the programming concept to facilitate student learning. Students had the opportunity to deepen their understanding of this concept through practical exercises. They were then given the task of creating a serious game that incorporated the programming concept they had learned using the C4G learning scenarios, while the teacher guided and supported them in solving the task.

Each C4G learning scenario provides a concise description of the learning activities required to create the intended serious game so that teachers can seamlessly incorporate them into their classroom practice. At the beginning of each document is information about the overall educational goal, concepts covered, specific learning objectives, and expected outcomes of the learning process. The main section of the scenario provides detailed step-by-step instructions for game development, while the final section includes assessment methods, discussion questions to encourage learner engagement, and a list of tools and resources for teachers and students. The collection of learning scenarios provided to the teacher covers basic programming concepts such as loops, conditionals, variables, statements, operators, events, and parallelism. Each scenario provides students with the opportunity to learn and apply one or more of these programming concepts by designing a game that addresses a real-world problem. To further encourage girls' engagement in programming, the topics of the real-world problems are chosen to be appealing to them. Examples include tasks like cleaning up trash in a park, promoting recycling, planning a picnic, and caring for animals at a shelter. A screenshot of a game created using one of the learning scenarios is shown in Figure 1.

After the GDBL activities, students were asked to complete the follow-up questionnaire to determine their perceptions of the C4G learning methodology. Both questionnaires also asked students to self-assess their current level of programming skills on the following scale:

0 - I have never coded or programmed before,
1 - I am a novice programmer (just have basic ideas),

2 - I can code simple programs,
3 - I am fluent in programming (can create a full program),
4 - I can design a solution of a problem in the form of a program.

Figure 1. Example of game developed in Snap! - Recycling

Both questionnaires were created using the Google Forms tool. The difference between students' self-assessed initial and final level of programming skills and the effect size were determined using Wilcoxon's Signed Rank Test for paired samples and Spearman's rank correlation ρ. The follow-up questionnaire assessed student satisfaction with the C4G approach and the organization of GDBL activities using the list of statements presented in Table 3 on a 5-point Likert scale (1 - strongly disagree, 5 - strongly agree). Student responses were statistically analyzed. In addition to the student questionnaires, the teacher reported in writing on student participation and engagement, as well as their own views on the relevance and effectiveness of the CODING4GIRLS approach.

Results and Discussion

Results of Preliminary Questionnaire

Preliminary questionnaire was solved by 18 students (16 males and 2 females) who self-assessed the level of their programming skills before C4G learning activities on the scale from 0 - I have never coded or programmed before to 4 - I can design a solution of a problem in the form of a program. Results are shown in the Table 1. Half of the students perceived their level of programming skills as level 2 - can code simple programs (50%), 11.11% perceived their level of programming skills as level 1 – novice programmers (32.51%) while others self-assess their level of programming with levels 3 (22.22%) and 4 (16.67). If we compare results by gender, it can be seen that only male students perceived their level of programming skills as level 3 and 4.

Table 1. Self-assessment of programming skills by gender

Level of programming skills	Male	Female	Total
0 - I have never coded or programmed before	0%	0%	0%
1 - I am a novice programmer (just have basic ideas)	12.50%	0%	11.11%
2 - I can code simple programs	43.75%	100%	50%
3 - I am fluent in programming (can create a full program)	25%	0%	22.22%
4 - I can design a solution of a problem in the form of a program	18.75%	0%	16.67%

Analysis of students' responses about motivators for learning programming are shown in Table 2. Students could choose one or more responses. According to the results, most of the students are motivated by success in the programming class (37.50%). Comparison by gender shows that the factor of showing other students programing skills motivates female students (100%) to a greater extent than male student (27.78%). Also, while both female participants want to follow a career in programming, only 38.89% of male students mentioned that factor. Among motivating factors males also mentioned enjoyment in solving logic problems and puzzles (27.78%) while 11.11% of them are not motivated at all.

Table 2. Motivation for learning programming by gender

Statement	Male	Female	Total
I'm not motivated	11.11%	0%	12.50%
I want to succeed in the programming class	33.33%	0%	37.50%
I want to show other students I can program	27.78%	100%	18.75%
I want to follow a career in programming	38.89%	100%	31.25%
I enjoy solving logic problems and puzzles	27.78%	0%	31.25%

Results of Follow-up Questionnaire

All 18 students (16 male and 2 female students) solved follow-up questionnaire and expressed their attitudes about the C4G activities using the 5-point Likert scale (1 – strongly disagree, 5 – strongly agree). Results show (Table 3) that both male and female students understood the presented concepts and felt engaged in this way of learning. They think that conducted activities were relevant for learning programming and it was clear what they had to do. Female students enjoyed programming to a greater extent and had (more) fun during C4G activities.

Table 3. Satisfaction with C4G approach

Statement		AVG	SD
I found programming challenging.	Male	3.50	0.86
	Female	3	1
	Total	3.50	0.90
I found programming motivating.	Male	3.44	0.93
	Female	4	0
	Total	3.50	0.90
I found programming easy.	Male	2.63	1.05
	Female	2.5	0.50
	Total	2.61	1.01
I enjoyed programming.	Male	3.25	0.90
	Female	5	0
	Total	3.44	1.01
I understood most of programming concepts.	Male	4.56	0.50
	Female	4	0
	Total	4.50	0.50
Learning this way is fun.	Male	3.50	1.22
	Female	4.5	0.50
	Total	3.61	1.21
I felt engaged with this way of learning.	Male	4.06	0.66
	Female	5	0
	Total	4.17	0.69
The activities were relevant to learn.	Male	3.75	1.30
	Female	3.5	0.50
	Total	3.72	1.24
At any time, it was clear what I had to do.	Male	3.94	0.75
	Female	4	0
	Total	3.94	0.70
What I learned will be relevant for my future.	Male	3.25	1.25
	Female	3.5	0.50
	Total	3.28	1.19

Table 4. The difference between the self-assessed initial level and the self-assessed final level of programming skill

	-2	-1	0	1	2	3	4
Male	0	6.25%	37.5%	37.5%	18.75%	0	0
Female	0	0	50%	50%	0	0	0
Total	0	5.56%	38.89%	38.89%	16.66%	0	0

The students also self-assessed the level of their programming skills again on the scale from 0 - I have never coded or programmed before to 4 - I can design a solution of a problem in the form of a program. Table 4 shows the difference between perceived levels of programming skill. A total of 55.56% of students stated that they

have progressed, most of them for 1 level (38.88%). 38.88% students stated that they are at the same level but most of them were students who initially self-assessed their skills with level 3 or 4. One student self-assessed their programming skills level higher before participating in C4G activities.

Table 5. The difference between the self-assessed initial level and the self-assessed final level of programming skill

Questionnaire	N	Mın	Max	Mean	SD	W	p	Effect size (Spearman ρ)
preliminary	18	1	4	2.44	0.92	4.5	< .05	0.62
follow-up	18	1	4	3.11	0.90			

Table 5 shows mean values and standard deviations, as well as the minimum and maximum values. The results of the Wilcoxon's Signed Rank Test for paired samples show that students self-assessed their programming skills significantly higher in follow-up questionnaire compared to preliminary self-assessment. Spearman's rank correlation (ρ) results indicate a strong effect size.

Teachers' Observations and Comments

After the implementation activities, the teacher was asked to express her qualitative opinion on the C4G methodology and the implementation process in a written form. The teacher expressed belief that the C4G methodology is very effective, not only with female students, but also with male students, even though it was primarily designed to popularize programming among girls. Teacher noted that the students seemed to acquire new knowledge and principles of logical reasoning without consciously realizing it because the methodology begins with simple problems and progresses to more complex ones, following a gradual approach.

As an advantage, the teacher stated the fact that the materials were fully developed and she received learning scenarios that she could simply use with students. She noted that after explaining the basics, students mostly came up with solutions independently. It is noteworthy that implementing this approach in natural sciences and mathematics gymnasium class made the implementation easy and straightforward.

The teacher acknowledged that some students already possess an inherent interest and motivation to acquire programming skills but by implementing this methodology, she managed to demonstrate to even the less enthusiastic individuals that programming is an attainable skill. Despite receiving comments from "experienced" students that some tasks were too simple for them, they still found themselves challenged by certain tasks, requiring them to invest additional time. Teacher reported that all participants actively engaged with the material, displaying genuine interest and even competing to solve tasks more quickly.

The teacher believes that such scenario-based approaches should be adopted in various disciplines, regardless of students' future careers, due to the rapid advancements in technology. Furthermore, she suggested the development of more advanced versions of these scenarios. Drawing from personal experience, the teacher emphasized that individuals already inclined towards programming do not require recruitment, as they have already made their decision. However, for those who are still considering their future profession, an experience like this can be a positive and enlightening one. The teacher didn't reported any technical problems that affected the implementation of the C4G activities.

Discussion

According to the results on *RQ1 - Do students consider the C4G methodology effective and appropriate for building programming skills?*, students expressed a positive attitude towards the GDBL approach based on the C4G methodology. Students feel that they have acquired programming skills and consider the approach both effective and suitable for learning programming. Thank to the clear instructions in the learning scenarios, they successfully developed games and found the process engaging and fun. Both female students enjoyed programming and had fun during C4G activities which shows that such activities have the potential to attract girls to programming.

Regarding *RQ2 - What is the difference in the students' perceptions regarding the level of their programming skills before and after C4G activities?*, the students' self-assessment of their programming skills showed a significant increase after participating in the C4G activities compared to their self-assessment before the activities. This effect is further evidence of the effectiveness of the GDBL activities in improving programming

learning. 38.88% of the students self-assessed their skills at the same level before and after the C4G activities. Since most of them were students who initially self- assessed their skills at level 3 or 4, this result is to be expected. It can be assumed that these students acquired programming knowledge and skills during their education in lower secondary school or through participation in extracurricular activities. Of the students who progressed, most of them progressed for 1 level (38.88%), while 16.66% of the students progressed for 2 levels. One student who self-assessed his programming skills level higher before participating in the C4G activities can be assumed to have been unrealistic in his initial self-assessment. Due to the small number of girls, the results related to RQ1 and RQ2 were not compared by gender. Further research with more (female) participants is needed to discuss gender differences related to these research questions in the context of upper secondary education.

The effectiveness of the approach is also confirmed by teachers' comments. Results related with *RQ3 - Does teacher consider the C4G methodology relevant, effective, and appropriate for building programming skills among students aged 15-16 and why?* indicate that the teacher has a positive opinion about the relevance, effectiveness, and appropriateness of the approach for students aged 15-16. According to the teacher, students were motivated to develop their own games, especially because the games involved solving real-world problems. According to the teachers' observations, the topics covered in the Snap! projects were captivating for both female and male students, which had a positive effect on their motivation to solve tasks and compete. The challenge of completing the game made programming an enjoyable experience even for more experienced students. This shows that the scenarios are well designed. If necessary, teachers can adapt them to the characteristics of their students and add additional game elements for more advanced students to challenge them.

Conclusion

This paper presents a study that investigates the effectiveness of game development-based learning for enhancing the acquisition of programming skills among first-grade students in natural sciences and mathematics gymnasiums in Croatia. The study employs the CODING4GIRLS methodology, which promotes the development of serious games in Snap! to prepare students, particularly females, for further education and future careers in computer science. During the study, the teacher and students applied C4G learning scenarios that required students to utilize programming knowledge and skills to solve real-world problems. The learning scenarios were designed to raise awareness of the relationship between ICT and the real world, covering topics of interest to both boys and girls.

The results of the study showed that the students embraced the process of developing games to solve real-world problems and were motivated to learn programming using this approach. It enabled them to achieve learning outcomes related to programming in a fun way. The teacher also provided positive feedback on the effectiveness of the approach in achieving the learning objectives related to programming. Additionally, the teacher reported that students actively engaged in the GDBL projects and were motivated to solve tasks. Therefore, the results indicate that the C4G methodology is suitable for students aged 15 and 16 years old.

A limitation of this study is the small number of research participants as well as the small number of female students in the class that was included in the study. Therefore, in future work, the research will be extended to a larger number of upper secondary schools and classes with larger number of female students. This extension will allow the effectiveness of the C4G approach to be examined on a larger sample and validate the findings of this study.

Recommendations

Based on the results of this study, it can be recommended to include GDBL activities for teaching programming classes because students find the opportunity to create their own games challenging, but also fun. They may be encouraged to finish the game by the fact that they can play it themselves or that other students can do it. GDBL activities should show students the possibility of practical application of programming skills in order to motivate them and stimulate their interest in programming. This can be achieved by designing tasks to solve real-world problems or create meaningful solutions that help them understand the importance of programming in practical contexts. Clear instructions for activities are essential for effective implementation of the GDBL approach, as is student access to all necessary materials and a supportive environment where they can enlist the help of peers or teachers when needed.

Ready-made learning scenarios offered to teachers can promote the use of effective methodological approaches. Each scenario should include clearly stated learning objectives and outcomes to assist teachers in selecting scenarios to use with their students. The variety of prepared scenarios saves teachers time and allows them to adapt teaching proces to meet the diverse needs of their students.

Girls are often less interested in education and careers in programming and ICT, so approaches like C4G should be used to engage them. Although the gap between male and female participation in these fields needs to be addressed, GDBL scenarios for teaching programming in mixed-gender classes should be designed so that the problems or topics covered are interesting to both female and male students. The effectiveness of the learning scenarios should be continuously evaluated, and based on the results and student feedback, modifications should be made to better meet student needs.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the author.

Acknowledgements and Notes

*This article was presented as an oral presentation at the International Conference on Research in Education and Social Sciences (www.icress.net) held in Budapest/Hungary on July 06-09, 2023.

*The research was co-funded by the Erasmus+ Programme of the European Union under the project „CODING4GIRLS“ (2018-1-SI01-KA201-047013) and by University of Rijeka under the project “Digital games in the context of learning, teaching, and promoting inclusive education” (uniri-drustv-18-130).

*The author would like to thank the teacher Višnja Pešut, who was involved in the presented study, for her dedicated cooperation.

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To cite this article:

Holenko-Dlab, M. (2023). Game development-based learning approach to teaching programming in upper secondary education: A case study. *The Eurasia Proceedings of Educational & Social Sciences (EPESS), 31*, 171-179.