A LARGE-SCALE PILOT STUDY ON GAME-BASED LEARNING AND BLENDED LEARNING METHODOLOGIES IN UNDERGRADUATE PROGRAMMING COURSES

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Abstract

In this paper, we present a large-scale pilot of the NEWTON project, in which both technology-enhanced learning materials and innovative pedagogical approaches are introduced into programming courses in 3 universities across Europe. This large-scale covered a 12 weeks' period, with more than 150 participants. Aiming at making the otherwise difficult and abstract programming concepts more appealing to students, we designed and developed four serious games that target different topics, namely variable declaration; loops; functions; and data structures.

In each serious game, the programming knowledge and key concepts are presented in an interactive and concrete way to stimulate students' engagement and interests in the learning process and improve their learning outcomes.

This pilot also employs student-centered pedagogy and blended learning methodology in one of the topics, i.e. the array. Instead of directly attending lecture sessions, students participate in flipped classroom, i.e., watch video lessons prepared by the lecturer through the online NEWTON project platform and prepare their questions which are then discussed in the lecture session. In the lab session afterwards, students further acquire knowledge and practice their problem solving and programming skills through working in group of three on an open-ended problem related to array. During this process, as opposed to traditional education approach where the teacher is the center of the lesson, students are taking initiatives and have more control over their learning progress.

Questionnaires covering demographic questions and affective state questions are given to participants prior to the pilot, which help us to learn their background and general attitude and motivation towards the subject. To evaluate the effectiveness of the piloted contents and methodology, pre-tests and post-tests that include several single choice questions related to the topics before and after each serious game and video content are conducted. Additionally, a usability questionnaire is employed following each game and video to measure participants' satisfaction. In this paper, the results of the aforementioned questionnaires are analyzed. The results show that the technology enhanced learning materials help to clarify abstract concepts and therefore enabling students to overcome the difficulties when learning STEM subjects. The results show that 54% of the mature students and 74% of the young students would like to use more technology in the classroom when learning STEM subjects.

Keywords: Serious game, flipped classroom, problem based learning

1 INTRODUCTION

Nowadays, science and technology not only penetrate into every aspect of human being's daily life but also deeply influence the global economy and hence define every country's competitiveness in the global market. The vast majority of the solutions proposed to solve the current societal issues such as poverty, healthcare, water supply, environment and climate change make use of technology. Therefore, there is a high demand of technology and science knowledge citizens that are able to propose, develop and apply innovative technological solutions. With the decline in the number of young generation students engaged in scientific disciplines, there is a foreseeable shortage of scientists in the near future. Most European countries are now facing a recognized crisis in this matter. As one of the key factors that contribute to the crisis, current pedagogical approaches in science, technology, engineering and mathematics (STEM) subjects urgently calls for innovations and improvements in teaching, learning and assessment process. With traditional educational approaches,

scientific subjects are perceived to be difficult by many students, and the students are often discouraged during the learning process. As response to the aforementioned concerns, the EU Horizon 2020-funded NEWTON project focuses on providing solutions that integrate innovative pedagogical learning approaches and technology enhanced learning materials in order to stimulate learners' motivation, encourage their engagement and improve learning outcomes. NEWTON Project's developed educational content is distributed through its platform - NEWTELP (NEWTON Technology Enhanced Learning Platform). NEWTELP provides courses as well as its assessment from multiple angles, such as knowledge gain, usability and affective state.

This paper presents a large-scale pilot of the NEWTON project that has been design to teach programming related modules. The pilot has run for a semester across different institutions, and entailed using technology enhanced education materials and pedagogical approaches such as educational games, flipped classroom, and combined flipped classroom and problem-based learning.

The paper shows results that assesses the learners motivation and affective state towards STEM related subjects. Among the most important findings include the fact that 54% of the mature students and 74% of the young students favour the use of more technology in the classroom when learning STEM subjects.

2 LITERATURE REVIEW

Computer programming courses are considered to be very difficult, especially for the beginners. This is due to the fact that programming is a subject that builds continuously. If a student fails to grasp a particular concept, then it can become increasingly difficult to catch up. However, programming is a very useful skill and it is fundamental in computer science education. Various research papers [1], [2], [3], [4], [5], [6], [7], [8] have reported their experiences of using technology-oriented teaching approaches when teaching STEM topics. For example, technology-oriented pedagogies such as Flipped Classroom (FC), Game-based Learning (GBL) and Problem based Learning (PBL) support student-centered learning, independent earning, actively engage students in their learning process, improve students' self-learner skill [9], and develop problem solving skills. One of the key benefits is that students are asked to study at home in advanced of the class, thus students can save their valuable class time for reinforcing content learned and clarifying any struggle they have [10]. Although this new technology-based teaching approaches have many advantages there are also many challenges to be addressed such as developing materials for both online and in-class activities, preparing lecturer own videos, game design and implementation, and there is no guarantee that students will do the assign homework.

Karaca and Ocak [11] have applied the FC approach to a computer science course on algorithms and programming, in order to evaluate its impact on students' cognitive load. The results showed that the students from the flipped group had lower cognitive load than the students from traditional face-to-face classroom. The main limitation of this study was that it was a bit narrow in scope by only looking to student's cognitive load and did not present other factors that may impact on their cognitive load.

The research work presented in [12] has investigated tutorless PBL in a large class. The results show that when a tutor is not present during the PBL sessions, the students become insecure regarding their progress towards finding the solution to the given problem and thus they become frustrated and lose motivation. It was also noticed that the group tends to have irrelevant chatting.

Educational games have been used a lot as a teaching tool in the past few years, especially due to the fact that students have become very familiarized with computer games in their everyday live. Anuradha et.al. [13] has analysed the effects of using an GBL in a programming course part of a computing diploma programme. Findings revealed that sstudents could easily relate gaming elements to difficult programming constructs and they were highly engaged in learning. Also, some students found the use of gaming elements as a better way to express their program's logic when giving oral presentations for the final assessment.

PBL is a pedagogy in which students learn by solving real-world or open-ended problems. PBL activities tend to focus on smaller scale problems for which pre-existing solutions may exist, and are usually applied within the context of a single module. PBL approach was investigated in connection with the use of LEGO Mindstorms in an introductory programming course. Results show that this approach improves students programming skills and motivates them to learn programming skills [14].

Tsai et al. [15] have conducted an evaluation study with 144 elementary school students to compare three different approaches of teaching: problem-based learning with flipped classroom (FPBL), PBL and traditional teaching. The authors collected both quantitative and qualitative data, including interviews with students and teachers' journal. The results showed that FPBL had statistically higher effect on improving students' learning performance as compared to the other two teaching methods compared.

The main conclusion that can be drawn from the literature review is that previous research studies have mostly focused on evaluating the impact of a single technology-based pedagogical method, FC, PBL or GBL versus traditional teaching and learning. While the literature review identified a study that assessed the effects of combining FC with PBL [15] that study was with elementary school students. To the best of our knowledge no previous research study has investigated the impact of combining FC, PBL and GBL with university students as this research is aiming to do.

3 METHODOLOGY

This section provides a description of the methodology applied within our research study, in particular we present the details of the pilot. This pilot is deployed in DCU and NCI during a one-semester programming course. We assess both the user experience and learning outcomes using the following technology enhanced education materials and innovative pedagogical approaches including educational games, flipped classroom (FC), and combined FC and problem based learning (PBL) project. Figure 1 and Figure 2 illustrate the schedule of the pilot activities in DCU and NCI respectively.

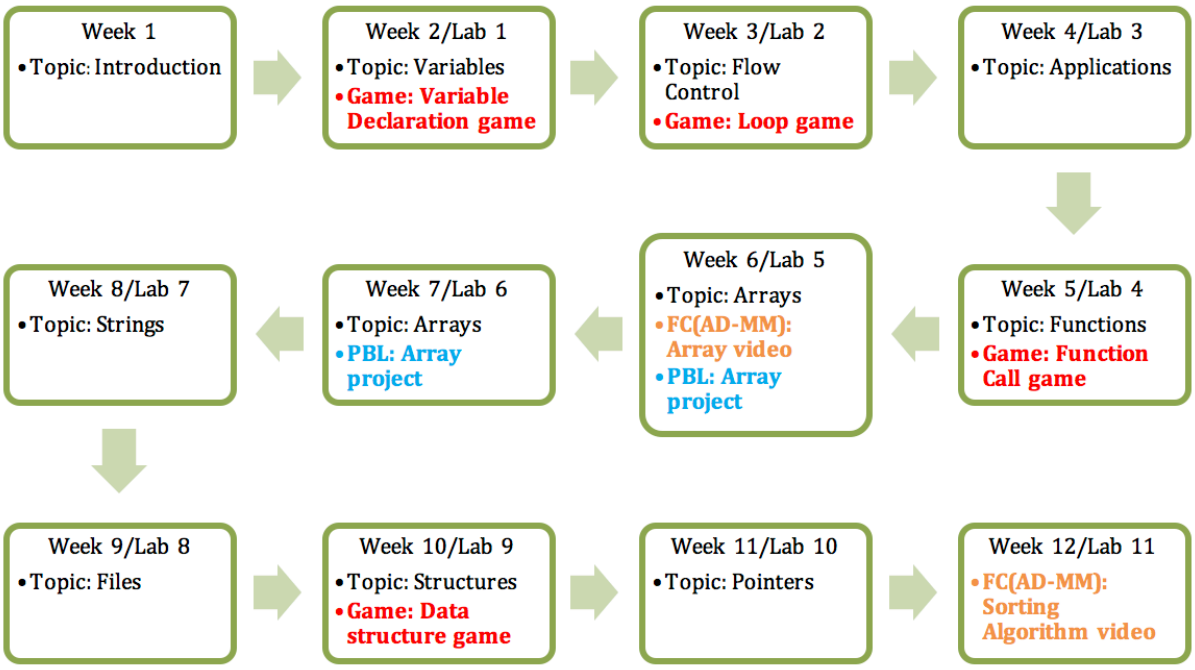

Figure 1 Programming Pilot DCU deployment schedule

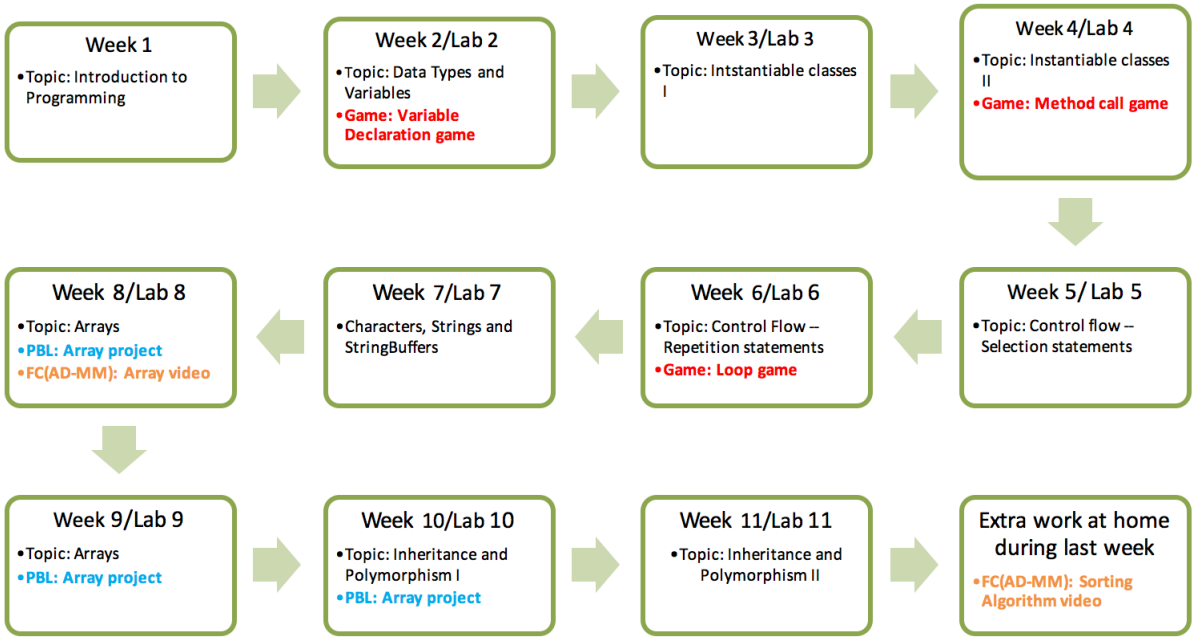

Figure 2 Programming Pilot NCI deployment schedule

During the semester, participants are exposed to a series of mini educational games developed by DCU NEWTON researchers. Each game visualizes one of the concepts/topics in the programming course and provides students interactive and fun experience during the learning process. Next we present the games used within the pilot.

Variable game – this game visualizes the concepts of primitive data types, variable declaration and type casting using a warehouse scenario. This game has two versions, as it is designed to teach these concepts for two different programming languages, namely C and Java. The computer memory is visualized by a shelf rack in a warehouse that has many spaces, each represents a 1-byte memory space. Boxes with different sizes represent different data types. The player needs to learn the size of different data types and then learn how to declare variables by allocating appropriate space in the memory, and dragging the boxes to the allocated spaces.

Function/method call game – this game visualizes the concepts of calling functions/methods and passing arguments in a firework scenario. This game has two versions as well, i.e. C and Java. In the game, there are several firework rockets, each carrying a line of code. The player needs to click the firework rocket one by one in the order that matches the execution sequence of the statements to fire the corresponding firework.

For loop game – this game visualizes the concepts and operations of the "for loop" in an underwater scenario where the player controls a mermaid to carry out tasks of collecting gems for a certain number of times. This game has 3 levels, demonstrating a basic for loop, the for loop with a "continue" statement, and the for loop with a "break" statement.

Structure game – this game visualizes the concepts of structure in C in a restaurant scenario. In this game, the player needs to design set menus, which represent structure templates in C. Then, the player will learn how to initialize structure variables through creating orders of the set menus.

The pilot also employs a combined flipped classroom (FC) and problem-based learning (PBL) pedagogical approach. The participants are given an open-ended real life problem on the topic of *arrays* and they are required to solve the problem in small groups by building on their own experiences. A video clip on the arrays concept is also provided in advanced of the class session and students are asked to watch it. During class time the students have the opportunity to ask questions, and then they have to solve the problems within their groups.

The aim of the study is to assess the benefits of the technology enhanced teaching materials and innovative pedagogical approaches on participants' learning experiences and learning outcomes. This is done through questionnaires, pre-tests and post-tests throughout the pilot duration. Table 1

summarizes the structure of the assessments used for the duration of the pilot based on the type of pedagogical approach used.

Table 1 Pedagogical approaches and type of assessments used within the programming pilot

When?	Pedagogy Method	Assessment Type
Before pilot starts		• Learner Demographic Questionnaire • Motivation and affective state questionnaire (pre)
During pilot	Serious game	• Pre-test • Post-test • Game experience questionnaire
	Flipped classroom	• Pre-test • Post-test • Questionnaire
	Combined flipped classroom and problem-based learning project	• Pre-test • Post-test • Questionnaire
After pilot ends		• Motivation and affective state questionnaire (post) • Platform usability questionnaire

4 RESULTS

In this section we discuss and analyse the results obtained from the surveys, namely the motivation and affective state questionnaires, taken by the students prior to the beginning of the pilot, and after the pilot has ended. The main aim is to assess whether the technology enhanced pedagogies help to engage students with STEM related subjects. As the two courses taught at DCU and NCI have a different students demographic namely young students and mature students respectively, we will present the results for each cohort of students separately.

4.1 DCU results

From the demographic questionnaire and the affective state and motivation questionnaire, we gathered data about students' background and their general attitude towards STEM lessons. Among the participants in DCU, 77% are male while 23% are female. Most of them are between 17 to 20 years old. Over 60% students claimed they obtained good marks in STEM subjects sometimes and 14% claimed they always obtained good marks in STEM subjects. Over 85% of students like/love learning STEM subjects. More than half of the students believed they have above average gaming skills. Around 50% of students had experienced serious games before the pilot. When asked why they chose the programming course, the majority of students selected either *"because I love science, technology and maths"* or *"because I believe I have good career prospects"*. More than 50% students expressed they are very interested in STEM subjects and 29% claimed they are somewhat interested. 40% students found STEM subjects difficult to learn. The results of several questions regarding students' general attitude towards STEM subjects are summarized in Figure 3.

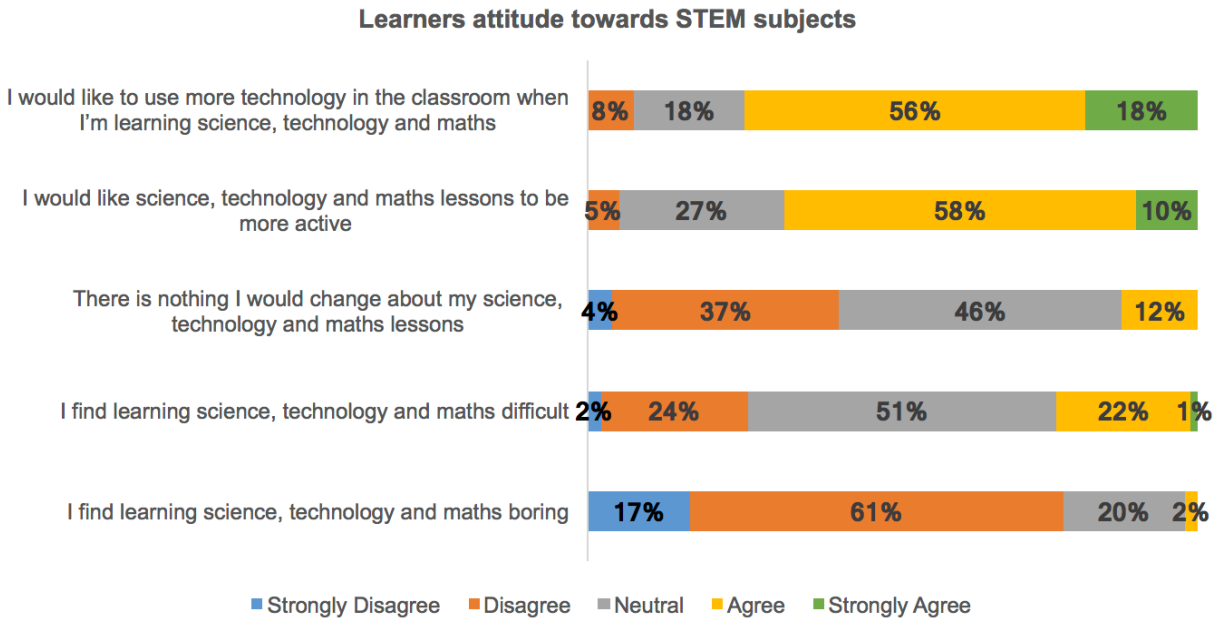

Figure 3 Part of results of demographic questionnaire in DCU

In summary, before the pilot started, most participants in DCU showed interests in STEM subjects as they mostly chose the programming module out of interests and longing for bright future. However, there are still a significant portion of students found learning STEM subjects difficult. This fact is also justified by the high failing rates in the same module in previous years.

According to the results of questionnaires after the pilot has run, 50% of students enjoyed learning programming with NEWTON while only 17% did not enjoyed. 45% students agree or strongly agree that learning programming with NEWTON was really interesting while only 17% disagree. More than 42% of students felt really positive about learning programming with NEWTON while another 39% kept a neutral opinion. 31% of students felt the NEWTON Platform helps me be more effective in a science class. 56% of students liked the PBL project the most while 35% liked serious games the most.

4.2 NCI results

In this section, we present findings from the demographic, and learner motivation and affective state questionnaires with a focus on the general attitude towards STEM subjects. The students who took part in this case study are mature students, namely students over 25 years old. The students are 65% male and 35% female. As these are mature students we wanted to assess the students prior experience with STEM subjects. 62% of the students mentioned that sometimes they obtained good marks in STEM subjects, while 38% of students mentioned that they obtained average marks in STEM subjects. The students seem to be inclined towards learning STEM subjects, with the majority answering that they like or love to learn STEM topics, namely 77% and 15% respectively.

As game-based learning is one of the pedagogical approaches used within this pilot we also wanted to investigate the students' prior experience with gaming. 31% of students believe that they have very good gaming skills. It is worth mentioning that 31% of students have played a serious game prior to studying the programming module.

Most of the students (i.e. 85%) chose to study the course because they believe they *"have good career prospects"*, while the other students chose the course because they "*love science, technology and maths".* Although 85% of students mentioned that they are either very interested or extremely interested in STEM subjects, it seems that many of them find STEM subjects difficult to learn with 50% agreeing or strongly agreeing about the challenges of learning such subjects.

Figure 4 presents a summary of selected questions that reflects the students attitude towards STEM subjects. The results show that 54% of students would like to employ more technology in the classroom when learning STEM subjects.

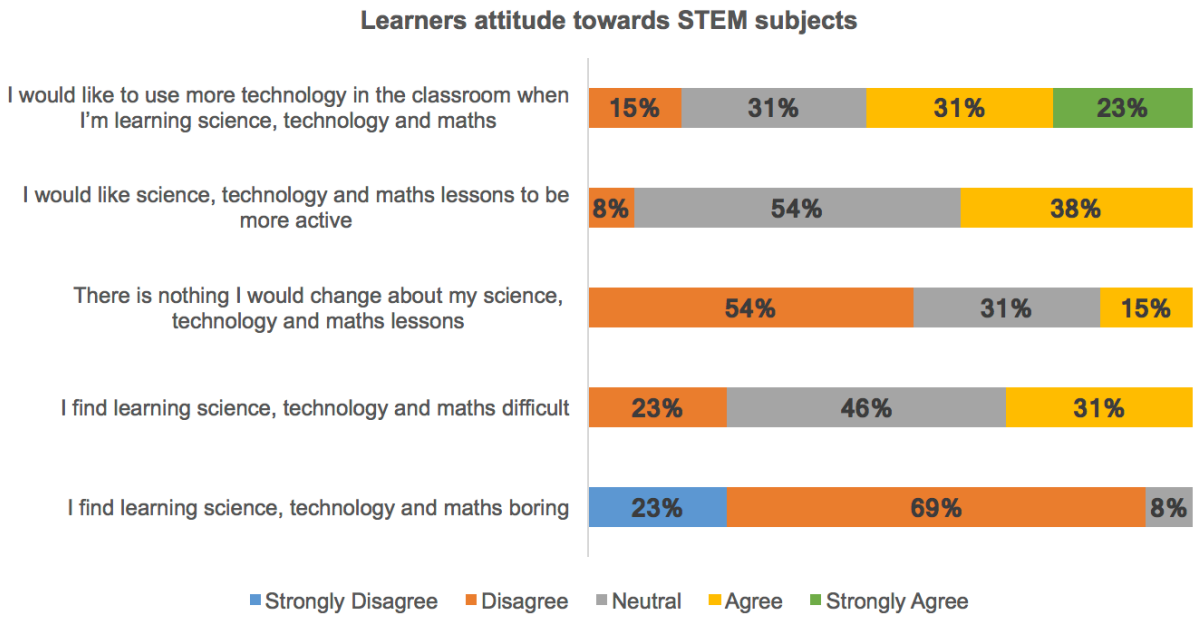

Figure 4 Part of results of demographic questionnaire in NCI

The results of the questionnaires taken by the students after the pilot has ended show that 40% of students enjoyed learning programming with NEWTON, while 10% did not enjoy. Furthermore, 40% of students stated that learning programming with NEWTON was really interesting, while 60% had a neutral opinion. Similarly, 40% of students felt really positive about learning programming with NEWTON, while the other students expressed a neutral opinion.

We can conclude that, the results of the surveys taken by the students prior to the beginning of the pilot show that the students are interested in STEM subjects. However, some of the students encounter challenges when learning STEM subjects. It is worth mentioning that 54% of students would like to use more technology in the classroom when learning STEM subjects. Technology enhanced learning materials would help to clarify abstract concepts and therefore enabling students to overcome the difficulties when learning STEM subjects.

5 CONCLUSIONS

In this paper, we introduce a large-scale pilot of the NEWTON project that employs innovative pedagogical methods with the aim to teach programming related modules. The pilot was conducted for a semester, 12 weeks period, across different institutions, and entailed using technology enhanced education materials and pedagogical approaches such as educational games, flipped classroom, and combined flipped classroom and problem-based learning. During the pilot have been used different type of assessments such as questionnaires, pre-tests, post-tests, and team-based project.

The paper shows results that assesses the students' motivation and affective state towards STEM related subjects. Overall, the results show that although the students are interested in STEM subjects, some of them encounter challenges when trying to learn such subjects. It is worth mentioning that the results show that the technology enhanced learning materials help to clarify abstract concepts and therefore enabling students to overcome the difficulties when learning STEM subjects. The results show that 54% of the mature students and 74% of the young students would like to use more technology in the classroom when learning STEM subjects.

In future work we will assess the effectiveness and edutainment aspects of using a game-based learning approach for programming concepts. Also, we will investigate whether the effectiveness and benefits of using the different teaching approaches mentioned in this paper varies across different students' demographic (i.e. young vs. mature students).

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