IMPROVING LEARNING OUTCOME USING THE NEWTON LOOP GAME: A SERIOUS GAME TARGETING ITERATION IN JAVA PROGRAMMING COURSE

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Abstract

In recent years, the world economy experienced rapid expansion of ICT sector, with large a number of positions made available in the job market every year. However, many European countries are suffering from a declined number of students who choose STEM subjects as their future careers. While there are multiple underlying causes, the fact that traditional teaching approaches often fail to deliver STEM knowledge in an easy-to-accept manner, which resulted in poor learning outcomes and hence discouraged students, has its fair share in such crisis. To address such challenge, educators have been experimenting utilizing technology-enhanced learning materials and innovative teaching approaches lately. In this paper, we present a 2D serious game developed for Java Programming, i.e., the NEWTON Loop Game, which targets third-level education. To evaluate the effectiveness of the game in improving students' learning outcomes, a case study was conducted in National College of Ireland. Before the case study started, all participants answered a *Demographic questionnaire*. During the case study, participants were asked to take a pre-test and a post-test before and after their interaction with the game to assess their knowledge level. In total, we obtained valid results from 31 students for the Loop game. Overall, there is a statistically significant improvement in learning outcomes before (average score 1.29/3) and after (average score 2.12/3) the game. Based on participants' answers to certain questions of the Demographic questionnaire, they were further divided into different subgroups in terms of educational ability, attitude towards university, initial attitude towards learning STEM, and gender. Considering different gender subgroups, the male group achieved statistically improved learning outcome, whereas the female group achieved an improvement which was not statistically significant. For different prior educational ability subgroups, statistically significant improved learning outcomes were observed in the "good mark" group of students while the "average mark" group only obtained improved learning outcome that was not statistically significant. Considering the attitude to school, the "love/like school" group of students achieved a statistically significant improved learning outcome, whereas the "school is OK" group obtained improved learning outcome that was not statistically significant. Regarding the initial attitude towards STEM, statistically significant improved learning outcomes were observed in both the "love/like learning STEM" student group and the "learning STEM is OK" group.

Keywords: serious game, technology-enhanced learning, STEM education, Java, Programming.

1 INTRODUCTION

The rapid growth in the ICT sector worldwide experienced in the past decade brought about huge economic profits and many vacancies in job markets [1]. Despite the overall relative demand, the education of STEM subjects in many countries is facing challenges as traditional teaching approaches often fail to deliver STEM knowledge in an easy-to-understand way. Such challenges would result in many unfilled vacancies in the ICT job markets in the near future [2]. Recently, researchers and educators have begun to introduce various innovative teaching approaches into STEM subject education as part of the effort to address the above challenge.

The NEWTON project[1] is an EU Horizon 2020[2]-funded project whose main objectives include building a networked platform to facilitate integration and dissemination of many technology-enhanced learning

[1] http://www.newtonproject.eu/

[2] http://ec.europa.eu/programmes/horizon2020/

(TEL) materials and innovative learning approaches. NEWTON also investigates the impact of using various forms TEL materials, such as serious games [3, 4], virtual labs [5, 20], fabrication labs [6], virtual reality, adaptive multimedia and multisemedia [7, 8, 23, 24] and innovative learning approaches, such as game-based learning, problem-based learning and flipped classroom [19, 21], on students' learning outcome and affective states. The targeted STEM subjects were deployed in various education stages.

In this paper, we present the Loop game, a third-level 2D serious game developed for a Java programming module, as part of the NEWTON project Programming large-scale pilot presented in [22]. This game conveys the key knowledge points related to the loop concepts in general, and in particular the iteration of a loop, including basic *for* loop, *for* loop with the *continue* statement, and *for* loop with the *break* statement, deployed in an interactive undersea world scenario. To investigate the impact of the game on students' learning outcome, the game was deployed during the H8SDEV Software Development module at National College of Ireland, in 2018. In this pilot, we have attracted mostly mature students (i.e., over 25 years old) with various educational backgrounds, including non-engineering/computer science. Before the pilot started, a demographic questionnaire was conducted. During the analysis of the results, based on the demographic questionnaire, the students were grouped into different subgroups according to their gender, prior educational ability, initial attitude towards school and initial attitude towards STEM subjects.

2 LITERATURE REVIEW

Educational games or game-based learning (GBL) is a technology-advanced innovative pedagogical approach introduced in both formal and informal education for teaching computer programming learning worldwide [9]. Computer games are considered promising for strengthening common understanding of computer programming education [10], and for supporting and motivating teachers to teach and students to learn abstract and complicated programming concepts difficult to be taught and assimilated in enjoyable classroom-related exercises.

As university students seem to fall short of previous experience in using programming concepts and exercising programming skills and a vast amount of time is needed to bridge the gap between computer programming theory and practice, with students indicating decreased motivation and interest in learning programming [11], computer games are regarded appropriate for dealing with the above challenges met by both programming students and lecturers alike. Either when designing or playing computer games (also described as "serious games") [12 p. 1991], the interactive game-based learning context applied becomes an active student-centered one, building upon "experiential learning" [13 p. 17] (i.e. head-on involvement, constant feedback and reflective consideration) and therefore, more engaging and motivational in captivating and keeping students stay in learning programming courses [14]. Notwithstanding the plethora of game-based learning environments deployed either as educational or industry-oriented ones, fewer studies have been reported as to evaluate whether computer or serious games tend to support or improve higher education computer programming learning in effect [15], as reported next.

Liu, Cheng and Huang [16] developed and tested a mockup game for computer programming university students. In assessing the participants' learning attitudes during their gameplay experience, they indicated that those reported as of being engaged with the game, they developed themselves and applied real-time problem-solving, while their peers who seemed not to perceive the game as motivational for programming learning, did not use deep and real-time problem-solving strategies during their play with the game. Muratet et al. [17] designed an actual-time strategy game for usage in preliminary computer programming context which is played by multiple players. In evaluating this game as a learning experience, undergraduate computer science students indicated positive attitudes towards the game in terms of perceiving it as engaging, while lecturers demonstrated negative views based on perceiving the specific game as of potentially confining computer science education learning experience to video games only. Malliarakis, Satratzemi and Xinogalos [18] report on 3 serious games for teaching computer programming in the same university computer science department, as follows: The first game aimed at instructing computer science degree students- by playing the role of a "wizard"- in answering questions related to variables and if-statements and loops concepts (p. 220). In two different sessions, 13 and 8 students prior basic computer programming skills, respectively, evaluated in 2 different sessions the game as fun, helpful, engaging and captivating. The second game involved the students as players to act as "heroes" to save the protagonist-princess from the monster who had kidnapped her by completing certain code exercises in diverse game levels corresponding to recursion and if-statements (p. 220). 13 and 8 students of different programming knowledge background appraised the game as absorbing and pedagogic, but they suggested further application database improvement in favour of the game's mechanics. Finally, the third game aimed at recursion and algorithm usage (p. 220) through the moving of the main character across several game levels to accomplish the designated missions. 43 students having previously attended the university's databases and algorithms module played the game and indicated that they would like to be taught even more complicated programming concepts through serious games.

The aforementioned overview of empirical evidence indicates that the majority of prior studies on game-based learning seem to explore motivation and learning effectiveness of diverse computer science or programming concepts, bearing contradictory findings. In that respect, the application of game-based learning in teaching programming concepts across different curricular courses in tertiary education within various country settings, needs to be further explored.

3 THE NEWTON LOOP GAME

The NEWTON Loop Game was developed to help students understand concepts and operations of *loops* in Java Programming. This 3-level 2D serious game, as illustrated in Figure 1, utilizes a vivid undersea scenario to deliver key knowledge points on loops. The game introduces the concepts incrementally, each level of the game building on top of the previously used concepts, and it entails the basic *for loop*, a *for loop* with a *continue* statement, and a *for loop* with a *break* statement.

Figure 1 Screenshots of the NEWTON Loop Game

Level 1 presents the basic *for loop*. The player is asked to control the movement of a mermaid character to carry out a repetitive task of swimming to a coin, collecting a coin, and then storing the collected coin into the treasure chest. The loop iterates 5 times. The corresponding codes, which refresh and update with the movement of the mermaid, are displayed on the aqua bubble on the left-hand side of the screen.

Level 2 covers the concept of a *for loop* with a *continue* statement. The player (mermaid) is asked to perform similar tasks as in Level 1, however, some of the coins would disappear upon collection. Whenever such coins are encountered, the player would skip the remaining steps of carrying the coin to the treasure chest to store it, and instead would directly "continue" to the next iteration of the loop.

Level 3 introduces the *for loop* with a *break* statement. This time, while the player carries out the usual repetitive tasks of coin collection, one of the coins would turn into a big jackpot upon touch by the player. When this happens, the task will terminate immediately, with all the remaining repetitions abandoned.

4 CASE STUDY AND RESULTS

In this section, we present a case study to evaluate the impacts of the NEWTON Loop Game on students' knowledge gain.

4.1 Research Methodology

This case study was deployed at National College of Ireland, within the H8SDEV Software Development module in Spring 2018. It is part of the NEWTON Programming Large-Scale pilot [22] which investigate the impacts of various NEWTON technologies in 3 universities across Ireland and Slovakia. The game, as well as associated evaluation was conducted during the class time session, under the supervision of the llecturerr. 31 students participated in this study. The majority of them are mature students, i.e., students aged over 25 years old. The students were from various prior education backgrounds, including computer science/engineering, humanity, education, and others.

Before the pilot started, students were asked to fill in a Demographic questionnaire. Based on students' answers to a few selected questions of this questionnaire, we group students into different subgroups, covering different angles of analysis such as educational ability, attitude to school, attitude towards learning STEM, and gender.

For educational ability, students are divided into *"good mark group"*, *"average mark group"* and *"low mark group"* according to their answers to the question *"Do you get good marks in science, technology and maths?"*. The *"good mark group"* includes students who selected *"yes, always"* or *"yes, sometimes"*; *"average mark group"* includes students who answered with *"average marks";* while *"low mark group"* includes students who answered *"low marks"* or *"terrible marks"*.

For attitude to university, students are divided into *"love/like university"*, *"university is OK"* and *"don't like university"* according to their answers to the question *"How do you feel about university?"*. The *"love/like university"* includes students who selected *"I love it"* or *"I like it"*; *"university is OK" group* includes students who answered *"It's OK";* while *"don't like university"* group includes students who answered *"I don't like it" or "I don't like it at all"*.

For attitude towards learning STEM, students are divided into the following three groups *"love/like learning STEM"*, *"learning STEM is OK"* and *"don't like learning STEM"* according to their answers to the question *"How do you feel about learning science, technology and maths?"*. The *"love/like learning STEM"* includes students who selected *"I love it"* or *"I like it"*; the *"learning STEM is OK"* group includes students who answered with *"It's OK"*; while *"don't like learning STEM"* includes students who answered *"I don't like it"* or *"I don't like it at all"*.

During the case study, before and after participants' interactions with the game, a pre-test and a post-test were conducted, respectively, to assess their knowledge levels. Each test includes 3 single choice questions. The questions of the pre- and post-tests are different but target similar learning outcomes (i.e. knowledge points), as covered in the game.

4.2 Results Analysis

In this subsection, the average scores of the pre- and post-tests for all students, as well as for students belonging to different subgroups (as identified by their answers to the demographic questionnaire) are compared, with paired-sample t-tests conducted to investigate whether the changes are statistically significant.

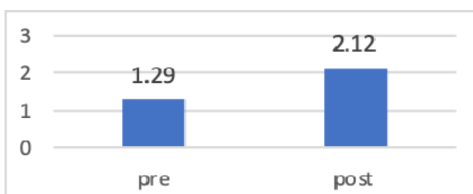

Figure 2 Comparison of average pre- and post-tests score of all students

Figure 2 illustrates the average score of all students in the pre- and post-tests of the Loop Game. The average score improved from 1.29 (out of 3) in pre-test to 2.12 (out of 3) in post-test. A paired-sample t-test confirmed that such improvement is statistically significant at α=0.05 significance level ($t(33) = 4.311$, $p = .000$).

Figure 3 shows the average pre- and post-test scores of students belonging to different educational ability groups. It is worth noting that there was only one student who belongs to the "low mark" group, who got 0 in pre-test and 3 in post-test. The "low mark" group is thus not included in the figure because of its small sample size. The "average-mark" group (N=10) achieved improved average score from 1.3 (out of 3) in pre-test to 2 (out of 3) in post-test. However, a paired-sample t-test indicates that such improvement is not statistically significant at α=0.05 significance level ($t(9) = 2.09$, $p = .066$). The "good mark" group (N=20) achieved improved average score from 1.35 (out of 3) in pre-test to 2.05

(out of 3) in post-test. A paired-sample t-test confirms such improvement is statistically significant at α=0.05 significance level ($t(19) = 2.774$, $p = .012$).

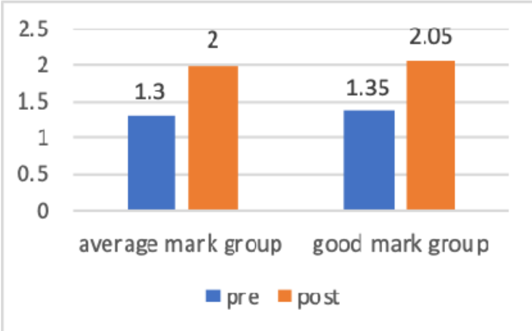

Figure 3 Comparison of average pre- and post-tests score in different educational ability groups

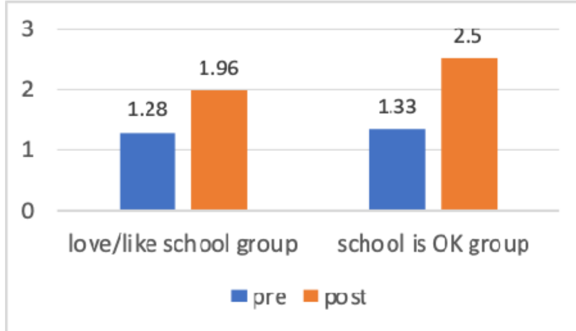

Figure 4 Comparison of average pre- and post-tests score in different attitude-towards-school groups

Figure 4 shows the average pre- and post-test scores of students belonging to different attitude-towards-university groups. The “love/like-university” group (N=25) achieved improved average score from 1.28 (out of 3) in pre-test to 1.96 (out of 3) in post-test. Such improvement is proved to be statistically significant at α=0.05 significance level by a paired-sample t-test ($t(24) = 2.971$, $p = .007$). The “university-is-OK” group (N=6) achieved improved average score from 1.33 (out of 3) in pre-test to 2.5 (out of 3) in post-test. However, a paired-sample t-test indicates such improvement is not statistically significant at α=0.05 significance level ($t(5) = 2.445$, $p = .058$). There was no student in the “don’t like university” group.

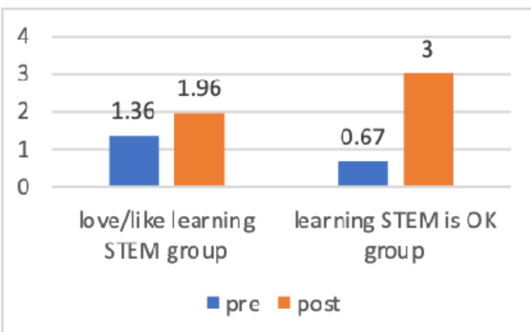

Figure 5 Comparison of average pre- and post-tests score in different initial-attitude-to-learning-STEM groups

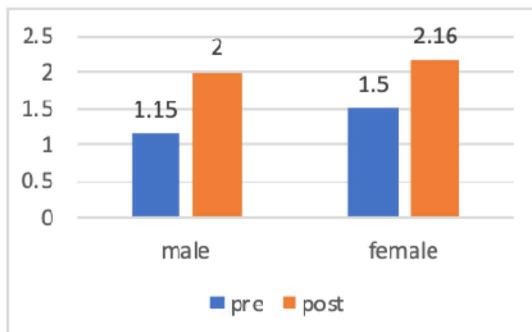

Figure 6 Comparison of average pre- and post-tests score in different gender groups

Figure 5 presents the average pre- and post-tests scores of students belonging to different initial-attitude-to-learning-STEM groups. The “love/like learning STEM” group (N=28) achieved improved average score from 1.36 (out of 3) in pre-test to 1.96 (out of 3) in post-test. Such improvement is proved to be statistically significant at α=0.05 significance level by a paired-sample t-test ($t(27) = 3.014$, $p = .006$). The “learning STEM is OK” group (N=3) achieved improved average score from 0.67 (out of 3) in pre-test to 3 (out of 3) in post-test. A paired-sample t-test certified such improvement is statistically significant at α=0.05 significance level ($t(2) = 7$, $p = .02$). There was no in the “don’t like learning STEM” group.

Figure 5The average pre- and post-tests scores of students belonging to different gender groups are illustrated in Figure 6. The male group (N=19) achieved improved average score from 1.15 (out of 3) in pre-test to 2 (out of 3) in post-test. Such improvement is proved to be statistically significant at α=0.05 significance level by a paired-sample t-test ($t(18) = 3.281$, $p = .004$). The female group (N=12) achieved improved average score from 1.5 (out of 3) in pre-test to 2.16 (out of 3) in post-test. However, a paired-sample t-test shows such improvement is not statistically significant at α=0.05 significance level ($t(11) = 1.876$, $p = .087$).

Table 1 Summary of comparison between average pre- and post-tests scores in different subgroups

Grouping angle	Subgroup	N	Average score		t	df	Sig. (2-tailed)	Is statistically significant?
			pre	post				
Educational ability	average-mark	10	1.3	2	2.09	9	0.066	no
	good-mark	20	1.35	2.05	2.774	19	0.012	yes
Attitude towards university	love/like-university	25	1.28	1.96	2.971	24	0.007	yes
	university-is-OK	6	1.33	2.5	2.445	5	0.058	no
Initial attitude to learning STEM	love/like-learning-STEM	28	1.36	1.96	3.014	27	0.006	yes
	learning-STEM-is-OK	3	0.67	3	7	2	0.02	yes
Gender	male	19	1.15	2	3.281	18	0.004	yes
	female	12	1.5	2.16	1.876	11	0.087	no

Table 1 presents the summary of comparison of pre- and post-tests average scores of students belonging to different subgroups. As can be seen, all subgroups had improved learning outcomes after playing the educational game. Out of the 8 subgroups, 5 subgroups (i.e., good-mark group, love/like-university group, love/like-learning-STEM group, learning-STEM-is-OK group, and male group) achieved statistically significant improvements.

5 CONCLUSIONS

In this paper, we presented a case study of the impacts of a Java Programming serious game, i.e., the NEWTON Loop Game, on students' learning outcomes in third-level education. The case study was conducted at National College of Ireland, where 31 participants experienced the educational game and answered pre- and post- knowledge tests during a Software Development class in 2018. To assist with the evaluation of the results and the effectiveness of the educational game, before the case study started, participants filled in a Demographic questionnaire, based on which they were divided into different subgroups for different angles of analysis. Considering all students, the result shows that there was a statistically significant improvement in the average score from pre-test to post-test. Considering students belonging to different educational ability subgroups, attitude towards university subgroups, attitude to learning STEM subgroups, and gender subgroups, 5 subgroups (i.e., good-mark group, love/like-university group, love/like-learning-STEM group, learning-STEM-is-OK group, and male group) achieved statistically significant improvements in post-test average scores, compared to the results obtained in theof pre-test. Therefore, the results of this case study show that the educational games help students in understanding complex and abstract concepts in programming and enhance their learning outcomes.

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