OneUp: Engaging Students in a Gamified Data Structures Course

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ABSTRACT

Although many CS courses require extensive practice, a large number of students show low motivation for engaging in non-graded, self-directed learning activities. To address this problem, we developed OneUp - a highly configurable course gamification platform that enables instructors to tailor the gamification features to fit their preferences. This paper presents a case study of using OneUp to gamify a Data Structures course. The focus is on encouraging students' self-study and better engagement with out-of-class online practicing. We describe the utilized game elements - badges, leaderboard, virtual currency, and learning dashboards, and provide a descriptive analysis of their use. The results of our evaluation show that this gamification intervention has been well received by the students, resulting in significantly increased student engagement and out-of-class practicing and in a reduced failing rate.

CCS CONCEPTS

• **Applied Computing → Interactive Learning Environments**

KEYWORDS

Active learning, gamification, out-of-class study, Data Structures

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1 INTRODUCTION

Student engagement and motivation in computing courses, especially at the lower level, is a commonly recognized problem [1]. Many of the courses are focused on skill development, where students are not merely memorizing concepts and principles, but applying them to solve everyday life problems. Central to the notion of skill-based learning is the notion of practice. For developing needed skills, learners need to spend significant time engaged in practicing problem solving and developing subject-related skills in a variety of hands-on scenarios

The majority of available educational tools for practicing are crafted to support skill development through self-study, which makes it hard to mandate and control their use. Self-study tools typically support recommended content/activities and as such, their use rarely counts towards the final grade, which results in a low usage [2]. Thus, although freely available, practicing problems that accompany self-assessment tools are rarely fully utilized. Our approach to ameliorating this problem is through increasing students' motivation by employing gamification. Gamification, the use of game design elements in non-game contexts [3], has attracted the interest of educators with its promises to foster motivation and behavioral changes in learning contexts, but there is a lack of appropriate tools to support instructors in gamifying their courses [4]. To bridge this gap we developed the OneUp Learning platform [5], which is aimed at facilitating the process of gamifying academic courses and enabling tailoring of the gamification features to meet the vision of the course instructor. To the best of our knowledge, it is the first highly configurable platform for gamifying courses. Our first evaluation of the OneUp platform was in a study to gamify a Data Structures course. In this study we aimed to address the following questions:

RQ1: Does gamification encourage out-of-class practice?

RQ2: Does gamification improve grades?

RQ3: What is students' perception of the usefulness of the gamification platform and their engagement with it?

The rest of the paper is organized as follows: Section 2 describes briefly the OneUp platform and Section 3 discusses the experiment for using it to gamify a Data Structures course. In Section 4 we present the results of the study and in Section 5 we introduce the related work. Section 6 concludes the paper.

2 THE ONEUP PLATFORM

The course gamification platform OneUp Learning (OneUp for short) supports the use of established game design principles and elements in the organization of academic courses. Being focused on skill development, it supports practicing, self-assessment, and testing particular skills. The system is described in [5], and here we only summarize its features. The main functionality of OneUp includes: (1) Support for instructors to incorporate game design principles and mechanics in the instructional methods they use in their course; (2) Support for creation and automatic checking of static and dynamic problems, and (3) Learning analytics and

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visualization to inform students and instructors of student performance and progress throughout the course.

2.1 ONEUP Gamification Features

OneUp can be viewed as a gamified Course Management System (CMS) that allows the instructor to enter assignments, practice exercises, and quizzes/tests and connect game elements to them by specifying appropriate rules. The gaming rules define under what conditions (based on activities, challenges, and skills) specific game elements will be applied. The following game elements are currently supported: points (skill points, challenge points, and activity points), avatars, badges, leaderboards, and virtual currency, along with immediate feedback and freedom to fail. The instructor selects the game elements at the time of creating and configuring the course in OneUp. A user-friendly graphical interface enables easy creating of badges and virtual currency rules. All elements of the framework - the targeted skills, learning content, activities, tests/quizzes, game design elements, and relations between them are configurable. Any game element can be turned on and off to fit the instructor's preferences. In addition, the instructor can enable the students to turn off some game features if found undesirable.

2.2 Practice Support

The OneUp adopted vocabulary reflects the game terminology: the learning objectives are skills, the tests and quizzes are challenges, and the questions included in them are problems. OneUp supports two types of automatically graded challenges: warm-up challenges (for student practice and self-assessment) and serious challenges (graded quizzes and tests). Instructors define the challenges and for each problem in a challenge, specify the challenge points earnable from that problem. The instructor could also specify skill points, which indicate how the problem contributes to increasing the level of student mastery of related course skills. Two types of problems are supported: static and dynamic. Static are problems for which the correct solution is given at the time of entering them in the system. These include multiple-choice questions, multiple answer questions, true/false questions, fill-in-the-blank questions, and matching questions. Dynamic problems are short computer programs, which use a random seed to generate a unique instance of a particular programming or calculating problem and then grade the correctness of the answer submitted for that problem.

2.3 Feedback and Learning Analytics

Feedback is provided to the students in a number of ways. At the problem level, the student gets feedback on their entered solution as specified by the instructor at the time of creation of the challenge. If the instructor specifies the course topical structure during the course configuration, the topics are used for grouping the displayed warm-up challenges. For each topic, the students see summarized information about their practicing performance on that topic – a row of colored squares indicating the score on each challenge: green ('You've got it!'), blue ('Getting there'), red ('Needs improvement'), and white ('Not attempted').

At the course level, students can see aggregated information about their performance in their personal learning analytics dashboard. This dashboard displays student experience points (XP), practice points (collected and possible), and course bucks they have earned so far. A central piece in the dashboard is the progress bar, which consists of four parts displayed in different colors: the course points earned so far (purple), the amount of course points that can be earned in the future (yellow), the amount of points already lost (red), and the learning predictor - the total amount of points that would be earned in this course if the student keeps the same level of performance in the course (black). The dashboard also shows the skill analytics and the student's results of taking serious challenges and warm-up challenges. Finally, it displays all badges earned by the learner. The instructors can see students' individual learning dashboards. In addition, they are presented with a grade book, visualizations of the class results on warm-up and serious challenges, and an instructor dashboard that summarizes students' engagement and outcomes: serious challenge points, activity points, number of warm-up challenges taken, earned virtual currency, and timestamp of the last action.

2.4 Social Comparison

OneUp supports social comparison in two ways. Firstly, for each of the performance indicators in the student individual learning dashboard there is an option for displaying the class average as well. Secondly, the course dashboard, which is shown on the main course website contains a leaderboard (XP ranking), skill ranking, and latest awarded badges to students from this course. The instructor can configure which of these to be shown and give the students the right to show/hide any of them on their own display.

3 CASE STUDY: GAMIFYING A DATA STRUCTURES COURSE

In this study we decided to use OneUp as both an online practice system and a gamified framework for maintaining information not only about student practicing but also about student overall course engagement and performance. We used OneUp in addition to the Blackboard CMS system. The instructor posted the course slides and assignments on Blackboard, however all grades were also entered in OneUp, so that students can benefit from the gamification intervention. Student usage of OneUp was voluntary. The goal of the study was to evaluate whether gamification would increase student motivation and course engagement, in particular, for out-of-class practicing, which is critically important for learning in STEM disciplines.

The preparation for gamifying the Data Structures course consisted of two parts: creating warm-up challenges for student practicing and configuring the course in the OneUp platform.

3.1 Challenges and Problems

We created 64 warm-up challenges with a total of 290 problems. The challenge distribution by topic is as follows: Java Classes (review) - 3, Recursion - 2, Bags - 14, Stacks - 14, Queues - 11, Lists - 12, and Trees - 5. Of the problems, 152 are multiple-choice,

9 multiple answers, 4 matching, 83 true/false questions, and 42 are dynamic problems. We created three types of dynamic problems:

1. Dynamic problems asking what would be the content of a particular data structure after applying a series of add/delete/view operations on it. For those, we modeled the specific data structure and generated random sequences of statements.
2. Dynamic problems for traversing a tree.
3. Programming problems. These required supporting code for running the student program and a testing program.

3.2 Gamification Features

In the gamified Data Structures Course we used all gamification features supported by the OneUp platform. Accordingly, the students could create avatars, earn badges, earn virtual currency and spend it in the Course Shop, check their performance on their private learning dashboard and the class performance on the course dashboard. Moreover, they were enabled to select the gamification features they wanted to see and whether to have the class average for the performance matrixes displayed on their dashboard.

The rewards in the gamified course were in the form of badges and virtual currency (VC), which students could earn and spend based on rules specified by the instructor. We decided to use badges primarily to reward students for their performance and to use virtual currency mainly to reward their course engagement and efforts to learn, including practicing, attending classes, etc.

The instructor created the badges and VC rules in the OneUp instructor's interface. Table 1 shows some of the badge categories, and Table 2 - some earning and spending rules defined in OneUp.

Table 1: Sample Badge Categories Used in the Course

	*Game Changer* (Level 1, 2, 3): the difference of student's percent score of an assignment with the previous one is between 10% - 19% for Level 1, 20% - 29% for Level 2, and > 30% for Level 3
	*Highest Score for Assignment*
	*Perfect Score on Test*
	*Persistent Practice* (Level 1, 2, 3): completes 5 distinct warm-up challenges for Level 1, 20 for level 2, and 40 for Level 3.

Badges did not affect the course grade in any way but they served as a recognition with social effect [6], since they were displayed on the class leaderboard. Differently from the badges, the virtual currency could affect the course grades directly or indirectly, depending on the rules selected by the instructor. Examples of the former are buying some extra credit points for a specific homework or buying credit for one problem on a test. Examples for the latter are requesting a deadline extension or a resubmission of a homework. The idea here is to stimulate students to practice more for earning more 'course bucks' by incentivizing them with purchasable course related 'benefit'. This way the virtual currency offers a strategy for encouraging persistent practicing and an alternative method for rewarding student learning.

Table 2: Examples of Earning and Spending Rules

Earning Rules	
Condition	*VC*
First taking of a warmup challenge with a score > 80%	5
Taking a new warmup challenge with a score > 75%	1
Submitting an assignment 2 days before the due date	1
Attending 5 consecutive classes	1
Spending Rules	
Condition	*VC*
Buy 5 extra credit points for an assignment	10
Buy a 15-min extension of the time for a test	5
Get 1 different problem on a test	10
Buy another attempt (re-submission) for an assignment	10

3.3 Research Method

The CSC 2331 Data Structures course is offered each semester hence the enrollment is not high. Therefore, we conducted a quasi-experiment [7]: we used the fall 2017 class (16 students) as a control group and the spring 2018 class (11 students) as an experimental group. The same instructor taught both classes using the same instructional materials, teaching methodology, and student assessment. Both groups used the OneUp platform for out-of-class learning and practicing, but for the experimental group all gamification features were activated, while for the control group they were disabled. All students in both groups signed an Informed Consent Form to participate in the study.

To answer the research questions we used two complimentary methods. For the first two (R1 and R2), we used the OneUp system log to extract data for tracking student visits to the gamification-related pages, how many practice quizzes they have completed, etc. We also used student final course grades to evaluate the impact of gamifying the course on students' academic performance. To answer the third research question (R3), we conducted a survey with the experimental group at the end of the semester.

4 RESULTS

4.1 Platform Usage

The use of the OneUp gamification platform was not required for either the control group or the experimental group. For both groups the instructor created accounts for all students in the beginning of the semester and regularly reminded the students of the benefits of doing practice exercises in OneUp for their learning and course performance. However, our study revealed a significant difference in the OneUp usage for the experimental group compared to that of the control group. In this section, we first report statistics on the use of the OneUp gamification elements by the students in the experimental group, and then we compare the use of OneUp as a platform for practicing by the students of both the control and the experimental group.

4.1.1 Use of the gamification features of OneUp. As described in Section 3.2, the core features used in the gamified Data Structures course were avatars, badges, virtual currency, the course leaderboard, and the learning dashboard. The students were not required to use any of these features. Regarding the avatars, 27% of the students chose not to use a personal avatar. It is interesting that the "no avatar" group included students from both ends (high and low) of the OneUp usage spectrum. The distribution of the student accesses to the OneUp gamification-related pages is presented on Fig. 1, where LD stands for Learning Dashboard, VC-E – for VC Earning Transactions, VC-S for VC Spending Transactions, BI for Badges Info, and VC-I for VC Info.

As Fig. 1 shows, the page most frequently visited by the students is the Learning Dashboard, where they could see the aggregated information about their course performance. A possible reason is that the students could check their progress bar, which not only reflected their current course points but also gave a prediction about the total course points/course grade that the student would have at the end of the course if they kept the same performance. The next in popularity is the page reporting the student's virtual currency transactions. This was the place where students could track the status of a *purchase* made in the Course Shop and the corresponding message from the instructor. The Earning VC Transactions page gave information about how exactly the students earned their virtual currency. As expected, the least frequent visits were to the pages that gave information about what kind of badges one can get in this course and what are the rules for earning and spending virtual currency. It is possible that after a few visits the students retained that information.

4.1.2 Badges. During the semester, a total of 54 badges were awarded. Notably, all of the students received at least one badge, with 18% receiving more than 10 badges. As shown in Fig. 2 (where only categories with more than one badge are shown), the most badges have been awarded for Persistent Practice Level 1 (completed 5 distinct challenges) and Level 2 (completed 20 challenges). These are followed by Game Changer Level 1 and Level 3 (Level 1 is given when the difference between the percent score of a test or an assignment from the previous one is between 10% and 19%, and Level 3 when this difference is > 30%).

4.1.3 Virtual Currency. During the course, 595 VC earning transactions were recorded. Each VC earning transaction is a result of satisfying a VC earning rule as defined by the instructor. Fig. 3 shows the distribution of the VC earning transactions by category (VC rules). As it can be seen, students earned most of their VC for taking new warm-up challenges: with a score > 70% (147), with a score > 80% (135), and with a score > 90% (112). The remaining transactions include VC earned for turning correct labs in class, attending 5 consecutive classes, getting a grade greater than the class average on a homework, etc. Fig. 3 depicts the distribution of the students' earning transactions by category.

Students made 95 purchases in the Course Shop using their accumulated virtual currency. All but one student made purchases, with an average of 9.5 transactions per student. 18% of the students made more than 20 purchases. Fig. 4 depicts the distribution of the students' spending transactions by category. This distribution shows that students' favorite has been buying extra credit points for an assignment (they were allowed to buy max 5 points for an assignment with 150 possible points).

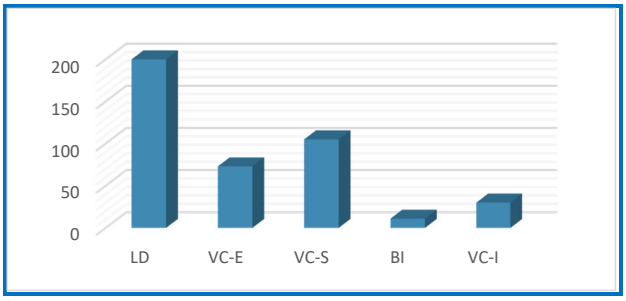

Figure 1: Access to gamification-related pages.

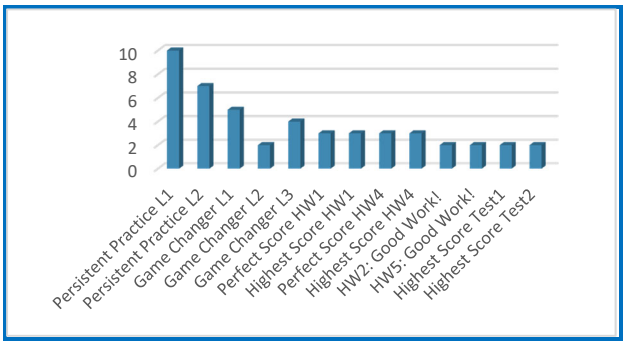

Figure 2: Earned badges by category.

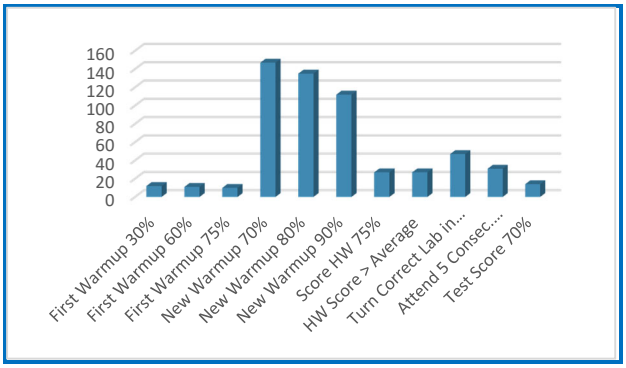

Figure 3: Student VC earned transactions by category.

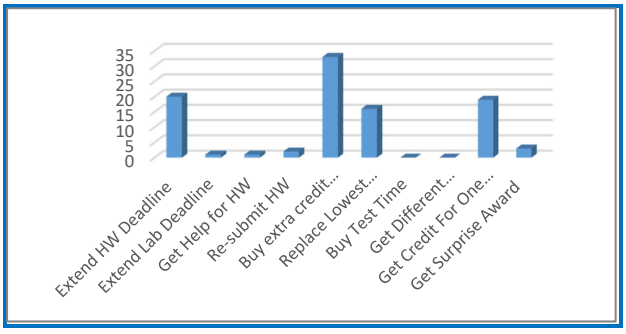

Figure 4: Student VC spent transactions by category.

This is followed by "Getting credit for 1 test question", "Extend the deadline of an assignment with 12 hours" and "Replace the lowest homework grade with the student average homework

grade". Remarkably, no VC was spent for extending test time or getting a different problem on a test.

4.1.4 Taking Practice Tests. Adding gamification features resulted in a significant increase of the taken warmup challenges: the experimental group took 239 distinct warmup challenges with a total of 554 attempts, while the control group took only 45 distinct warmup challenges with a total of 73 attempts. Fig. 5 (a) shows the percent of students who have taken 1-10, 11-20, 21-30, or 31-50 challenges for both groups.

As evidenced in Fig.5 (a), most of the students in the control group (69%) have taken between 1 and 10 distinct challenges, with 25% - none, and only 6% between 11 and 20 challenges. No students have taken more than 20 distinct challenges. In contrast, all students in the experimental group have taken some challenges, with 46% of the students, between 21 and 30 challenges and 18% between 31 and 50 challenges. The difference in the number of warm-up attempts is even more pronounced (see Fig. 5 (b)): 25% of the students from the control group have not taken warm-ups and none of them have taken more than 20 warm-ups, while 37% of the experimental group students have taken between 51 and 60, 18% between 61 and 70, and 9% more than 70 warm-ups. The average number of warm-up challenge attempts for the control group was 4.5625, while the average number of challenges for the experimental group was 46.1667. The one-sided t test ($t = -3.1574$, p-value = 0.008895) shows that the difference is statistically significant. These results signal that after the gamification intervention, students' practicing has intensified significantly.

For the experimental group, we also looked at the distribution of warm-ups taken by date. This distribution shows clear picks around the dates of the three course exams. The results are consistent with previous findings reporting that the students take online practice exercises mainly before course milestones [10].

4.1.5 Performance. We use student final course grades to evaluate the impact of gamifying the course on students' learning and academic performance. We consider course failing rates as relevant and important measure of the impact. Fig. 6 depicts the distributions of the final course grades for both groups.

While we cannot claim statistical significance of these results, they reveal a drastic change of the numbers of Fs and a significant increase of the passing grade (C) for the experimental group. For comparison, the Fs and Ds for the previous two course offerings are as follows: F16 – 10% Ds and 10% Fs and for S17 – 15% Ds and 20% Fs. There is also a slight increase of the As and Bs.

The results in 4.1.4 and 4.1.5 positively confirm RQ1 and RQ2.

4.2 Student Feedback

At the end of the semester, we conducted a survey to gather further quantitative feedback about students' perception of usefulness of the system and engagement with it. We were particularly interested in understanding what motivated students to continue a practice session after taking one challenge. The survey used a 5-point Likert scale (1 = strongly disagree, 3 = neutral, 5 = strongly agree).

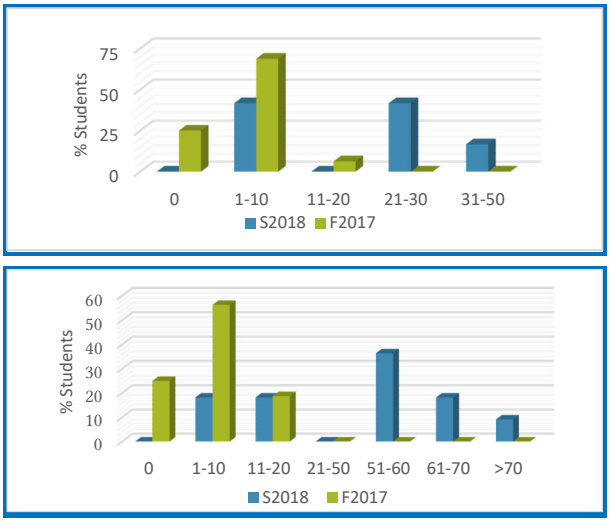

Figure 5: (a) Distinct warm-up challenges; (b) Attempts.

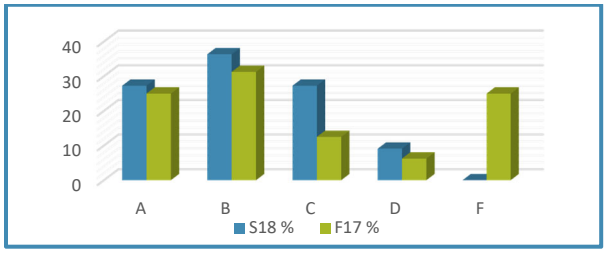

Figure 6: Final Course Grades.

Table 3 shows three sub-scales of the questionnaire: *Perception of usefulness* (Q1-Q3), *Motivation to keep using OneUp* (Q4-Q8), and *Level of engagement* while practicing (Q9-Q12). All students from the experimental group completed the survey. The results are presented in Fig. 7. The answers, indicate that the majority of students perceived OneUp as very useful, with a mean score of 4.33 for questions Q1 – Q3, with a particularly high score of 'Agree' and 'Strong Agree' (100%) on Q3 ('Using OneUp helped me to improve my grades'). The answers of the questions in the category 'Level of Engagement', characterized by a mean score of 3.90, with the highest score for Q9 (4.27) and lowest for Q10 (3.72) were also largely positive.

The overall result shows a good engagement of the students at the time of practicing, which, in turn, is an indication for an effective intervention. Of interest are student responses to questions about what motivates them to keep practicing once they have started. The desire to improve their grades (Q5) and to earn more virtual currency (Q7) are the leading factors for student persistency to practice (100% Agree and Strongly Agree for both). Enjoying the experience of using the system (Q8) elicited mixed but mostly positive responses. One possible interpretation of these results is that: (1) the motivation to use OneUp was mainly driven by the provided learning experience; (2) the enjoyment arose from the practicing experience with OneUp.

These data clearly indicates positive results for the indicators associated with RQ3.

Table 3: Survey Questions by Category

Q1. I felt more effective in self-learning when using OneUp. Q2. Using OneUp made it easier for me to prepare for the tests. Q3. Using OneUp helped me to improve my grades.
A desire to Q4: improve my skills. Q5. improve my grades Q6. earn more badges Q7. earn more virtual currency Q8. enjoy the experience of using the system encouraged me to continue practice sessions in OneUp.
Q9. When taking a warm-up I put in effort to complete it. Q10. I do not take the challenges in OneUp very seriously. Q11. When taking a warm-up I do not pay much attention to my performance. Q12. I intend to use OneUp if offered in future courses.

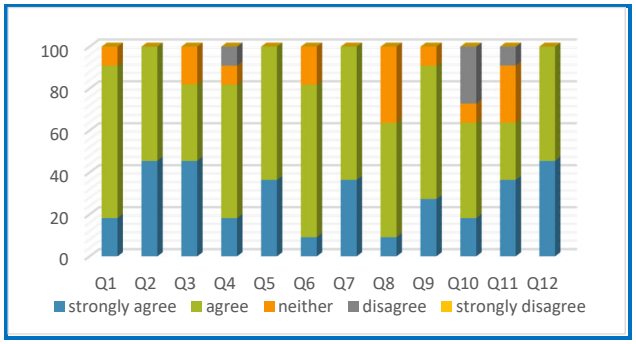

Figure 7: Answers to Survey Questions.

5 RELATED WORK

There have been several reports on using gamification in CS courses. In a "Data Structures and Algorithms" course, Haaranen and colleagues [8] used badges which students could earn by doing online exercises with certain restrictions, such as completing them a full week before deadline or getting them correct on the first try. The exercises contributed 20-30% to their course grade. The authors concluded that student behavior can be affected with badges but they did not have a significant effect on the course results because some students stopped doing the exercises once they had achieved their desired grade. In this context, the intervention was not aligned with students' goals. Latulipe et al. [9] used gamification to reward students for extra engagement in a flipped CS1 class with a focus on teamwork. The study has been constrained to using a leaderboard, stamps, and tokens and the evaluation showed positive ratings of the questions related to gamification. With the goal to increase attendance and engagement in the practical sessions for CS1 and CS2, Harrington et al. [10] used the TrAcademic system, a public leaderboard of points that could be awarded by TAs during the sessions for attendance, completion of problems, and assisting other students. The authors report that gamifying the practical sessions dramatically improved attendance and retention rates. Iosup and Epema [11] describe a Computer Organization gamified course, which uses points, levels, badges, leaderboards, and social engagement. Key features included enabling various paths of advancement and fostering social interaction inside and outside the classroom. Their evaluation found that gamification could help in many ways, from increasing passing rates and participation, to high student satisfaction. O'Donovan et al. [12] used a reward system based on Experience points, which students earned by completing quizzes, attending lectures, and participating in class exercises. They used Steam Points as an in-game currency: for every 200 XP, students get 1 SP. They can spend SP in the steam shop on quiz do-overs, puzzle hints, class rewards, and assignment extensions. The authors concluded that gamification improved student engagement and had a significant positive impact on student grades.

There are two main differences between our work and the previously reported works. The first one is that the authors of those reports have implemented gamification support for a specific course, which cannot be easily reused for another course. In contrast, we are using our course independent gamification platform, where any reconfiguration of the game features by the instructor is straightforward. The second difference is that all the reported works have gamified course activities, which were required, meaning that they were part of the course structure. In our experiment, we focus on student self-directed learning. In addition, we examine the use of virtual currency, one of the least explored gamification elements, which was favored by the students.

6 CONCLUSION

We have used the OneUp platform to gamify a Data Structures course and performed an experimental study of the use and effect of the gamification elements on student practicing, as well as the students' perception of the system. The results successfully confirmed our hypothesis that the addition of the OneUp gamification features to the online practicing platform would lead to increased self-study and practicing of the students. This, in turn, led to improved course performance.

The offered incentives were well received, with the majority of students expressing a preference for virtual currency compared to badges. Our interpretation of the high level of earning and spending of virtual currency is that this particular game design element was attracting students as a lever for improving their grades. The variety of badges earned shows that they also played a stimulating role, in particular, for strong students for which the grades were of less concern. The high frequency of visits to some gamification related pages suggests that the goal orientation and competition was driving those visits: students were curious to understand how they perform in relation to their goals and in relation to their classmates.

Overall, the results of the study indicate that the gamification intervention had a positive effect on students' learning experience.

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