TrAcademic: Improving Participation and Engagement in CS1/CS2 with Gamified Practicals

Brian Harrington
Dept. of Computer & Mathematical Sciences
University of Toronto Scarborough
brian.harrington@utsc.utoronto.ca

Ayaan Chaudhry
Dept. of Computer & Mathematical Sciences
University of Toronto Scarborough
ayaan.chaudhry@mail.utoronto.ca

ABSTRACT

Practice is an important part of introductory CS courses, and practical sessions are a student's best opportunity for hands-on experience with the material covered in the course in a supervised, supportive environment. However, finding a balance between challenging more experienced students and alienating newcomers can be difficult and frustrating. One possible solution is to let the students self-select the problems they wish to attempt. The difficulty then becomes one of motivation and administration.

This paper details our experiences with implementing a gamified system for practicals whereby students in CS1 and CS2 level courses receive points for various activities, including attendance, attempting basic problems, completing challenge problems and aiding fellow students with their work. These points have no bearing on final grades, but are displayed on a public leaderboard.

In our experience, this gamified system dramatically improved attendance at practical sessions, was well received by students and TAs alike, improved retention rates, and offered students the opportunity and motivation to overcome poor performance early in the course and improve their results.

CCS Concepts

•Social and professional topics → Computing education; Computer science education; CS1;

Keywords

Computer Science Education, CS1, CS2, Practicals, Gamification, Engagement

1. INTRODUCTION

Introductory CS courses regularly suffer from an "experience gap". Some students enter the course knowing nothing about computer science/programming, while others have extensive experience either from high-school, or by being self-taught. The challenge for instructors is to design a course which challenges and interests the latter group, without alienating the former, while still teaching the fundamentals of computer science necessary for upper year courses. One solution to this problem is to offer *à la carte* practical sessions, where students can choose the number and difficulty of the practice problems they complete. This solution relies on students choosing to attend these sessions, and having the discipline and maturity to participate to the full extent of their ability.

Prior iterations of our courses had made course marks contingent on participation in these practical sessions. This ensured attendance, and added a measure of accountability, but we found this system to be time consuming, frustrating, and not particularly beneficial to either experienced or novice students. Experienced students felt the sessions were a waste of their time, while newcomers were intimidated and felt lost. Teaching assistants felt they spent all of their time dealing with administrative duties rather than actually helping students with the material.

Making the practical sessions entirely optional alleviated several of these problems: experienced students didn't waste their time, novice students didn't feel intimidated, and TAs were relieved of their administrative burden. The one problem: no one showed up.

The ultimate goal of this project was to develop a practical system that offered the flexibility and administrative simplicity of optional sessions, but with the engagement and accountability of the mandatory sessions. Our attempts at finding this balance eventually led us to the solution of gamification. We developed the TrAcademic system, a public leaderboard of points that could be awarded by TAs during the practical session for a number of engagement related activities. The goal was to reward students for not just attendance, but participation and peer assistance, in a way that is public and enjoyable, without being intimidating or administratively prohibitive.

The TrAcademic system for gamified practicals was implemented in CSCA08 and CSCA48, a CS1 and CS2 level course pairing with enrolments 850 and 525 students respectively. We found that the gamified practical sessions vastly increased attendance at the practical sessions and improved the experience subjectively for both the students and the teaching assistants. We further discovered that participation in the system appears to correlate well with student performance and that the inclusion of gamified practicals appears to have improved student retention. There is even data to indicate that the gamified practicals are helping struggling

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students get back on track. Overall, the gamified practicals were a huge success, improving all aspects of the course, and helping to develop a much more convivial atmosphere among the student population.

2. BACKGROUND

2.1 Game mechanics and Gamification in Education

The use of games to enhance education has a wide assortment of benefits, and there are several game design mechanics that have shown success in different education environments [18][7]. Games allow a "player" to restart or play again when they fail a task. This ability to recover from failure allows players to experiment without fear of severe repercussions and will thereby enhance students' engagement [15]. Feedback for students in the normal education setting are often limited: In class, teachers can often only interact with and provide feedback to one student at a time, while feedback on assignments can be more extensive but usually involves an associated mark, which can prevent students from feeling comfortable learning from mistakes.

Thus, incorporating the frequent and immediate feedback found in game design, without the usual association of grades, may be even more beneficial [13]. Furthermore, instructors usually use scaffolded instruction, where information is presented to the class in categories that scale by difficulty. This technique does not allow for accommodation to each individual student's level of understanding and experience. Games, on the other hand, can be adjusted for progression through different difficulties on an individual basis, keeping student's at a specific level until they can show mastery of the skills to move onto the next level [1]. In addition, other elements of game design commonly applied to gamification might be helpful: leaderboards encourage engagement through competition, and differentiating between types of points can offer a visual display of mastery [4][13].

Despite considerable speculation about the benefits of introducing gamification to courses [16][9], there has been limited empirical research on the effectiveness of gamification. The few studies conducted on the inclusion of various components of gamification into educational setting are mixed. One study found that students who were given feedback about performance in the course through the use of a competitive game enjoyed the experience more, learned more, and had lower rates of failure than previous classes [5]. A second study reported higher student interest and engagement after gamifying a course using competition, leaderboards, and multiple serious games intended to teach course concepts [2]. DeMarcos et al[7] used a gamification system that gave students rewards and trophies, and used a leaderboard to encourage competition. They compared this and a traditional platform with a social networking learning platform where students could comment, blog, and interact with each other. The authors found that students in both the gamification group and the social networking group outperformed the control group on skill based assignments, however the control group did better on the final written examination designed to assess course knowledge. Additionally, students tended to have very low participation rates with the gamified (24%) and social networking platforms (38%). These findings are similar to those that study gamification in non-education contexts. Hamari et al[10] conducted a comprehensive review of empirical studies of gamification across different contexts (e.g., marketing, entrepreneurial, education), but were only able to identify a handful of studies. Of the studies identified, only 2 were found to report entirely positive effects. Most studies found some positive aspects of gamification, such as increased engagement and enjoyment, but these outcomes were often dependent on the context of the gamified system (e.g., computer science, educational) and the characteristics of the player. The authors also found major methodological problems with the studies; of the 24 reviewed, only a few were found to actually compare gamified and non-gamified experiences [10]. Thus, it is uncertain whether the effects found can be attributed to gamification or other factors.

Some studies have indicated that providing too strong an emphasis on gamification, in particular courses having final marks heavily tied to the gamified elements, can negatively impact students satisfaction with the course by promoting a competitive and anti-collegial atmosphere [11].

2.2 Social comparison and leaderboards

By nature, humans make judgments about their own abilities and those of others through comparison, since it is difficult to make an assessment of a person's ability without a reference point [12]. Theories on social comparison predict that an individual compares himself to other people in order to reduce uncertainty, make judgments, and validate opinions [8]. Typically, individuals would compare themselves with those that are equal on a desired trait, but research shows comparisons often occur with others who are worse (downward comparison, which are meant to invoke positive affect and a feelings of superiority) or better (upward comparison, which invoke a negative affect and can be used as a form of motivation) than the individual making the comparison [3]. Gamification of a course typically involves the addition of a leaderboard, where players' scores on given tasks or points accumulated are displayed for everyone to see. Depending on a given person's position, a leaderboard can offer both the opportunities for upward and downward comparisons, dependant on the fields displayed [6]. Although individuals high on the leaderboard may have a sense of superiority and positive affect, they may also feel greater pressure to maintain their higher position [19]. This increased pressure from social comparisons may influence students' academic performance [6]. Social comparison fits almost naturally into the classroom setting, where objective evaluation and exposure to peer performance and ability are constantly provided [19], and the addition of leaderboards might provide a visible, objective reminder of their performance relative to others. The effects of a digital leaderboard may be even more substantial when compared to other traditional methods (e.g., a sticker chart posted in a classroom). Traditional leaderboards are only accessible to students in one location whereas digital leaderboards are accessible to students anywhere using the internet. Since digital leaderboards can be accessed outside of the classroom at any time, students can spend as much time as they like evaluating the class or comparing their achievements with others. Furthermore, students are able to compare themselves to other students on multiple dimensions, and customize the leaderboard by sorting according to different criteria.

3. THE TRACADEMIC SYSTEM

In this section we detail the decisions that led to the inclusion of gamified practicals, and the automated system we developed for managing/tracking the sessions.

3.1 Mandatory Labs: 2013 – 2014

For multiple years, our CS1 and CS2 courses had used weekly 2 hour lab sessions, with paired programming to complete a specific task. Students had 10% of their mark allocated to these labs (1% per lab for 10 weeks). To receive the mark for the week, students had to demonstrate a working completed program to the TA by the end of the session.

Post course surveys showed students to be unhappy with these labs. 55.7% of students rated the labs as unhelpful, compared to only 26.8% rating them as helpful. All other course components (Lectures, Assignments, Readings, Office Hours) had positive response rates of at least 50%. Student complaints tended to cluster into those saying the labs were a waste of time (e.g., "I would normally be done the labs in the first 20 minutes, but would have to sit around waiting forever for the TAs to sign me out"), and those saying the labs were too difficult (e.g., "My partner and I would get stuck all the time, and not know what to do next. The TA would help, but then 5 minutes later we would be stuck again and have to wait"). Overall, the major complaint seemed to stem from the fact that the TAs had to spend large portions of their time taking attendance and validating the work of all of the students, and had little time remaining to actually help the students understand the material.

3.2 Optional Practicals: 2014 – 2015

For the 2014 – 2015 academic year, the labs were changed to be entirely optional (with marks re-distributed to weekly quizzes and auto-marked exercises). Rather than a single lab exercise to complete in a set period of time, a variety of exercises of varying difficulty were made available. Students were not assigned to specific times/rooms, but instead a full schedule was posted, and students were told they could "drop-in" for as many or as few hours as they felt they required. Rather than taking attendance, TAs were free to offer help to whomever required during the session.

In informal surveys, the TAs responded positively to these changes, saying they felt their time was better utilized in this new system (e.g., "Last year I spent most of my time running from group to group checking things off a list, this year I actually feel like I got to help students"). And the student surveys seemed to agree, with only 10.6% of students rating the practical sessions as "unhelpful", and 23.3% who rated them as "helpful". Unfortunately, 66.1% of students chose "No opinion/I did not use this resource" (up from only 17.5% the previous year).

While we did not take formal attendance during the practical sessions, TAs were asked to keep track of the number of students in each session. The average attendance rate was 4 students/hour (26 students/week). The maximum attendance was 15 students (on a session just before the second term test). Some sessions had no students attend at all. In a course of 500+ students, this paints an even worse picture of attendance than the surveys, and indicates that only approximately 5% of students are attending practical sessions in any given week.

3.3 Gamified Practicals: 2015 – 2016

For the 2015 – 2016 academic year, the practical sessions themselves were left unchanged . The schedule, rooms, rules and exercises were identical to the previous year (with the exception of a few questions being updated to fix minor errors or to provide better emphasis). However, this time, we introduced gamified elements to the practical sessions. The goal was to provide a simple, unobtrusive, publicly viewable leaderboard to reward students for participation and engagement. TAs were provided with a tablet outfitted with a magnetic card reader and specially designed app that allowed them to swipe a student card to pull up the record of an individual student (a search feature was also implemented for students who did not bring their card). TAs could award a student 3 different types of points:

- Experience Points: 1 point for attendance at practical session (students could swipe their own cards at a kiosk for this point) and 1 point for completion of a minimum number of exercises (awarded by TAs).
- Challenge Points: 1-3 points for weekly "challenge questions". Usually designed to require reading beyond the core course material or group work (awarded by TAs).
- Teaching Points: 1-3 points for aiding other students in their learning (awarded by TAs). Activities which could earn teaching points included: assisting with front-of-class demonstrations, explaining concepts to other students (whether at the request of a TA or by a student's own volition), or aiding other students with debugging or coding efforts.

The swipe-based app meant that awarding a point took on average 1-2 seconds (5-7 seconds if the student did not have their ID present and the TA had to use the search feature). It was made clear to the students that these points had no bearing on their grade in any way, and existed purely for fun [1]. This policy of not connecting grades directly to points was done partially due to the author's dislike of paternalistic approaches, but also to avoid adding any extra stress to the students and risking the development of an overly competitive and adversarial atmosphere. The decision was also made to limit the gamification to this simple leaderboard in order to properly evaluate the impact of a minimally invasive, low-cost approach.

A public leaderboard displayed the students point totals and individual category points as shown in Figure 1

4. RESULTS

The gamified practicals were used for the 2015–2016 academic year in the CS1 and CS2 courses (627 and 456 students respectively). In this section we review the data collected during that time. Our primary goal was to increase attendance and engagement in the practical sessions. To this end, we estimated attendance by analyzing the usage data of the TrAcademic system. We also wanted to see how this affected the student and TA perception of the course. For this purpose we analyzed the standard end-of-year surveys, as well as a separate survey given to teaching assistants

[1] In the interest of full disclosure, it should be noted that the instructor did mention that points, particularly teaching points, could be used as a selection criterion in future TA hiring.

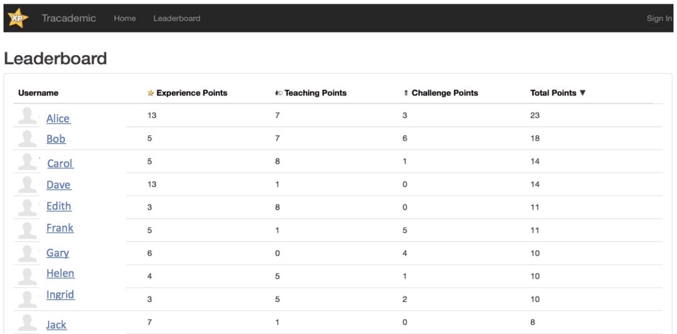

Figure 1: The TrAcademic Leaderboard

	Non-Gamified	Gamified
Min Attendance/hour	0	18
Max Attendance/hour	15	50
Avg Attendance/hour	4	27
Avg Attendance/Week	26	243

Table 1: Attendance in gamified vs non-gamified practical sessions.

specifically targeting the gamified practicals. Finally, we analyzed the performance of the students based on their usage/attendance patterns in the gamified practicals to obtain quantitative data of the relationship between participating in the practicals and course outcome.

4.1 Attendance/Usage

In the 2014–2015 academic year, attendance was not formally taken, but the TAs were asked to report on the total number of students in each practical session. Attendance was skewed greatly to sessions immediately prior to assignment deadlines and term tests. The maximum attendance for any single hour of practical session was 15 students, and several sessions had no students attend at all. The average across the entire term was 4 students/hour or 26 students/week.

In the 2015–2016 academic year, with the addition of the gamified practicals, attendance improved dramatically. Several sessions had to turn students away (the room had a maximum capacity of 50 students), and the lowest attendance was 18 students in an hour (3 more than the maximum attendance a year previous). The average across the term was 27 students/hour, or 243 students/week (an increase of over 500%). Full details are shown in Table 1.

It should be noted that the course enrolment did increase between the two years (20% for CS1 and 18% for CS2), but this is unlikely to account for the dramatic increase in attendance.

Prior to using the TrAcademic system, it was not possible to accurately monitor how many questions were attempted/completed by a student, but the attendance numbers show that even if no students were double counted (a very un-likely scenario), less than 6% of students attended practical sessions regularly.

In the gamified practicals, we were able to more accurately track individual students (though it should be noted that participation in the TrAcademic system was entirely optional, and many students attended the practicals, but did not bother to record their points). 57% of students enrolled in the course received at least one experience point for attendance, 18% solved at least one challenge question, and 13% received at least one teaching point.

4.2 Surveys

In the end of term survey 45% of respondents rated the practicals as “helpful” as opposed to 20.6% which rated them as “unhelpful”. While the ratio of helpful to unhelpful respondents was similar to previous years, the response rate was almost double. Results of the surveys are summarized in Table 2

The teaching assistants completed a short survey at the end of the course specifically targeting the gamified practicals. All 21 TAs (all upper year undergraduate CS students) completed the survey, 7 of whom had TAed the course in the previous academic year. All of the TAs agreed or strongly agreed with the statements: “The practical sessions were helpful for the students”, “The TrAcademic system encouraged students to attend practicals”, and “The TrAcademic system encouraged students to help one-another”.

Of the 7 returning TAs, 100% strongly agreed with the statement: “The new gamified practical system is an improvement over last year’s practicals”.

	Helpful	Unhelpful	No Opinion /Did Not Use
2013–2014 (mandatory)	26.8%	55.7%	17.5%
2014–2015 (optional)	23.3%	10.6%	66.1%
2015–2016 (gamified)	45.0%	20.6%	34.4%

Table 2: Results of student surveys rating helpfulness of practicals

4.3 Performance

After collecting data on usage, we decided to compare the number of points gained by students against several other metrics to determine whether there was a relationship between system usage and performance.

Points vs Performance

Simply opting into the system seemed to have a high correlation with success in the course. We divided the class into 3 groups, non-users (those who never opted into the system, or received 0 points), users (those with at least 1 attendance point), and ‘heavy-users’ (those with at least 5 attendance points). The heavy users performed better than the regular user group, which in turn performed better than the non-users. This pattern was evident in all course components (except weekly quizzes and exercises, for which the average was very high among all groups), as can be seen in Table 3. Differences were found to be significant in all course elements (using Kruskal-Wallis one-way analysis of variance, with $p < 0.01$) with the exception of the CS2 project mark, where there was little difference between users and heavy users.

A similar pattern can be found for the various types of points. Students with at least one challenge point or at least

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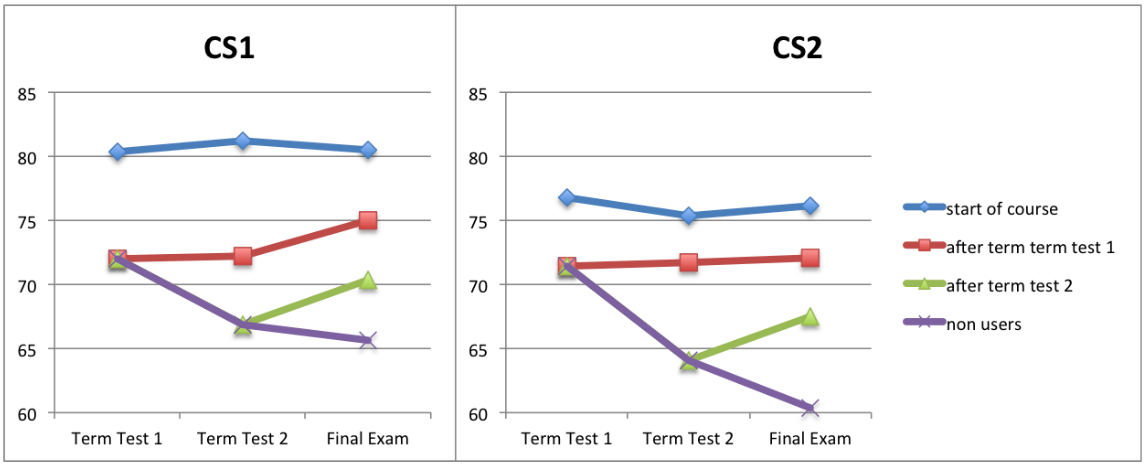

Figure 2: Comparison of average student results on major course components based when they started using the TrAcademic system

		Projects	Midterms	Exam	Final
	Non-Users	58.22	58.22	58.91	60.94
CS1	Users	68.27	66.28	65.89	69.26
	Heavy-Users	69.39	69.87	67.80	71.68
	Non-Users	53.03	64.18	63.38	62.39
CS2	Users	60.43	72.41	70.66	70.24
	Heavy-Users	60.84	75.64	72.08	72.15

Table 3: Average grade received vs degree of use

one teaching point had final grades significantly higher than users who only had experience points, as can be seen in Table 4. All differences were statistically significant (Kruskal-Wallis, $p < 0.01$). There was a positive, but not statistically significant correlation between the number of challenge/teaching points and final course grade.

	CS1 Final	CS2 Final
Users with 1+ challenge point	76.64	75.34
Users with 0 challenge points	67.30	67.27
Users with 1+ teaching point	75.11	75.12
Users with 0 teaching points	68.17	69.25
Non-users	60.94	62.39

Table 4: Average grade received vs presence/absence of challenge/teaching points

The relationship between usage and marks seemed to affect the entire grade spectrum, as seen in Table 5. There was a strong relationship between system use and a lower fail rate, as well as a higher rate of achieving a grade over 80%. All differences were statistically significant (Kruskal-Wallis, $p < 0.01$)

		mark < 50	mark ≥ 80
	Non-Users	20.97	18.98
CS1	Users	7.60	29.23
	Heavy-Users	5.88	35.29
	Non-Users	16.39	17.86
CS2	Users	8.05	29.88
	Heavy-Users	5.00	35.00

Table 5: Percentage of students failing the course and receiving a final grade of A for users vs non-users of the TrAcademic system

Starting Stage vs Outcome

Obviously correlation does not imply causation. So comparing points and performance does not tell us whether the system was actually directly benefiting students, or the better students were using the system more. In order to better analyze the effect that the system had on users, we divided user groups based on when they actually began using the system, in order to see if there was a temporal relationship between the direction of marks over time and usage of the system. We hoped to see that students who are performing poorly and begin to use the system part way through the term would see an improvement in their marks.

Usage of the system tended to jump in between the major course milestones, with a steady (percentage) increase throughout the year. We analyzed the results of students on the 3 major components of the courses (two term tests and a final exam) and plotted them against whether the students started at the beginning of the term, after the first term test, or after the second term test. As can be seen in Figure 2, it is clear that even when students started later in the term, they were able to improve their outcome.

Once again, it should be noted that there are many confounding variables here, and we would naturally expect students who begin to take their studies more seriously part way through the term to be more likely to take advantage of available resources. However, this trend is promising.

Retention

Introductory CS courses have notoriously low retention rates [17] for a variety of reasons [14]. One of the initial goals of the gamified practicals was to improve engagement among struggling students, which would hopefully result in a lower drop rate. With this in mind, we compared the retention rates (percentage of students who signed up for the course who wrote the final exam) in the 2015–2016 year with those of the previous year, where the only significant difference in the courses was the introduction of the gamified practicals. We found that there was a marked improvement in retention for both CS1 and CS2, with the retention rising by 3% in CS1 and 6% in CS2. The results for both CS1 and CS2 were found to be significant (using Chi-Squared test, $\chi = 4.2946, 6.7926$ respective, $p<0.05$). The results can be found in Table 6.

	CS1	CS2
2013–2014	0.72	0.79
2014–2015	0.73	0.81
2015–2016	0.76	0.87

Table 6: Retention (percentage of enrolled students who wrote final exam) in CS1 and CS2 for 2014–2105 (non-gamified practicals) vs 2015–2016 (gamified practicals)

5. FUTURE WORK

The implementation of gamified practicals has been a huge success. We have every intention of continuing to use the gamified practical model and the TrAcademic system in the future. One major aspect of the system that we were not able to cover here is the social effect that it had on the course. From instructor feedback and TA reports it was clear that the gamified practicals lead to a much more dynamic, convivial and social atmosphere. Not just in the practical sessions themselves, but across the entire course. We hope to study this aspect with a series of surveys and interviews, and also to continue to monitor the effect that the gamified practicals have on the course more generally. For example, evaluating the effect based on gender, prior programming experience, intended major, and other personal data could provide very interesting insights into how to make these practicals more effective for specific target groups. Inclusion of the TrAcademic system into our CS1/CS2 courses will not only improve student engagement and provide an additional avenue for students to gain programming experience, but will also provide us with a valuable resource to track trends in student development, which can be used for future pedagogical improvement. We intend to release the TrAcademic system under an academic license for public use.

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