Blended Learning in Multi-disciplinary Classrooms
Experiments in a Lecture about Numerical Analysis

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Keywords: Blended Learning, Gamification, Real-life Experiments, Multicultural Classes, Numerical Analysis, Evaluation.

Abstract: Numerical analysis (NA) is a core, compulsory discipline in most scientific, particularly engineering undergraduate programs. Teaching numerical analysis to students with diversified backgrounds and different abilities of learning (visual, aural, read/write kinesthetic learners) is challenging because of its interdisciplinary nature and modelling requirements. Such a challenge in turn, can lead to low success indicators (related to but not limited to student performance) at both whole-class and per-student levels. Negatively affected indicators include subjective (e.g. satisfaction with the subject) and objective ones (e.g. lower overall grade average and absenteeism from class). This paper reports on efforts made at the Federal University of Campina Grande (UFCG) in Brazil to favorably change such indicators. The efforts involve applying blended learning (BL) together with gamification procedures to motivate students to engage more deeply in the learning of numerical analysis. As a consequence, it is expected that the other performance indicators will also be positively impacted. Data for a set of success indicators have been collected since 2007 at UFCG. A total of 25 classes encompassing close to 1,500 students and other professionals using the approach in different application domains – including chemical, electrical and civil engineering, environmental studies, security services, health services – have been observed. Collected evidence indicates the BL/gamified procedures improve results over conventional face-to-face only classes. This positive evidence suggests that "soft skills", typical of social sciences (as opposed to the "hard skills" of numerical calculus) as well as interdisciplinary subjects – particularly those that is crossovers of computer science and design or culture or music – may also benefit from such an approach, particularly in multicultural classrooms.

1 INTRODUCTION

The co-existence of diverse interests, assumptions, patterns of thinking, backgrounds, knowledge levels, skills, and tools students in a class bring forth and use while attempting to conceive, develop and apply a solution to a problem. This solution may require building a model, i.e., a simplified abstraction of relevant aspects of reality – and selecting and/or adjusting methods for solving the model. Of particular interest here are mathematical problems that cannot be solved exactly due to computational complexity or lack of closed-up formulae. Solving such problems approximately is the subject of numerical analysis (Burden and Faires, 2010).

Numerical analysis (NA) is a mandatory subject in almost all science and engineering courses at university level. NA classrooms are usually made up of students from subject areas as different as Health Care and Civil Engineering and could thus be termed "multi-disciplinary" because the students are used to very different approaches to problem-solving. A NA multi-disciplinary classroom has interests in diverse problems originating from real-world situations in several scientific and engineering application domains. The disciplinary of participants' backgrounds and the diversity of the subject matter can turn teaching NA into a challenging task with sometimes undesirable yet frequent psychological effects such as lack of motivation, decline of engagement in group work and failing performance among students.

Barros M., Moura A., Borgman L. and Terton U..
Blended Learning in Multi-disciplinary Classrooms - Experiments in a Lecture about Numerical Analysis.
DOI: 10.5220/0005409001960204
In *Proceedings of the 7th International Conference on Computer Supported Education* (CSEDU-2015), pages 196-204
ISBN: 978-989-758-108-3

Conventional, face-to-face NA didactics tend to emphasize the application of numerical methods to generic mathematical problems with no explicit linkage to real-world, professional scenarios of interest to the students. This tendency, also observed in other calculus subjects (Thome et al., 2014), only compounds shortfalls in NA learning outcomes.

NA´s applicability (usefulness in real-world situations) and scope (most if not all science and engineering fields use it) make its teaching and learning important and worthy of attention.

We suggest that blended learning/gamification combined with modelling of real-life phenomena, activities on the Web and face-to-face sessions may improve NA didactics and student engagement and performance. We use "gamification" here with the same meaning as that provided in (Werbach & Hunter, 2012; Deterding et al., 2013), that is, the ancillary use of game mechanics and game design techniques in non-game contexts (e.g., in an NA lecture).

Blended learning (BL), in its simplest and initial form, refers to the integration of online and face-to-face-instruction (Bersin, 2004; Graham, 2006). BL experiments have since evolved to deal with richer blending options and have become frequent in particular in many university and other higher education courses (Garrison and Kanuka, 2004; CSEDU, 2010-2014; see also Section 2). Little attention, however, has been devoted to NA courses. Notable and recent exceptions include: the work (Mrayyan, 2013) reports on the performance of 45 students when video lecture notes are blended with conventional classes; and, (Cepeda, 2013) blends regular classes with online and mobile materials for engineering students whose performance was observed over three years. However, additional experiments with other blended resources (e.g., gamification) and a more comprehensive coverage of application domains with more students are still needed. This paper contributes to the discussion with such additional experiments.

Experiments did run with conventional learning and the suggested BL, gamified approach (detailed in Section 3) applied to NA lectures in 25 classes encompassing almost 1,500 students and professionals from different application domains, including chemical, electrical and civil engineering, environmental studies, security services, health services, at the Federal University of Campina Grande (UFCG), Brazil.

The general research question (RQ) of interest with these experiments is (see also Section 4):

Can there be evidence that the suggested BL approach for multi-disciplinary NA classrooms addresses shortfalls of conventional face-to-face lectures?

Here, we assume that statistically significant evidence may consist of (1) increased motivation by students; (2) increased student engagement; and (3) improved test scores. (Evidential statistics collection and analysis are carried out in Section 5.)

A positively answered RQ could signal that other multi-disciplinary classrooms – particularly those that deal with crossovers of computer science and design or art or music – may also benefit from the suggested BL approach. (Section 6 concludes the paper by discussing whether a similar BL approach could facilitate the acquisition of "soft skills" or "transferable skills" – the core of art studies and social sciences – as opposed to the "hard skills" in the core of NA.)

2 RELATED WORK

This paper directly relates to BL and gamification research efforts in higher education courses with multicultural audiences. Although experimentation with BL is on the rise in all fields of education, the work of Drysdale et al., (2013) indicates that much of it is carried out at the university level. The analysed works in (Drysdale et al., (2013) – over 200 graduate dissertations and theses on BL – relate to this paper in the sense that in one way or another they investigate the benefit of BL-programs over traditional face-to-face programs. Gamification was use as a means to add the important factor called *joy* which can enhance the level of engagement (Nielsen, J. 2002).

For instance, subjective outcomes such as learning effectiveness, cost effectiveness, institutional commitment, student satisfaction, faculty satisfaction, etc. were described (Moore, 2005); another study noted that students preferred BL classes compared to traditional classes in the following areas: "(a) accessibility and availability of course materials; (b) use of web-based or electronic tools for communication and collaboration; (c) assessment and evaluation; and (d) student learning experiences with real-life applications" (Arano-Ocuaman, 2010). These two works parallel ours in the choice of (some) performance indicators and BL course design aspects (web tools and real-life applications). The work (Caputo, 2010) considers calculus; ours, *numerical* calculus.

Graham (2013) outlined opportunities for research exploring the link between satisfaction data and specific blended learning methods (besides accessibility, opportunity costs, cost effectiveness, and psycho-social relationships), which is also done here for NA students and in (Miyazoe and Anderson, 2010) for English as a foreign language (EFL) in a university in Japan. The BL EFL considered three different online writing facilities (forums, blogs and wikis). A mixed-method evaluation of BL EFL was applied with survey, interview, and text analysis used for triangulation. Section 4 ahead also uses triangulation but with questionnaires, peer reviews and NA exams.

The inclusion of online and offline game aspects and simulation in our proposal of a BL approach for NA can be said to have been influenced by the VITAE approach (Fox, 2009). Some works in the literature use games to provide an engaging, self-reinforcing context in which to motivate and educate players (serious games) (Kankaanranta and Neittaanmki, 2008). Other works simply try to engage users with work through fun (Castellani et al., 2013). The bibliography on gamified education indicates that gamification aspects facilitate learning and working in professional and business environments in general (cf. proceedings of CSEDU 2010-2014). Intrinsic motivators such as achievement, responsibility and competence are motivators that come from the actual performance of the task or job, which can be facilitated through a game. Those motivators trigger intrinsic interest of the work, in our case the learning of mathematical procedures. Extrinsic motivators on the other hand such as scores, promotion to the next level, positive feedback, are designed by the game desigfner to nurture interest and to keep the lerener gamer in the state of flow. As described by Csikszentmihalyi, M. (2014). Aaron Delwiche (2006) argues that games such as massively multiplayer online games (MMOs) are living, breathing textbooks that provide students with first-hand exposure to critical theory and professional practice and therefore ideal to enhance the teaching and learning experience. Not much, however, has been published on applying gamification to NA teaching contexts.

Our proposed BL approach also took into consideration some of the "Harvard Consortium Calculus principles", namely: motivate by practical problems ("the way of Archimedes"); chose topics which interact with other disciplines; and, favour a completely example-driven approach and natural language (plain Portuguese in our case) over formal descriptions

Our analysis of face-to-face NA instruction shortfalls correlates well with that of (Mrayyan, 2013) but we consider a much longer observation period, larger student population and a BL experiment encompassing more NA topics.

The Blended Learning in Numerical Analysis (BLIN) project developed tools and modules are oriented towards students in engineering and informatics curricula and applied them to over 600 students (USI, 2008). Although BLIN seems interesting and useful, we found no information on its results. Development efforts were also reported in (Cepeda, 2013) where the aim was to simulate / integrate several numerical methods in order to mathematically analyse complex engineering problems. It might be a good experiment to blend the resulting tools of these works with existing resources of our proposed BL approach.

The BL approach proposed in this paper contributes to existing BL research by illustrating, complementing or extending most of the works briefly reviewed here.

3 A BL COURSE FOR NA

The proposed BL, game-based approach for students of a numerical analysis course in a university in Brazil is detailed here in order to ascertain how the approach will: i) motivate and prepare students, regardless of their backgrounds, to absorb and apply NA concepts, methods and tools to solve real-life problems of their application domains; ii) help to reduce their aversion to the subject; and, iii) improve their grades in the subject compared with face-to-face instruction.

Intended NA learning outcomes cover proficiency with numerical methods (Burden and Faires 2010) for: determining roots of functions; solving systems of equations; interpolation and curve fitting; numerical integration; and error analysis for each method. Students´ proficiency is checked through game achievements (accumulated “knowledge currency”) and by conventional exams.

The proposed BL gamification approach is simple and consists of making groups of up to six students; identify problems of interest to persons and institutions in the real world that can be solved through numerical methods. For instance, if one had a model (e.g. a multivariate function) for thefts in a city, and if all model variables were kept fixed but for the number of police officers, how big should the police force be for thefts to drop by 40%? (The solution is obtained from the police size roots of the function.) Problem enunciation and model building are carried out with the assistance of invited, real-world application professionals (such as an expert on crime and police work).

Problem and solution identification activities are carried out by each group of students according to missions they receive in a Role-Playing Game (RPG) (Kim, 2014) called N-able. Activities take place in three spaces: i) the physical space of the classroom used for intra- and inter-group, lecturer-mediated communications, including face-to-face classes and exams; ii) a virtual space in the Web ("Mathville") that serves to synchronize and support N-able´s activities, including mandatory Web lessons (also available but optional to face-to-face classes); and, iii) the real-world surroundings of the students´ living spaces. Students move between spaces as they are exposed to a sequence of situations during four months according to gamification strategies that include missions, challenges, deterministic and random rewards (e.g., the right to ask the tutor whether an answer to an exam question is correct), peer reviews of tasks, tutorials, knowledge money (e.g., to buy extra time for task completion) and progressive game levels.

N-able situations are created within a story where a "MathWizard" (the NA lecturer) coaches, rewards or penalizes other characters (played by students in each group) as they strive to become heroes. Missions are short, 5-step journeys during which, students: i) always depart from the classroom (The Council of Wise Persons - CWP) where they are assigned missions and are motivated to pursue them by the MathWizard; ii) go through the Village of Reachable Knowledge (VRK) in the world of Mathematics (a collection of five online environments, one for each of the learning outcomes that in turn, defines a level of the game) where they face challenges that include reading and production of multimedia content that help them understand and share knowledge about NA; iii) wander in their own (real-world) city where they identify, model and solve problems using NA (e.g., the theft modelling problem) and face challenges to motivate other group members and to convince experts from other areas (cultures) to help them; iv) return to VRK to publish their group´s feat of heroism (problems-NA solutions) and to evaluate other groups' feats; and, finally, v) return to the CWP where they present their work to the MathWizard, to other groups and to invited, participating experts. Although details of the story change to reflect seasonal, cultural or class´ preferences, basic game-structuring elements, such as those in (Campbell, 1949), and alternate reality aspects as in (McConigal, 2011) to create alternative social experiences around every day spaces, are maintained. Heroism is achieved by finding a NA solution to a problem that affects individuals, or society as a whole – as in the above theft-reducing modelling example. During the journey, all players develop the ability to manage the multicultural knowledge as advocated in (Girard, John P., and JoAnn L. Girard, 2011).

Modelling activities are simplified by validating functions using proportionality of influencing factors, i.e., sensitivity analysis (Saltelli et al., 2008). This allows students to abstract from formal mathematical demonstrations and to concentrate on the most relevant aspects of identifying cause-effect relationships of real-life cases and on the application of numerical methods to solve them.

The N-able RPG was implemented on the Moodle learning management system (LMS) with graphical and animation add-ons developed with several image editing software and game engines such as Construct2 and RPGMaker. The LMS was integrated into an RPG development platform because the N-able methodology needs to create a *hero experience* (hero´s journey) in collaborative learning under the supervision of the NA lecturer. Properly supporting such an experience by just using a conventional game engine is rather difficult if not impossible. Moodle was chosen for its open source code that facilitates the integration of add-ons. Further, it offers a range of facilities and resources for people who play MathWizards to instigate potential heroes to explore knowledge made available in the virtual scenarios as well as in real life. Resources include forums, wikis, blogs, synchronous and asynchronous communication tools, and facilities for uploading files with real-world-challenge-overcoming proof. In addition, such an integrated system allows for the continuous and automatic logging and evaluation of players' contributions or other actions (e.g., access to games, completion of activities), peer evaluations, accumulation of quantitative indicators (game money, awards, grades, badges) and even, the elicitation of attitudes in written tasks by differentiating between connected knowledge (CK) and separate knowledge (SK) (Galotti et al (1999). (While players with higher CK tend to enjoy learning, cooperate more easily and build on others' ideas, SK players tend to be critical and to polemicize more frequently. They may therefore be coached appropriately, in order to reduce intra-group friction). These integration and combinations may make the proposed N-able RPG an innovative tool for multicultural professional education and knowledge management.

The success factors of the resulting BL, gamified course for NA relate to the students´ capacity to: i) isolate a problem (question) in a real-professional or personal-life situation and quantitative human and natural factors which influence the problem (i.e., students should be able to model the real-world by means of quantitative variables); ii) establish proportional and inversely proportional mathematical relations between these factors (i.e., build coherent, linear and non-linear equations and models); and, iii) produce and apply numerical methods to solve the resulting equations/models. Players collect or lose points ("knowledge currency") as they achieve or fail to achieve success in assigned activities, which increase in complexity at higher game levels.

4 DESIGN OF EXPERIMENTS

Evaluation of the proposed BL, gamified approach for NA as compared to that of face-to-face lectures involved 1,478 students at UFCG, Brazil, in 25 classes from 2007 to 2014. All students were taught the same program with the same learning objectives. The same lecturer taught and assessed both BL gamified & face-to-face using the same criteria. To reduce eventuality of a bias towards BL a large number of classes and students were considered. Face-to-face students totaled 552 in 9 classes; the remaining 926 BL students composed 16 classes. Students were mainly, but not exclusively, from engineering undergraduate programs: agricultural, chemical, civil, electrical, environmental, food, materials, mining, etc. Professionals who assisted the N-able RPG groups had varied backgrounds, such as food safety, health services, public health, and security. Face to face students have the same challenge situations (isolate, modeling and solve a problem) and scheduling to home study but the problem is proposed by the lecturer, the activities (lectures and assessments) are performed in the class and knowledge are mainly constructed by interactions between lecturer and coleagues, with no contributions of characters from the two (virtual and real) worlds of the game.

Experiments were designed to objectively compare the NA proficiency and engagement of BL students against the expected, "typical behavior" of their face-to-face counterparts. Here we assume that this "expected, typical behavior" is provided by the average for each of the objective indicators of the 9 face-to-face classes in the experiments.

The experiments also call for students to subjectively evaluate their overall experience with the adopted NA lecturing approach (either face-to-face or BL).

4.1 Objective Indicators

The objective analysis focuses on grades as representatives for NA proficiency and class attendance and subject dropouts as proxies for student engagement. Objective indicators are:

- μ - mean of students´ grades over all 9 face-to-face classes; it is used as the expected mean of BL students in corresponding H_0 testing.
- μ_k^{BL} - mean of students´ grades in BL class $k = 1, 2, \dots 16$; it is used as the k^{th} observation for this indicator in Chi-square calculations. (μ^{BL} is the average of all μ_k^{BL}.)
- σ – average standard deviation of students´ grades over all 9 face-to-face classes; it is used as the expected standard deviation of BL students´ grades in corresponding H_0 testing.
- σ_k^{BL} - standard deviation of students´ grades in BL class $k = 1, 2, \dots 16$; it is used as the k^{th} observation for this indicator. (σ^{BL} is the average of all σ_k^{BL}.)

A more effective BL NA course should yield $\mu^{BL} > \mu$ and possibly, $\sigma^{BL} < \sigma$ – meaning in this last case that BL students show more homogenous proficiency with less grade scattering around the mean.

And as an engagement indicator, we define:

- η – overall mean fraction of failing face-to-face students per class (includes dropouts, failures due to insufficient grades and excessive absenteeism); it is used as the expected failing fraction of BL students in corresponding H_0.
- η_k^{BL} - fraction of failing students in BL class $k = 1, 2, \dots 16$; it is used as the k^{th} observation for this indicator. (η^{BL} is the average of all η_k^{BL}.)

Similarly, if the BL approach motivates more students to follow through with the NA course, one expects $\eta^{BL} > \eta$.

4.2 Subjective Indicators

Subjective evidence data collection was carried out by structured questionnaires available to the students. Questions attempted to determine the average satisfaction level of the students with the adopted NA lecturing approach. Given "satisfaction" is highly subjective, we attempted to obtain an indication of its level from respondents' perception of each NA lecturing approach´s contribution to:

a) Grades.
b) Understanding and use of concepts.
c) Engagement in course activities.
d) Help colleagues with activities.
e) Work in a multicultural environment.
f) Having fun during the course.

Respondents could offer their answers on a 5-point Likert scale (Uebersax, 2006): 1- Very little 2- Little 3- Neutral 4- Much 5- Very much.

φ was defined as the mean and ψ as the mean standard deviation of the satisfaction level overall 9 face-to-face classes. One may thus write:

$$\varphi = 1/6 \sum_{i \in \{a,b,c,d,e\}} \varphi_i \qquad \text{Eq. 1}$$

$$\psi = 1/6 \sum_{i \in \{a,b,c,d,e\}} \psi_i \qquad \text{Eq. 2}$$

where φ_i and ψ_i for $\forall i \in \{a,b,c,d,e\}$ are the mean and standard deviation, respectively, for the values of the answers in Question *a,b,c,d,e* and *f* above over all 9 face-to-face classes.

One may define and write equivalent equations to 1 and 2 for φ^{BL} and ψ^{BL} likewise for the overall 16 BL, gamified classes. (We leave this out, in the interests of brevity.)

The basic tool for data collection from BL students is the N-able´s game platform itself since it offers evaluation instruments for the indicators (e.g., login/event counters and the structured questionnaires) – some of which are implicit in the gameplay while others are explicit in the highest game level. Face-to-face students may answer the questionnaire on the Web or during the written, last formal exam.

4.3 Research Questions and H_0

The Research Questions (RQs) which the objective evaluation experiments are designed to answer take the following general form: *Are there statistically significant differences between the objective performance "indicator x" of the BL, gamified NA students and that of face-to-face students*?

Here, "indicator *x*" refers to one of the indicators in section 4.1, i.e., $x \in \{ \mu_k^{BL}, \sigma_k^{BL}, \eta_k^{BL}\}$ and each of these is to be compared to its face-to-face counterpart μ, σ or η, respectively.

Thus, the corresponding underlying Null Hypothesis (H_0) for each objective "indicator x" takes the form: *There are no statistically significant differences between the objective performance "indicator x" of the BL, gamified NA students and that of face-to-face students*. In the experiments, H_0 will be tested using *p*-values (Nuzzo, 2014) and will be rejected if $p \leq 0.05$. A rejected H_0 implies a positively answered RQ.

In contrast to the objective indicators, subjective indicators are essentially, "impressions" concerning satisfaction with a given lecturing method, i.e., indications are attributed depending on the respondent´s feelings, personal preference and even, state-of-mind. Hence, it seems appropriate to discuss and interpret the subjective results, rather than offering a more formal statistical analysis.

Therefore, the RQ for the case of the subjective indicators is more loosely presented as: *Is there evidence that the BL, gamified approach offers a more satisfying student experience than the face-to-face alternative*? Answering this RQ omits null hypothesis testing. Rather it is done by comparing φ_i's to φ_i^{BL}'s (and ψ_i's to ψ_i^{BL}'s) for $\forall i \in \{a,b,c,d,e\}$ in order to lead to comparisons of φ to φ^{BL} (and ψ to ψ^{BL}) and then check for gains in favor of the proposed BL, gamified approach for NA.

5 RESULTS

Face-to-face classes varied in size from 47 to 80 students with a mean of 61.33 students/class. Populations of BL classes varied from 26 to 83 with a mean of 57.88. Classes were offered in the morning, afternoon and in the evening. All face-to-face classes but one were at night; out of the 16 BL classes, 7 were at night. Class hours did not seem to perceptibly affect performance results.

5.1 Objective Results

Grade intervals were from 0.0 to 100 (perfect score). Minimal passing grade at UFCG is 50.0. Students who are absent from a quarter of classes and other programmed official activities fail the course. The face-to-face classes' "typical behavior", as given by the triple (μ, σ, η), was observed to be: $\mu = 64.3$, $\sigma = 20.3$ and $\eta = 27.43\%$.

Results for the BL students are plotted in Figures 1 and 2. The face-to-face corresponding indicator for typical behavior is inserted in each figure for comparison purposes.

Figure 1 plots and compares the average grade (top solid line) for each of the 16 BL classes (μ_k^{BL} for k=1,2,…,16) against the overall mean (broken line) of the 9 face-to-face classes ($\mu = 64.3$) – one can see that the BL approach offers higher grade averages throughout; it also plots and compares the standard deviations (underlined, solid line in the bottom) for each of the 16 BL classes (σ_k^{BL} for k=1,2,…,16) against the overall average standard deviation (underlined broken line) of the 9 face-to-face classes (σ = 20.3). Here, the BL approach shows lower standard deviations for class grades.

From the values in Figure 1, one can calculate that, for the case of the grade average of BL students, $p \leq 0.05$. This value for p indicates that H_0 is to be rejected and that there are in fact, statistically relevant differences in favor of the BL, gamified approach. Similarly, for the standard deviation: the corresponding H_0 is also rejected since $p \leq 0.05$. For the case of NA lectures, BL approaches not only increase the class grade average but they also tend to homogenize attainment of learning outcomes, as a lower spread of grades (smaller standard deviation on the average) indicates.

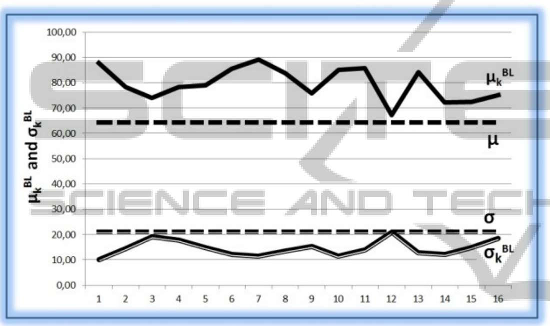

Figure 1: μ_k^{BL} vs. μ and σ_k^{BL} vs. σ, k=1,2,…,16.

Figure 2 plots and compares the fraction of students who fail the NA courses (the solid line is again, for BL).

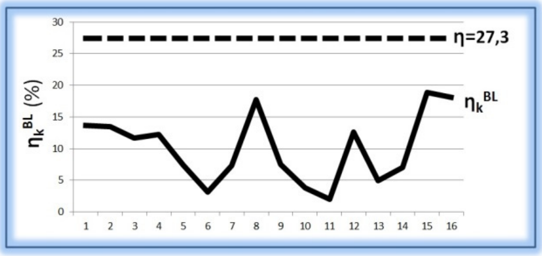

Figure 2: η_k^{BL} vs. η, k=1,2,…,16.

Figure 2 also leads to $p \leq 0.05$, indicating once again that H_0 be rejected. This figure tells us that the BL, gamified NA lectures have the added benefit of motivating students to participate in class activities more consistently. When the fraction of failures is broken down into its 3 component types, the advantage of the BL, gamified approach over face-to-face NA lectures become clear: failures due to failing grades, 3.05% vs. 14.07% on the average overall; failures due to absenteeism, 3.99% vs. 9.73%; and, failures due to dropout, 3.63% vs. 3.06%. Here, BL has a slight higher dropout rate. A possible reason for this is that BL requires more effort to take part in activities (see also Section 5.2). The overall BL advantage may be because it is more fun or because it is more attractive and challenging, because it promotes "cross pollination" with other cultures, as the subjective results seem to suggest.

Table 1 summarizes overall comparison results.

Table 1: Face-to-face vs. BL/gamified averages.

	Face-to-face	BL, gamified
Mean class grade	μ = 64.3	μ^{BL}= 79.6
Grade Std. Dev.	σ = 20.3	σ^{BL} = 14.6
Mean Fraction Fail	η = 27.43%	η^{BL} = 10.10%

5.2 Subjective Results

Figure 3 shows and compares the averages and standard deviations for the answers to each question provided by the face-to-face and BL/gamified NA classes, i.e, the figure compares φ_i's to φ_i^{BL}'s and ψ_i's to ψ_i^{BL}'s for $\forall\ i \in \{a,b,c,d,e\}$ (please refer to sections 4.2 and 4.

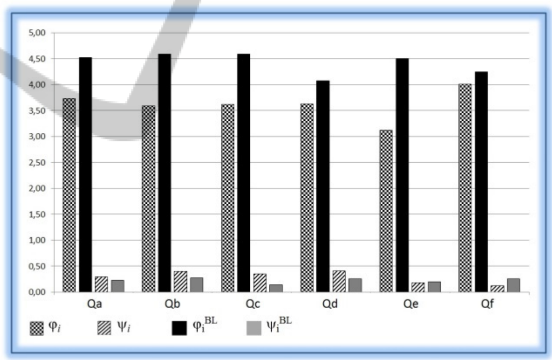

Figure 3: φ_i, φ_i^{BL}, ψ_i and ψ_i^{BL} for $\forall i \in \{a,b,c,d,e\}$.

Figure 3 provides evidence that on average, one can expect the proposed BL, gamified NA lecture to have higher-valued satisfaction components (questions a to f of Section 4.2) than its face-to-face alternative, i.e., $\varphi_i^{BL} \geq \varphi_i$, $\forall\ i \in \{a,b,c,d,e\}$. The BL approach is clearly superior when students consider its contribution to work to be carried out in multicultural settings. Indeed, for question e, the difference in means is +1.50 in favor of BL, a full 50% gain over that of the face-to-face lecture (and over a full 50% reduction in the mean standard deviation). Note however, that the means for question f (having fun with NA classes) are close (4.01 vs. 4.27) and that the mean standard deviation of the BL approach is actually less favorable (higher) than that for the face-to-face classes (0.13

vs.0.25). This may challenge the natural expectation of more fun in a BL, gamified class: the actual, additional effort of participating in a RPG and in online studying and reporting activities is likely to increase the time allocated to learning the subject. (This may also explain BL's higher proportion of dropout students.) The evidence supporting that however, should be the subject of more investigation.

Overall, the mean satisfaction level for the face-to-face NA lecture comes out as $\varphi = 3.60 < \varphi^{BL} = 4.43$, i.e., the satisfaction level of the BL, gamified approach is 23% higher on the average. (The overall mean standard deviation is also 34% better, i.e., lower.) These results provide clear evidence in favor of a positive answer to the research question: for the considered subjective experiments, the BL, gamified approach proposed in this paper leads to higher satisfaction levels of the participants, i.e., they have a better learning experience.

6 CONCLUSION & OUTLOOK

Teaching Numerical Analysis (NA) in face-to-face classes has typically yielded mixed results in terms of success indicators (students' grades and motivation). An alternative, BL and gamification approach was described in this paper as applied to NA lectures at UFCG in Brazil. This paper has presented the results of a seven-year effort that collected data and evidence on the learning effectiveness from close to 1,500 students and 25 classes, of which nine were face-to-face and served as reference for "expected results". The pilot courses were designed with game-based blended learning components in the hope of favorably changing success indicators. Results of the BL, gamification classes were significantly better,–both in objective (better grades and lower absenteeism) and subjective (satisfaction with the lectures) terms. As such, the paper contributes to the existing knowledge of BL applications, by offering data from long-running experiments with BL (and serious games).

The results, so far, are restricted to engineering NA students working in settings at UFCG. Experiment was geared towards a NA course for engineering students at UFCG which may limit application of conclusions. But results seem to indicate that BL and gamification may indeed help with other science and technology courses. Also, in this work step the aim was evaluate the integrated impacts (grades and satisfaction) of the two combined dimensions of the approach (BL and gamification).

Could we attune BL and gamification dimensions to improve the approach in order to achieve learning objectives? Could these encouraging findings in the subject area of "hard skills" possibly be transferred to so-called "soft skills" (or "people skills", or "transferable skills") such as leadership, team work, or intercultural awareness? Would the less specific, but also more complex subject matter of "soft skills" perhaps allow educators to create even more complex, captivating and intriguing story-lines than the model building for the "theft vs. police officers" ratio (see point 3 above)? Perhaps the officer who can quickly and reliably calculate that in order for thefts to drop by 40%, New York City needs 11.543 new permanent staff, can be proud of their numerical skills. However, this "solution" may be too simple for contemporary challenges and unlikely to be put into practice. A colleague with better-trained "soft skills" is likely to find a more complex solution, which does not involve massive recruitment.

In the light of changing requirements in the work place where in almost all sectors "soft skills" have become more relevant than specific knowledge of the product and market or "hard skills", it is time to explore the full potential of blended and game-based learning. If the same levels of objective and subjective improvement could be demonstrated for "soft skills", blended and gamified learning could enter the domain of social and communicative skills. Further studies and a truly international approach to teaching "soft skills" with a blended and game-based learning approach promises to generate useful and much-needed didactic advice for the future of education.

ACKNOWLEDGEMENTS

This work is partially supported by the ClipCult Project of the Paraíba State R&D Foundation (FAPESQ), the Brazilian Ministry of Communications and UFCG. Comments and suggestions from anonymous reviewers are also gratefully acknowledged.

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