When Personalized Gamification meets Computing Education: A Multidimensional Approach to Motivate Students to Learn

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Abstract. *Computing Education (CE) is associated with motivational issues, which might lead to poor performance and dropouts. Whereas gamification might tackle motivational issues, it must be personalized to both user and contextual characteristics to achieve its full potential. However, most guidelines for personalizing gamification are limited to a single user dimension, and the few that go beyond that limitation lack empirical evaluations comparing them to the standard, one-size-fits-all (OSFA) approach. Hence, in the context of CE, this thesis developed and validated an approach for personalizing gamification designs of educational systems to contextual and user characteristics. As results, we generated 10 studies, two recommender systems, two datasets, a number of assessments/quizzes on CE, and data analysis plans. Those contributions might solve the issues of OSFA gamification, posing multidimensional personalization of gamification - based on both user and contextual dimensions - as the new state of the art. Furthermore, our empirical evidence reveals a new perspective in which multidimensional personalization might address equity and inclusion issues in gamified learning. Thus, this thesis informs the design of gamified practices and provides research questions and materials for future studies.*

1. Introduction

Teaching and learning computing is challenging. For instance, students often lack motivation to learn, which is associated with low grades and high dropout rates [Mow 2008, Gari et al. 2018]. Accordingly, computing educators have sought to understand which teaching strategies might address Computing Education's (CE) challenges [Denny et al. 2019]. In that regard, gamification (i.e., the use of game elements outside games) has yielded an overall positive effect on motivational learning outcomes [Palomino et al. 2020]. However, researchers have highlighted that, if not properly designed, gamification might decrease performance and fail to improve motivation [Toda et al. 2018]. A common issue, related to properly designing gamification, is that most gamified applications offer the same design for all users (i.e., the one-size-fits-all - OSFA - approach), whereas different people are motivated differently and by distinct game elements [Liu et al. 2017]. Hence, researchers started exploring the personalization of gamification (i.e., tailoring gamification designs to specific aspects) [Klock et al. 2020].

The common practice when personalizing gamification is to, based on a list of game elements (e.g., [Toda et al. 2019]), select and offer for each user the ones that better

suit their characteristics [Rodrigues et al. 2020b]. For instance, one might accomplish this by ensuring that the gamified system will only show the leaderboard to people who like competition and that stories will be available to those who enjoy role-playing games. The assumption is that this approach will acknowledge people are different and, consequently, maximize gamification's contributions to addressing student motivational issues. Based on that, researchers proposed several models to guide the process of personalizing gamification, as we found in a literature review [Rodrigues et al. 2020b], which also revealed two main limitations of this research field. First, most strategies focus on personalizing gamification to a single user dimension, whereas empirical evidence demonstrates that several user and contextual dimensions affect user motivation. Second, most empirical studies compared personalized designs to random or no gamification, while gamification in education is often implemented using the OSFA approach with points, badges, and leaderboards. Also, none of those approaches targeted CE, despite its relevance for nowadays's world.

Therefore, to our best knowledge, when we started this Ph.D. research, there was a lack of guidance on how to perform a multidimensional personalization of gamification in education supported by empirical evidence on how it compares to the standard, OSFA approach [Rodrigues et al. 2020b]. Such multidimensional approach could benefit educators with i) a personalization strategy based on a more holistic view of who (students) and to what/where (context) gamification will be used and ii) empirical evidence on whether/how this approach contributes to gamified learning compared to the standard approach that addresses all users and contexts in the same way. Thus, addressing this lack would contribute to CE by tackling students' lack of motivation, enhancing their learning processes, and, ultimately, empowering software companies with improved professionals.

2. Objectives and Method

This thesis objective was **to develop and validate a personalization approach for personalizing gamification designs of educational systems to contextual and user characteristics**. Hence, we would contribute empirical evidence and a multidimensional approach by validating and considering both contextual as well as user dimensions, respectively. To achieve that goal, the research project was driven by three broad research questions (RQ), all of which we answered in the context of CE.

- **RQ1** asks *what factors impact the success of gamified systems*. This answer is important because the user and contextual factors influencing gamification's success are not defined [Sailer and Homner 2020]. Hence, we sought to answer **RQ1** to inform the dimensions to consider in creating our multidimensional approach.
- **RQ2** asks *how to tailor gamified educational systems to the context and the user's characteristics*. This answer is relevant because there are multiple dimensions that must be considered simultaneously. Thereby, we sought to answer **RQ2** to inform practitioners on how to properly select game elements given user and contextual information.
- **RQ3** asks, in the context of educational systems, *whether gamification designs personalized to user and contextual dimensions are more effective than one-size-fits-all designs*. This answer is pertinent because practitioners need empirical evidence to support an intervention's effectiveness (i.e., multidimensional personalization of gamification). We sought to answer **RQ3** to provide such support.

To answer those questions, we first conducted a literature review to understand the personalization methods and empirical evidence available on the topic (Chapter two of the thesis [Rodrigues 2023]). Then, we adopted an iterative method based on four steps. Overall, steps one to three (Sections 3 to 5) address the RQs, generating results that provide independent contributions as well as inform the subsequent step. Step four (Section 6) expands the previous contributions to increase our empirical studies' reliability.

3. Factors that Impact Gamified Systems' Success

While empirical evidence demonstrates there are several factors that moderate (i.e., maximize or minimize) gamification's effect on learning outcomes, which suggests those should be considered when personalizing gamification, what are those factors, as well as how they act (e.g., to what extent they maximize/minimize the effect) remain an open problem [Sailer and Homner 2020].

Major Contribution 1. We addressed those gaps with empirical evidence from four (quasi-)experimental studies in the context of CE, which are described in Chapter 3 of the thesis. Next, we present a summary of those studies. Then, discuss their overall findings and implications. In the initial study, our aim was to understand how task-related factors moderate competition's impact on learners' motivation. Accordingly, we investigated how competition affects learners' motivation, based on a quasi-experimental design, in a real learning setting with 15 graduate students from the Artificial Intelligence subject. Students worked with a console-based fight simulator, created a reflexive intelligent agent, and self-reported their motivation after participating in a control, no-gamification condition and in the gamified competition. We analyzed paired measures' differences, including descriptive measures and effect size, and evaluated task-dependent factors as possible moderators. This study was published in the *Brazilian Symposium of Computers on Education* [Rodrigues et al. 2020a].

To expand our prior study, we enriched the gamification design and increased the intervention duration to test the effect of gamification on undergraduates' programming learning in an Algorithms class. We tested three hypotheses: (1) completing quizzes and intrinsic motivation positively affect learning gains, (2) gamification improves intrinsic motivation, and (3) the more learners' intrinsic motivation, the more quizzes they complete. We randomly assigned 19 Brazilian male students to complete quizzes in a gamified or non-gamified Moodle version for half a semester. We implemented gamification heuristics focused on affecting student intrinsic motivation, which led to unannounced badges and graphic-enriched missions. We analyzed cognitive, motivational, and behavioral learning outcomes, using multiple linear and multilevel regressions to consider the moderating role of context, based on intervention duration and students' familiarity with course topics, while testing our hypotheses. This study was published in the *ACM Technical Symposium on Computer Science Education* [Rodrigues et al. 2021b]

Subsequently, we advanced our prior research by analyzing another gamification design based on 14 instead of six weeks. We analyzed the effects of gamification on the academic achievement of CS1 students, as well as how user and contextual factors influence those effects. For this, we conducted a retrospective, quasi-experimental study with 399 Brazilian students from seven STEM majors. Participants completed programming

assignments in either a gamified or non-gamified version of Codebench[1] during the whole semester. We used multilevel regressions to analyze the data and considered student age and gender as moderators, among other factors. We also included context factors, such as previous experience, current working status, and having internet access. This study was published in the *ACM Transactions on Computing Education* [Rodrigues et al. 2022a].

Lastly, we conducted another study that mainly differed from the previous one in the data analysis perspective. Both were conducted in the same context, but this one focused on understanding *how gamification's effects on CS1, STEM students' behavioral outcomes change over time*. The quasi-experimental study involved 756 Brazilian students from STEM majors, wherein participants similarly completed programming assignments in either a gamified or non-gamified version of CodeBench. In contrast to [Rodrigues et al. 2022a], in this study we analyzed the students' behavioral outcomes using the number of attempts to complete assignments, Codebench's IDE usage, and system access. Additionally, we considered a second factor besides gamification: usage time (in weeks). We used robust ANOVAs and posthoc tests to determine whether there was an interaction between the two factors and how that effect changed over time. This study was published in the *International Journal of Educational Technology in Higher Education* [Rodrigues et al. 2022b].

As results, in [Rodrigues et al. 2020a], we found task-related factors moderated gamification's effect, but it was limited to a one-time usage of a single game element. In [Rodrigues et al. 2021b], we found similar results based on a six-week intervention that deployed an enriched gamification design, which also indicated usage time's role on gamification's effect. In [Rodrigues et al. 2022a], we analyzed multiple possible moderators simultaneously, after a 14-week usage period, yielding results that question our previous findings. In contrast, findings from [Rodrigues et al. 2022b] extended those from [Rodrigues et al. 2021b] based on a 14-week study of another gamification design. Overall, those findings corroborate previous literature from two perspectives. On the one hand, they provide evidence that user and contextual factors might moderate gamification's effects. On the other hand, they demonstrate the challenge of understanding which/how those factors affect gamification's success. As the main takeaway, these studies suggested that multiple user and contextual factors, as well as their interaction, play a significant role in gamification's success. Thus, supporting the view that, if one wants to personalize gamification, they should do so by considering user and contextual dimensions simultaneously.

4. How to Personalized Gamification to Users and Context

Our studies on moderators of gamification's effectiveness revealed that user and contextual dimensions, especially when considered simultaneously, play an essential role in properly understanding student motivation and performance in the context of gamified educational systems (see Section 3). Nevertheless, our literature review demonstrated personalization strategies are mostly based on one or few user dimensions, often failing to consider contextual information and dimensions' interactions [Rodrigues et al. 2020b]. Furthermore, our review also revealed that most personalization strategies are conceptual. Hence, they cannot be readily deployed into gamified educational systems.

[1] `https://codebench.icomp.ufam.edu.br/`

Major Contribution 2. We tackled those lacks with two studies that inform the multidimensional personalization of gamification with guidelines that we implemented in a web-based, ready-to-use prototype of a recommender system. Initially, we proposed the idea of thinking about contextual information, concerning what users would do in a gamified system (inside the box), to address the limitations of personalization strategies that only focused *outside the box* (thinking about the user). Therefore, we proposed that one should consider the learning activity type (LAT) as the input for defining personalized gamification designs. Our rationale was that different game elements, as well as distinct LATs, have different functions and effects. Hence, our hypothesis was that selecting the most appropriate game elements for each LAT holds the potential to maximize gamification's success. Accordingly, we conducted a conceptual study that compared our proposal to similar personalization strategies and presented three case studies. However, this approach was limited due to the lack of empirical evidence on which game elements are appropriate for which LAT and the propensity to yield a personalized design appropriate for the LAT but inadequate for a specific user. This study was published in the *Brazilian Symposium of Computers on Education* [Rodrigues et al. 2019].

Those limitations led to our subsequent study, which aimed to address the need for personalized gamification that considers multiple factors, including users' profiles, application context, and interactions. Mainly, our research sought to answer whether users' preferences vary based on their characteristics, geographic location, and LAT. Specifically, we sought to determine the most useful game elements set according to users' preferences, considering their characteristics, geographic location, and LAT. For this, we used a survey-based approach, a methodology similar to prior studies, which asked participants (n = 361) to indicate their preferred game elements for each LAT. Then, we analyzed the answers along with participants characteristics (e.g., gaming habits) to create our guideline. We also recognized and faced the need to provide technological support for personalizing gamification, given that most related work is limited conceptual guidelines. This study was published in the *IEEE Transactions on Learning Technologies* [Rodrigues et al. 2022d].

As results, in [Rodrigues et al. 2019], we contributed a conceptual personalization approach considering the task users of a gamified educational system would do, but limited to this single dimension and lacking guidance on which game elements to select. Next, in [Rodrigues et al. 2022d], we advanced that approach by acknowledging both user and contextual information should be considered simultaneously, modeling user preference as such, and providing a concrete personalization strategy implemented as a free-to-use recommender system that provides transparent guidance on which game elements to use when/to whom. Mainly, these results advanced the literature by offering guidance and technological support for those interested in deploying gamification personalized to multiple dimensions into their educational activities. This can be achieved by either consulting our recommender system to receive recommendations on which game elements to use or using it as a service to automate the personalization of the gamification design of an educational system.

5. How Personalized and One-size-fits-all Gamification Compare

Despite we contributed guidance and a recommender system that inform the multidimensional personalization of gamification (Section 4), those still lacked an empirical valida-

tion with users to understand how gamification personalized based on such recommendations compares to the OSFA approach. Related work suffered from a similar issue [Rodrigues et al. 2020b].

Major Contribution 3. We addressed that lack with empirical evidence from two experimental studies conducted within the context of CE, which are described in Chapter 5 of the thesis. In Study 1, we sought to understand the effect of gamification personalized according to our guidelines, compared to the OSFA approach, on users' motivations in assessment learning tasks. Therefore, we conducted a mixed-methods sequential explanatory study. At first, we compared OSFA and personalized gamification through a 2x2 mixed factorial experiment. We manipulated *gamification design* (between-subject) to create two versions of the system where students would complete the assessments. Those versions featured either an OSFA or the personalized gamification design. Computing students (n = 26) engaged in two sessions that differed by the assessment *discipline* (within-subject): Programming Techniques and Object-Oriented Analysis and Design. Thus, we were able to compare the gamification designs based on two applications. In the second phase, we conducted semi-structured interviews to understand participants' motivations to use and engage with the gamified system. This study was published in the *Proceedings of the ACM on Human-Computer Interaction* following its acceptance in *CHI Play* [Rodrigues et al. 2021a].

In Study 2, we conducted another experiment with Computing students, acknowledging the need for replications to increase the reliability of experimental studies. In this study (n = 58), the goal was to further test how the OSFA approach and gamification personalized to multiple dimensions compare, as well as investigate possible moderators of that difference. Compared to the Study 1, Study 2's main differences are i) involving three, instead of one institution, ii) sampling northwestern Brazilian students instead of southwesterns, and iii) capturing repeated measures with four to six weeks of spacing instead of a one-day interval. Additionally, this study performed exploratory analyses to understand variations in multidimensional personalization's effect. This is important to advance the field from *whether* to *when/to whom* personalization works. Differently, Study 1 is limited to confirmatory analyses. This study was published in the *International Journal of Artificial Intelligence in Education* [Rodrigues et al. 2023].

In [Rodrigues et al. 2021a], the findings suggested that multidimensional personalization improved student autonomous motivation, compared to the OSFA approach, by supporting their needs and mitigating drawbacks from regular assessment activities. Although the results were promising, we found no support for those findings in our replication [Rodrigues et al. 2023]. Nevertheless, Study 2's exploratory analyses provided additional insights. For instance, they suggested *gender* and *education* positively moderated personalization's effect, in contrast to *preferred game genre* and *preferred playing setting*. Exploratory analyses also revealed motivation varied according to six characteristics for students who used the OSFA design, while the motivation of students who used personalized gamification varied according to only four factors. Additionally, qualitative results indicated the gamified assessments provided positive experiences that students considered well designed and good for their learning, although a few of them mentioned the overall gamification needed improvements. Overall, those results suggest a new way of seeing personalization's role in gamification and inform designers, instructors, and researchers

by: i) showing whereas personalization might not increase the learning outcome's average, it might improve gamification by reducing its outcome variation; ii) showing gamified review assessments provide positive experiences students consider good learning means; and iii) raising several hypotheses to be tested in future research.

6. Evidence-based Personalization Model Refinement

Most personalization strategies - including the one introduced in Section 4 - are based on potential experiences: they were created according to people's opinions, not feedback collected after actually using gamified applications [Rodrigues et al. 2020b]. However, there is no guarantee that one's opinion of what they like the most will translate to, for instance, increased motivation. Accordingly, the findings from [Rodrigues et al. 2023] raised the hypothesis that relying on a personalization strategy based on true, instead of potential experiences, could maximize personalized gamification's effectiveness.

Major Contribution 4. We tackled this gap with an initial study that refines our previous personalization approach and provides a new, data-driven recommender system: GARFIELD - The Gamification Automatic Recommender for Interactive Education and Learning Domains[2], which is introduced in Chapter 6 of the thesis.

GARFIELD is a recommender system for personalizing gamification based on feedback from real usage data. GARFIELD's aim is to recommend a suitable gamification design that will lead students to an expected level of intrinsic motivation while also considering their characteristics (e.g., educational background and gaming preferences). To do so, we followed the CRISP-DM methodology and used data from 221 students that actually used a gamified educational system in our previous studies. To create GARFIELD, we first built a regression model able to recommend the gamification designs that are more likely to offer one's expected intrinsic motivation level. Then, we evaluated this model and found that it had a moderate agreement with the ground truth (Cohen's Kappa = 0.43). Next, we created GARFIELD's its graphical user interface as an interactive, web-based system. This tool provides practitioners with technological support to help them personalize their gamified practices based on empirical data from real usage, bridging the gap between academic research and interested parties. Notice we understand that GARFIELD's recommendations have limited predictive power. Nevertheless, we believe GARFIELD provides a reliable starting point for practitioners and researchers to expand and improve in future research as - to our best knowledge - GARFIELD is the first tool that guides practitioners and instructors on how to personalize gamification to multiple user and contextual dimensions based on empirical data. This study was published in the *International Conference on Artificial Intelligence in Education* [Rodrigues et al. 2022c].

7. Products

This thesis includes studies published in the most prestigious venues for Computing Education: *ACM Transactions on Computing Education* (Qualis A1, JCR = 2.493) and *ACM Technical Symposium on Computer Science Education* (Qualis A2). Other publications include the *International Journal of Educational Technology in Higher Education* (Qualis A1, JCR = 7.611), *IEEE Transactions on Learning Technologies* (Qualis A1, JCR = 4.433), *International Journal of Artificial Intelligence in Education* (Qualis A1),

[2]https://github.com/rodriguesluiz/GARFIELD/wiki

Proceedings of the ACM on Human-Computer Interaction (via CHI Play; Qualis A2), *International Conference on Technological Ecosystems for Enhancing Multiculturality* (Qualis A2), *International Conference on Artificial Intelligence in Education* (Qualis A3), and *Brazilian Symposium on Computers in Education* (Qualis A3). According to Google Scholar, the 10 publications that resulted from this thesis sum 143 citations at the time of submission. Furthermore, this thesis generated two recommender systems, two datasets, a number of assessments/quizzes on CE, and data analysis plans, as detailed in the byproducts document. Finally, this thesis helped hundreds of Computing students and over 10 professors from four institutions around Brazil as we had the opportunity to enhance their lessons with gamified activities while conducting empirical studies.

8. Final Remarks

Computing Education (CE) is hard to learn and teach. Computing students often lack motivation to learn, which likely decreases performance and increase dropout rates. Gamification might alleviate such motivational issues, which would consequently contribute to improving CE, but research demonstrates that standard gamification strategies might fail and end up negatively influence learning outcomes. To mitigate such failures, scholars have explored personalization of gamification. However, at the start of this Ph.D. research, the literature was unclear on how to properly personalize gamification, as well as how it compares to the standard, one-size-fits-all approach. Moreover, we found a lack of approaches validated within the scope of CE.

This thesis faced this problem with 10 studies, in the context of CE, organized in three parts and based on an iterative method. First, we sought to understand which dimensions to consider in personalizing gamification, which we answered with empirical evidence from four (quasi-)experimental studies. Second, we sought to understand how to personalize gamification designs (i.e., which game elements to use), which we answered with a recommender system built upon guidelines created from data collected through an empirical, survey-based research that expanded our previous conceptual study. Third, we sought to understand how our personalization approach compares to the OSFA approach, which we answered with empirical evidence from other two experimental studies. Lastly, we iterated back to the project's second phase, conducting a data-driven study to create an improved personalization strategy. This led to GARFIELD: the first tool that, to our best knowledge, informs the multidimensional personalization of gamification based on empirical data from *real* usage instead of potential, opinion-based data. Furthermore, my work - together with those of Prof. Isotani's advisees - has been leading the standards and approaches to effectively use gamification in education, particularly in CE. As evidence for this is that, our group is one of the most prolific and cited in the world [Swacha 2021].

Based on that context, this thesis' main contributions to CE are threefold: i) empirical evidence on which factors moderate gamification's effectiveness; ii) guidance, conceptual, and technological support on how to personalize gamification to user and contextual information simultaneously; and iii) empirical evidence on how our personalization approach affects student motivation and what to expect from it compared to OSFA gamification. We acknowledge that, as with every research, this thesis has a number of limitations that we discuss in Chapter 7 [Rodrigues 2023]. Nevertheless, we believe our contributions are valuable to practitioners and researchers by, respectively, informing the design of gamified practices based on empirical evidence from the CE domain and raising

research questions to be addressed in future research, both in the Computing as well as in the overall domain of technology-enhanced learning.

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