Gamification in Education: Proposal for Gamified Learning Tools in Computer Systems and Organization Courses

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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ABSTRACT
The University of Virginia's Computer Systems and Organization 2 course (CS 3130), laden with complex topics that often confuse students, is largely considered one of the hardest courses in the University's CS curriculum. To improve the learning process and student retention rate, I propose a gamification of the topics covered in CS 3130 to reduce the complexity of topics and make the material more accessible. The methods I propose seek to take individual topics such as virtual memory paging or out-of-order processing, some of the most difficult concepts, and create a game allowing students to practice these concepts. A reactive, visual, interactive tool will provide students with immediate feedback, reinforcing concepts as they are learned. With the gamification of learning in CSO 2, I anticipate that students will find learning complex topics easier and more intuitive, enabling them to retain the information at a greater rate. Studies should be conducted to evaluate the efficacy of the proposed tools to inform future decisions on implementations of gamification in CS education.

1. INTRODUCTION

When asked what language machines think in, most people will say 0s and 1s, or binary. However, if a human were to try and think in binary, it would take them years to do what a machine can do in a second. So, how can undergraduate CS students be expected to master binary and understand low-level machine architecture in only a year?

Computer Systems and Organization, also known as Computer Architecture, is a course in many college and university CS curriculums that maintains a reputation for its difficulty. This course involves understanding and implementing many low-level machine processes involving binary, hexadecimal, and assembly. These processes are the closest humans will get to thinking like a computer, making it difficult for students to adjust to. This difficulty paired with the time pressure of assignment and quiz deadlines leaves students with inadequate understanding of the topics and low retention rates.

Topics such as multi-level page table translation, parallel processing, and out-of-order processing are some of the most difficult concepts with multiple steps and many different variations for each. While these topics are not impossible to learn, with the time pressure the students face and the resources they currently have, mastering and retaining the content is not reasonably achievable.

My proposed solution to this problem is the gamification of these concepts so that students can actively learn and receive feedback on their work. I expect the outcome of this solution to be an improved learning experience for students as well as higher retention rates of the gamified concepts.

2. RELATED WORKS

Gamification in education is not a new concept and gamification in CS education specifically is not unexplored either. In a study conducted by IEEE, Ibanez, et. al. (2014) found that gamified learning activities modeled around learning the C-programming language showed positive effects on student engagement as well as moderate improvement in learning outcomes. They also reported that a badge system as well as students' professional desires were the driving factors for continued learning after earning the maximum amount of grade points. My proposal takes these findings as reinforcement for its potential benefits, and I plan to use the same methods, including a badge or achievement system, for student engagement.

An analysis of gamification in education done by Stott and Neustaedter (2013) reveals that there are four main concepts found in game design that are "shown to be more consistently successful than others when applied to learning environments": freedom to fail, rapid feedback, progression, and storytelling. While my proposed solution will not make use of storytelling, it will utilize the other three concepts to maximize student engagement and meet learning goals.

3. PROPOSAL DESIGN

This section will discuss the details of the proposed application. It is divided into two sub-sections: Requirements, features needed by the application to be effective and efficient; and Proposed Solution Application, specifications of the application and the features it will implement.

3.1 Requirements

The problem that this proposed design attempts to solve is the simplification of complex, multi-step concepts that are challenging for undergraduate students. The goal, then, of this proposed solution is to supplement content learned in lectures by providing a tool to practice and master these complex concepts. For this solution to be effective and efficient it must meet three important criteria: gives the user the freedom to fail, provides rapid and clear feedback on errors, and motivates the user to learn and master the content.

Giving the user the freedom to fail is imperative as in many of their other sources of learning, such as quizzes and homework, they cannot afford to fail as their grades are at stake. Freedom to fail and make mistakes will allow users to learn in a low-risk environment.

Once a user fails or makes a mistake, it is critical for their learning experience to receive rapid and clear feedback on their error. If users do not know where they made their mistake or how to correct it, their understanding of the concepts will be compromised.

Users must also be motivated to continue their learning and mastery of the concepts for the best effect. While there may be some short-term benefits from practicing once or twice, consistent practice will yield better results.

3.2 Proposed Solution Application

My proposed solution is a web-application that provides users with a way to practice complex concepts such as multi-level page table allocation and translation, parallel processing, and out-of-order processing. Each concept will include tutorials on how each process works as

well as a problem set users can complete to achieve mastery. The tutorials will focus heavily on visual cues and models to help users understand the process on a mental level. Users will then be allowed to practice with the problem set to understand the process on a practical level.

Problem sets allow users to practice concepts with no risk attached, giving the users freedom to fail and learn without stress. My solution implements these problems sets to be randomized, providing an infinite amount of variation in the problems, meaning that users can continue to solve problems without duplicates. The problem sets also provide immediate feedback on errors and advice on where the user made a mistake and what should be done to correct it. Not only will the application provide feedback through text but also through a visual animation showing the process in real time. This will allow users to not only make mistakes but to immediately learn what they did wrong and improve their understanding of the concept on a fundamental level.

The proposed solution will also include means of motivating users to be consistent and master the concepts. One way to motivate users is by providing a feeling of progression. The proposed application will achieve this by giving the user smaller and easier examples in the problem sets, moving on to more difficult and complex examples as users show improvement. Another way the solution will motivate users is by providing a feeling of accomplishment through an achievement system. As users progress through and complete their problem sets, they will be awarded with achievements that recognize their accomplishments and signify mastery over a concept.

By focusing on both the mental understanding and practical application of the concepts through visual tutorials and hands-on problem sets, the proposed solution will address the needs of undergraduate students while also meeting the requirements of an effective and efficient learning tool.

4. ANTICIPATED RESULTS

My proposed solution is expected not to replace lectures but to supplement them and help students understand complex concepts in a shortened time period. By providing a solution that affords students the ability to fail while also giving them access to rapid feedback and feelings of accomplishment, undergraduate students can be expected to perform better on their quizzes and exams while also retaining a greater understanding of the concepts reviewed.

This expectation is supported by a study conducted by IEEE in which gamified activities for learning C showed improvements in learning outcomes (Ibanez, et. al., 2014). This is also supported by a literature review done on gamification in education which found that affordances such as achievements and progression result in “mainly positively oriented” results (Majuri, et. al., 2018). Should this solution be implemented, an observable, positive difference in student performance on quizzes and tests involving concepts reviewed by the proposed application can be anticipated.

5. CONCLUSION

The proposed application and its expected results would not only benefit CS undergraduate students at the University of Virginia but also at any other institution teaching computer architecture courses. By improving the learning experience, users can focus more on learning and retaining education content rather than on short-term cramming for a grade.

The proposed solution would also build upon existing literature on gamification and education and provide a niche data point of gamification for computer architecture learning. This would be beneficial, regardless of the actual efficacy of the proposed application, and provides a justification not only for its existence but also its significance.

6. FUTURE WORK

The most obvious next step for this project is to implement the proposed solution. Beyond the implementation, a study of the efficacy of the solution would be prudent. Based on previous studies on gamification in learning, the results are expected to be positive; however, a study specific to this application and its efficacy would solidify its purpose as a tool for education.

Based on the results from a potential study done on the efficacy of the application or out of faith in gamification as a concept, this project could also be continued by applying it to different concepts and classes within the CS curriculum such as learning computer network traffic protocols, low-level computer architecture patterns, or any number of complex, unintuitive concepts.

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