Framework for Using Professional Engineering Tools to Develop Games in Post-Secondary Education

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Abstract

Teaching is changing with increasing emphasis on teaching digitally to enable remote learning. While it gives more opportunities to engage students, it also makes it harder to learn professional skills, which is especially important for the engineering field. One problem might be the lack of professional tools for the digital education of engineers. The purpose of this work is to assess the feasibility of creating digital educational games by shaping professional tools themselves as games for post-secondary education, and to develop a framework for such a process. This article demonstrates a case for applying the proposed framework to develop a game for a communication network course using a computer network simulator. The findings of this work highlight the need to create such games in higher education based on professional tools.

Keywords: Education games, Digital Education, Engineering studies

1 Introduction

Traditional education is changing with the current paradigm shift towards digital or blended education. There are multiple reasons for it, such as better flexibility and adaptability for the individual needs of students to worldwide pandemics [1], which made many educational institutions rethinking ways to provide physical and digital education. Some fields of education tend to be more adaptable to such a paradigm shift; but some fields require hands-on practical skills like medicine or engineering science, which makes the shift to digital education harder.

A lot of the digital tools available for engineering education are not easily adaptable for remote or digital learning [2]. Yet such tools are important to foster challenge-driven education and encourage students to deepen their theoretical knowledge and motivate them to develop their critical thinking. However, the way to combine existing tools used by engineers with courses for digital or blended education is an open question. Hence, the purpose of this work is to assess the feasibility of educational games to address this challenge and to develop a framework for the design educational games based on professional tools.

In this work, we present our experience designing and implementing a game for teaching computer network communication. We follow the approach suggested by Briggs [3] to map our course objectives to game design elements. We demonstrate a case by creating an educational game based on a computer network simulator. We hope to highlight the need to create such modules for professional tools in higher education.

A brief description of the challenges and some related work is described in section 2. Section 3 describes a framework for our approach with an example of how each step can be implemented. Sections 5 and 6 provide a discussion and conclusion for the work.

2 Background

2.1 Challenges for teaching in higher education

The general purpose of education is to prepare students academically to be good employees and citizens [4]. In professional and higher education contexts, this would require that the students achieve a higher level of engagement with their education and be able to apply their knowledge to real-world problems [5, 6]. Traditionally it is achieved by engaging students in physical labs where they can practice their skills. The advent of learning based on digital games [7] and the recent need for distance education have required us to reconsider the design of circular and teaching techniques to better suite current circumstances [8].

The idea of digital education is not new [9]. Among others, online education provides the advantages of flexibility for self-paced learning and adaptability to different learning styles [10]. However online education has its limits, especially when hands-on practical experience is required like in medicine or engineering science.

Engineering science often uses complex instrumentation to set up a context for an experiment, measurement or simulation [2]. Students are then taught to understand the methods to use their instruments to perform their tasks while understanding their limitations.

In our example, the context is of a communication network course HE1033 [11] at the KTH Royal Institute of Technology, Sweden. During this course students are taught how to use high-fidelity network communication simulation software to understand the fundamentals of packet-switched networks, machine addressing and how to plan, design and test computer networks. The learning objective for the student would include:

- Identify and understand the function of various hardware components and their functions.
- Understand the use of the computer network simulation tool.
- Apply this knowledge to design, set up and test a computer network.
- Infer the various properties of the network based on experiments, observations and measurements using the simulation tool and other software utilities.
- Demonstrate the ability to combine all the knowledge gained to tackle real-world scenarios for debugging or designing a given computer network.

2.2 Theory and related work

The seminal work for experiential learning as stated by [12] presents the framework for the experiential learning cycle; creating an environment where students can go through iterations of learning, gaining knowledge in each loop. This presents a case for the development of a space for the students to experiment and learn with trial and error. As discussed earlier, digital game-based learning environments already present such a space for students. [7] discuss the role of epistemological games and their use in developing educational artefacts. They present multiple examples of serious games that have been used as pedagogical artefacts.

The seminal work of [3] provides the theoretical framework to use the course and learning objectives of students and map them to learning objectives in game design. [13] explores the *Constructive Alignment* as an approach for aligning learning objectives and game mechanics in higher education. The constructive alignment provides the theoretical basis for the proposed approach where we align the use of professional tools in game environments to the learning objectives of the course. The use of constructive alignment in professional courses was demonstrated as a comparative analysis of two courses in different engineering schools by [14]. [15] focuses on efficacy and structure critical reflection of games and simulations within the curriculum. Finally, [16] discusses the best practices for pedagogically driven game design. Among the recommendations is the need to situate the learning within a given context, minimise the cognitive load and provide an experience space to the learner.

3 Proposed Framework

To make educational games feasible they should to follow a framework or model, for example, learning mechanics and game mechanics (LM-GM) model [17]. Additionally, educational games for post-secondary education for engineers need to satisfy the following conditions:

First, the game needs to be based on an existing tool that is used in the field by professionals. This is important to ensure that efforts in designing an educational game are targeted in the right direction of optimizing the learning process.

Secondly, the game must be able to naturally integrate into the course's curriculum. If the game seems artificial to the learning process or creates a burden to students or teachers, it is not feasible to use successfully such a game in the long term [18].

Lastly, the game needs to have a mechanism to assess student knowledge and interest based on the experience of playing the game. Such a mechanism serves as an indicator that the game is serving its purpose as an educational game and does contribute to the increase of theoretical and/or practical knowledge of students.

To meet these conditions and to make such a game feasible, a potential framework for game design needs to be built upon three pillars: functionality & limitation of professional tools, objectives & curriculum of the course, and best practices in educational game design.

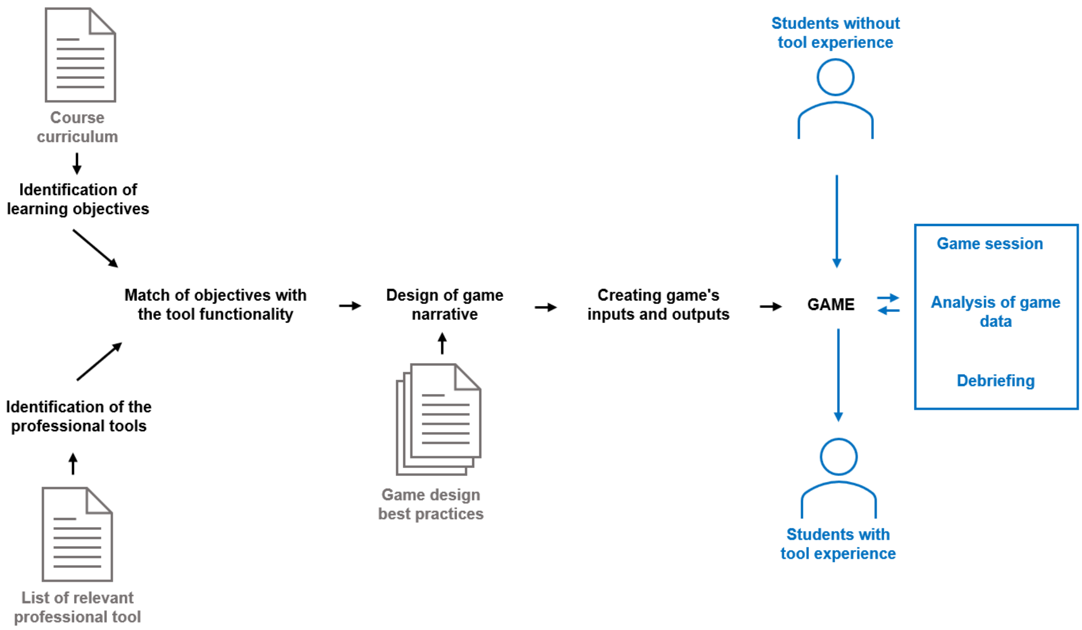

Figure 1: *Proposed framework for educational game design.*

This work proposes a such framework that is built based on eight steps as seen in Figure 1. It starts with the identification of learning objectives and a tool. Then it continues in matching the objectives with the tool, designing the game narrative and the game's inputs and outputs. Following that, the proposed framework describes a process for a game session. Finally it provides a description for data analysis and debriefing. A more detailed explanation of each step is given in the following chapter.

4 Steps for Game Design

This chapter presents a deeper explanation of each step of the proposed framework. While the aim is to describe each step comprehensively, one needs to keep in mind that it is not feasible to include all variants of educational games for all engineering fields in one general solution. Nevertheless, this framework still is useful to create a wide range of different games.

To illustrate how the proposed framework can be implemented, a game case is presented for a game for the communication network course as described in Section 2.1.

4.1 Identification of learning objectives

The first step to developing a game is to consider the objectives of the game. In the case of a pedagogical game, the learning objectives of the course or programs form the basis for the objective of the game. The general goal of education or training game is to provide experience to participants through repeated trial and error and increasing levels of difficulty and complexity [19, 20]. As they are part of a course or program, the games can also be designed to track a player's actions and measure progress. This provides a unique opportunity for an instructor to monitor each player's abilities uniquely and provide more personalized feedback and help the instructor to better tune the subsequent programs to the player's needs. The design should also consider the course objectives such as the application of practical skills, writing a piece of code, using different commands, and application of specific theorems as part of game mechanics.

Game case: as part of the development of the game for communication network course, the objectives of the course were analyzed. The main objectives were related to the following three clusters: 1) gain the ability to analyze the system and use proper commands/configuration for different devices, 2) understand theoretical concepts and 3) define facts and properties related to the communication network. Hence, these three clusters were selected as learning objectives for the game.

4.2 Identification of the professional tools

The next step in the design is to identify which professional digital tools are being used within the field of study. Most branches of engineering science have well-established tools that are used well established. For example, civil engineers might choose to use AutoCAD [21] or ANSYS [22], and chemical engineers might use ChemBioDraw [23] for modelling. However, it should be noted that most of these tools are not designed for education or educational games. Regardless of the specific tool, it is important that students do have access to the chosen tools.

Game case: specialists within communication networks also use different digital tools for different purposes. Programs like ns-3 [24], GNS3 [25] and Packet Tracer [26] are network software simulators, Wireshark [27] allows analyzing network protocols, and other tools allow network monitoring, remote control, amortization, and much more.

Since the objective of the course is mainly to gain skills with network configuration, Packet Tracer by Cisco Systems was selected [26]. Packet Tracer as seen in Figure 2 advertises itself as a virtual lab that allows an interactive way to practice networking skills interactively without physical hardware.

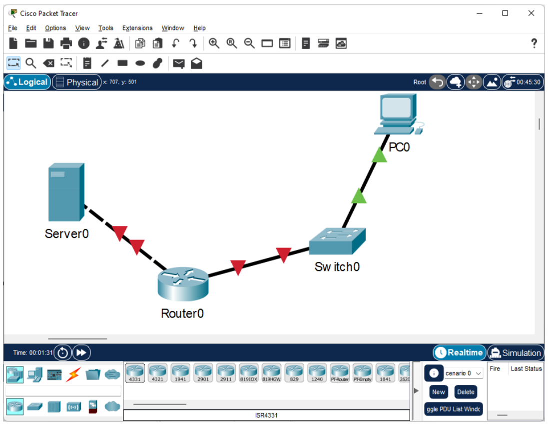

Figure 2: *Network example in Packet Tracer program.*

All students have access to Packet Tracer since this program can be used for free after registration. All students also had some previous assignments using this program; thus the students are familiar with the tool.

4.3 Match of objectives with the tool functionality

Once learning objectives and a tool are identified, it is important to see how the objectives can be implemented in the tool. For some areas, this task can be trivial, while some other tools can be less easy to adapt to fulfil all necessary objectives. A proper reassessment of what can be done with the tool needs to be performed. If it is still possible to include the main objectives, this is a path to go. If the tool cannot support the main learning objectives, there is a need to select a different tool that will provide the necessary functionality to support the goals.

Game case: for the test game, three learning objectives were selected.

Objective 1: Commands/configuration of different devices is easily implemented in Packet Tracer. For the sake of the game a computer, a network switch, a network router, and a server are used. Eight activities are designed to configure different devices: 1 configuration of a personal computer, 1 configuration of a switch, 5 configurations of routers, and 1 configuration of a server.

Objective 2: The second objective was to focus on concepts that cannot be easily tested on smaller networks or using conventional devices that students are familiar with. These concepts become questions that students need to answer to receive additional clues. Packet Tracer has no built-in mechanisms to deal with it. However, Packet Tracer allows the construction of simple websites using HTML (HyperText Markup Language) and Javascript languages. Hence, the second objective was achieved by building a web page that asks a question, and if answered correctly, the page will show a clue. Activities included 3 theoretical questions that were framed as multi-choice questions as seen in Figure 3.

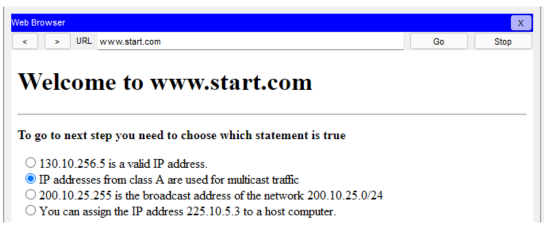

Figure 3: *Web page with the game to access clues.*

Objective 3: The third objective is to introduce some facts about communication networks. These are not covered in course materials or course books but can be found online with additional efforts by students. This objective could be implemented by using again websites; however, to differentiate it more from the second objective, these facts were used as passwords for different devices, which is a built-in function of Packet Tracer. Four activities were made that included facts about other layers of the communication network model, the history of the Internet, and organisations that are involved in the proper function of the Internet. An example of such implementation is seen in Figure 4.

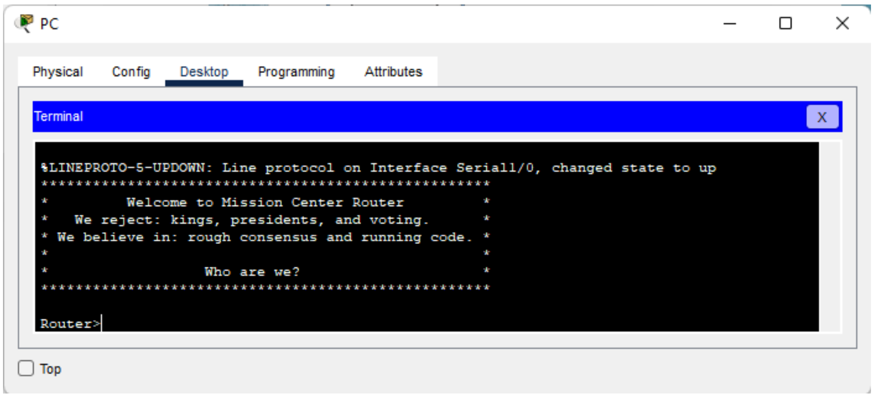

Figure 4: *Authorisation screen with a password hint.*

4.4 Design of game narrative

With clear learning objectives and the digital tool, it is time to figure out how the objectives can be incorporated into the game design by creating a game narrative. The narrative describes a flow of activities and events during the gameplay. Several topologies describe different narratives [28, 29], but they can be summed up as the linear narrative, branch narrative, quest narrative, and sandbox narrative.

Linear narrative: In a linear narrative, a player needs to complete a set of tasks in a sequence. Subsequent tasks can only be completed by completing the previous ones. Hence, progress can be made only by completing the tasks in a defined sequence.

Branch narrative: Players are offered a list of tasks to choose from, but once a task is selected, it gives a new set of tasks to do. Players will proceed in a tree-like structure based on their connections and choices to various tasks. It might be allowed or not to return to previous choices depending on the game design. Hence, this structure gives the freedom to choose a task based on various conditions, but tasks are still performed in a specific order.

Quest narrative: Provides tasks that players must complete, but it is up to an individual player to decide in what order to perform these tasks. This narrative gives the freedom to choose the order of performed activities, but still, activities need to be completed.

Sandbox narrative: Allows players to explore the game as they wish by choosing any tasks and performing them in any order. The sandbox narrative is a good narrative for exploring activities, but it is hard to achieve winning conditions with this narrative.

A connection between game narrative, objectives of a game and objectives of a course is summarised in Table 1. Typically, a game will not follow fully one specific structure, but the structure helps to determine the main flow of events and tasks within the game. While developing the game it also might be wise to think of a proper balance between the level of challenge and level of abilities – if the game goes outside this balance, it decreases motivation to play by causing anxiety if the game is too hard or causing boredom if the game is too easy.

Table 1: *Connection of game narrative with objectives of a game and a course.*

Narrative	Game objective	Course objective
Linear	Complete series of activities	Training processes or procedures, learning concept in depth
Branch	Choose the right path and complete activities for this path	Comparing alternatives, avoiding obstacles, searching for best path
Quest	Choose the order in which activities need to perform and complete them	Explore consequences, learn the importance of the right order, train procedures, and understand complex and emergency systems
Sandbox	Explore environment by choosing activities and their order freely	Free exploring, understanding complex and emergency systems, training system thinking

Irrespective of the chosen narrative structure, there are two additional aspects that one needs to remember about game narrative. First of all, games often use metaphors that are used to combine already known concepts or elements with new concepts based on similarities and parallelisms [30]. Metaphors make it easier for players to emerge in the game and are often presented as fantasy, fairy-tale or comical ludic environments. Secondly, the game design should also include elements for players to track their progress. This would include elements for scoring, rules, resources that a player must achieve their objective and finally feedback when players make decisions. It should be noted that the design of these elements will also be based on the affordances of the chosen tool.

Game case: to ensure that the game for the communication network course can achieve selected learning objectives, a linear structure is selected. With such narrative players start from a launching device and need to reach the end device by solving obstacles along the way, similar to escape room games. Players receive clues on what they need to achieve. While it is preferable to organise different obstacles based on the level of their challenge starting from easier and slowly progressing to more complicated, in this case, the obstacles were selected based on the logical sequence of network configuration actions. To ensure a proper level of challenge, a decision was made to include more help in clues at the start of the game and make clues harder closer to the end of the game.

It was decided to bring a ludic element to the game by making a challenge not just to fix the network but give a mission to stop a comically evil hacker group that wants to freeze the Earth. This was done to build interest and motivation around the game, to explain why there are some clues rather than information being presented in a normal way, and to make the entire game feel more exciting and authentic to a critical network communication scenario.

4.5 Creation of game's inputs and outputs

The final components of game design of game elements [31]. This work focuses on the following elements: roles, rules, objectives in the game, and constraints. The connection between them can be represented as seen in Figure 5.

Based on the objectives, the game can have one **role** for all students or different roles. An example of a game with different roles can be related to manufacturing, where roles in the game can include workers, managers, quality controllers, suppliers, consumers, and others. Roles can also be combined – for example, workers, managers, and quality controllers are performed by one player with one big role. Some of the roles can be simulated, for example,

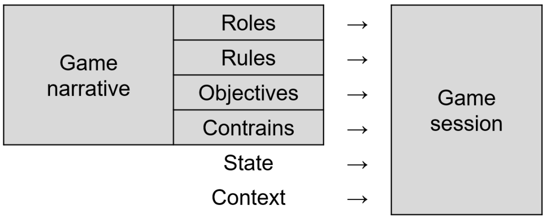

Figure 5: *Inputs for a game design based on [32].*

the demand from consumers can be a function within the game. Finally, some roles can be played by an educator, for example, students act as a manufacturer while a teacher act as a supplier. Each role must have a clear description and connected rules, objectives, and constraints.

The **rules** of the game explain what every role can do and how it can be done. It is important to be clear about what rules exist and how they are integrated into the game. Some rules need to be explicitly explained to players, while some can be done by changing the setting of a digital tool used for the game. For example, it might be possible within the tool to block or allow some functionalities or access to specific elements or processes.

The **objectives** of the game define what players need to do to win the game. Each game can have one or several defined objectives. The exception can be in sandbox games, where players decide for themselves what they want to achieve. Objectives usually have some sort of mechanism, like scoring, to indicate how close the player is to winning the game.

Resources and **constraints** create the complexity of the game [17]. Constraints are based on real-world constraints for the specific role. It can be limited information, money, time, or other resources that create a challenge to overcome. Different roles can have different constraints, but even with different roles, there could be constraints that are applied to everyone, for example, the total budget for all players or the total amount of resources. Constraints critically affect a balance between the level of challenge and level of abilities and thus, multiple gameplay tests may be needed to achieve this balance.

With all elements in place, the game is ready to be used. Two additional elements are **state** and **context** which refer to design variables, such as whether will players play in teams or individually, for how long, will the game be graded or not, and others. The context deals with other variables in connection with the game session like the knowledge level of students.

Game case: in the developed educational game, only one **role** for a player was defined, which is the network administrator. Since the game was designed to be based on a mission to stop a hacker group, this role was named Secret Agent to continue with the ludic aesthetics. Additionally, a simulated role was created which is the hacker group that freezes the Earth over time. While this role has no practical effect on the game, it is an important constraint within the game in terms of simulated consequences and an element of urgency.

The following **rules** were defined in the game. The Secret Agent role is allowed to access any devices considering that they had previously been properly connected to the network and all passwords were correct. The players were not allowed to use automatic configuration mode for devices but can use only the command-line interface, which is closer to the reality of working in a professional setting.

The **objective** of the game was to stop the hacker group by getting access to their server. To achieve it, the player had to understand issues with the current network, figure out how these issues can be resolved, and properly configure all devices to ensure that the network works.

In the developed game, **constraints** for a player are limited access to the devices: only the command-line interface is available, and devices had to be configured in logical order. Players were not allowed to add any new devices or remove any existing devices.

The **state** of the game session was that students could play individually or in pairs. All game players had to play at the same time and report that they finished to an educator based on the instructions that are available after the game is solved. The game was played digitally, and participants logged in remotely from their homes during the game session.

The **context** of the game was that it was available for all students who had enrolled on the same computer networking course, their knowledge levels should be similar. The game was not a mandatory part of the course and participation was completely based on students' choice. The completed game is seen in Figure 6.

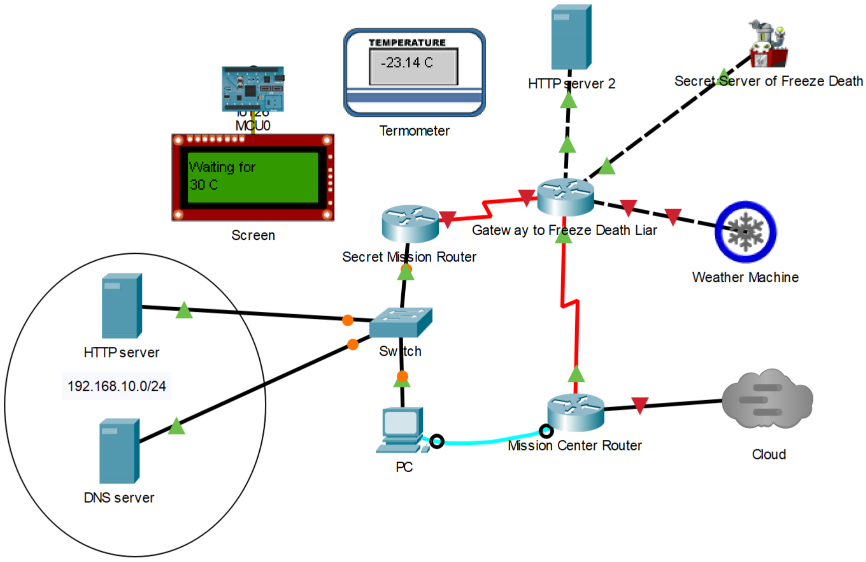

Figure 6: *A complete Freeze Death game view.*

4.6 Game session

The game can be a mandatory part of the course, for getting extra credits or it can be used just as an activity within the course for illustration or purpose without any bearing on credits. This decision depends on the nature of the course and its structure and the learning objectives of the students. The preparation for the game session includes briefing students about the game, The briefing includes time for the game session, materials that might be included in the game, rewards, roles, rules and objectives.

During the game session, the educator now plays the role of a facilitator and guides the players during the game session with information, clues, or support.

Game case: for the developed game, all students from the course were invited to participate in the game. The announcement was sent via a digital learning platform for the course that is used for all announcements for the course. Invitations were sent two weeks in advance:

> "We need your help to stop the upcoming catastrophe. The hacker group the name of Freeze Death has sent threads to cool down all of Earth. We already have seen some of their work consequences with extreme cold weather in some regions. You have a chance to stop them by getting access to their network and turning off the cooling machine to stop their plans. This is a dangerous mission

where you will be tested. Our spies say there are some clues that can help you! Can we count on you?"

The invitation text also includes a) information that work can be done individually or in teams of two, b) information about software and that it is remote activity, c) the start time and date, and d) information about rewards for winners.

On the day of the game session, before the game started, students received a small file in the chosen program, Packet Tracer, to ensure that the version software and all connections work. The game started at the same time for everyone. All participants work digitally from their homes or other places. One educator was available via phone calls, online video conference platforms and emails for support.

4.7 Analysis of game data

When the game session is completed, it is time for the assessment of the game as an educational tool [33]. Did students manage to complete all required activities? Were some learning objectives harder or easier to achieve by students? Did students demonstrate their practical skills? These questions can form the basis for a debriefing or a discussion session.

Game assessment can include two types of feedback data: quantitative and qualitative. Quantitative data is obtained based on the statistics from the game. It can include a percentage of completed games, average time, and average score. While quantitative data rarely answers why students performed in the game as they did, it often shows the picture of how the game was played.

Qualitative data is related more to the perceptions of players and goes a bit beyond just activities within the game. Qualitative data can include some observations of how students played a game: which parts were easier or harder and why, what made students most excited or most frustrated, and how well students implemented their knowledge to solve activities in the game. Qualitative data also can come as feedback from students about the game. The questions that ask to assess their experience or learning path or just general feedback about the game can provide more information for the educator that later can be used for improving the teaching process.

Game case: a proper analysis of game data was excluded due to a low number of participants.

4.8 Debriefing

The last step is a debriefing of the game that includes a discussion with students about the game and how the game experience is connected to real-world experience [34]. The debriefing can focus on what students learned from the game and how it matches other information provided within the course. The debriefing also can focus on similarities and differences between the experience of different players, especially in the engineering field where a problem can have several solutions. Additionally, during the debriefing one can discuss a difference and similarities between theoretical knowledge, the game experience, and real-life work.

Game case: debriefing was excluded due to lack of time within the course.

5 Discussion

The literature, as described in the Background chapter, and the game that was developed as a part of this work, clearly indicate that it is feasible to develop educational games based on existing professional tools. Furthermore, such games can be designed merely by using a tool as an artefact within the game. For example, if we consider a calculator as a professional tool then, a game like Monopoly can be considered an educational game that teaches the use of a calculator for all financial transactions.

However, our goal in this work was about using a professional tool as a simple artefact, but to completely reshape the tool as a game. Thus, continuing the example with the calculator, this work is about how to build a game within a calculator. The benefit of this is a deeper understanding of the importance of a tool as the full game experience.

The second part of the work was to develop a framework for the design of educational games based on professional tools for training. The framework was developed and described in Chapter 4 which also presents a demonstration of how each step was implemented in the real game. The attempt was to explain the framework extensively so it can be applied to a wide range of possible solutions.

The framework presented here provides an indication for how a game can be built and not necessarily a definitive game design for a given communication network course. Other game designs are possible while following the framework by using different tools, course objectives or game design elements. With that in mind, using professional engineering tools for learning games requires that a person responsible for the game development is knowledgeable either in the course context and available tools or in the general game design process. This is because the success of the proposed design depends on the merging of the three pillars: course context, available tools and game design.

Additionally, one needs to understand that the selected tool will have constraints and limitations, which can make the game development process more complicated. For example, in the game presented here, Packet Tracer does not have the ability to present questions or track student response times by default. We had to exploit the tool's scripting interface to build these features into it. The development of the game presented in this work required a lot of creative thinking and implementing elements in a nontraditional way that probably none tried before.

The game created using the proposed framework was well received by the students. They were asked after the game to review the experience. They enjoyed the backstory about the evil hacker group, and one student commented as follows "The funniest part of the game was obviously logging into the secret server. It made me laugh so much and was certainly the best part of the game by far. Now, the rest of the game was challenging and pretty interesting, but if there is something I will miss about the game, it would surely be that secret server". Other students were a bit more reserved about focusing just on the fun part, but still acknowledged it: "really fun and every course should have something similar". Students commented on the level of challenge that the game was more difficult than they expected, but it still did not stop them from participating. They also mentioned the experience with the game in the overall course evaluation as a positive part of the course. Considering the learning in the game, all students that took part in the game did well during the course final examination. However, specific empirical data collected from 9 persons tended to support the impact of the game, but finally was found to be not significant.

6 Conclusion

The discussion of changing the way how we teach is not new. We see that more courses are given using digital education or blended learning. However, as a consequence, it is impossible to give all proper hands-on practical skills. This introduces a big challenge for teaching practical engineering skills, which is essential to perform well in real work.

The present study suggests a framework for designing educational games for engineers and showcases its application within an actual course scenario. The proposed framework incorporates the use of existing digital engineering tools or software as the foundation for the game. This incorporation allows students to deepen their understanding of the course's material and improve their skills remotely without physical labs. The process of developing such games is not trivial and it requires making a lot of decisions and thinking about how to combine learning objectives with the existing professional engineering tool in the most efficient way. It is also observed that students see such games positively as a way to learn practical skills in an efficient and fun way.

This framework has been tested and validated in post-secondary education settings through the creation of a game for a Communication Networks course. The results indicate that it is possible to design digital educational games that are constructed using professional engineering tools. This demonstration provides evidence of the feasibility and effectiveness of the proposed framework. The use of existing digital engineering tools and software as the base for educational games has been shown to be a practical and valuable approach to teaching complex engineering concepts in an engaging and interactive way.

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