POLITECNICO DI TORINO

Master's Degree Thesis in Computer Engineering

Master's Degree Thesis

Gamification in Computer Engineering Education

Supervisor

Prof. Luca ARDITO

Dr. Riccardo COPPOLA

Prof. Morisio MAURIZIO

Candidate

Kylie BEDWELL

July 2022

Summary

Gamification is a field of research that applies game-like elements to non-game scenarios with the aim of increasing the interest and motivation of people working within these scenarios. In computer engineer education gamification can be used as a tool to increase the engagement of students with learning processes. This study used the principles of gamification to design a supplementary learning tool for the teaching of information systems technology, in particular to improve student understanding and use of Business Process Model and Notation (BPMN) diagrams.

The goal of this study was to design a gamified tool for the teaching of BPMN and to analyse the effectiveness of different game elements at increasing student motivation and performance. From an analysis of relevant literature it was determined that further research into the cruciality of the various game elements was required. A prototype web application (known as BIPMIN) was thus developed which implemented three different designs, each one incorporating different game elements relating to either progress, competition or rewards based elements.

The design of the gamified web application included: the development of the requirements; an analysis of software tools available; the analysis and selection of appropriate game elements to be incorporated; the design and implementation of an evaluation engine for automatic assessment of BPMN diagrams; the design and testing of a graphical user interface; and the selection of an appropriate software architecture for the application.

An evaluation was then conducted on the prototype to evaluate and improve the usability of the tool and the effectiveness of the game-like components. The trial program involved volunteer participants from the cohort of masters in engineering students who were asked to complete a number of tasks using the BIPMIN prototype. These tasks aimed to answer two specific research questions:

1. *Is the system usable by students of computer engineering?*, and
2. *Which game elements are the most important for motivating students?*.

The results of the evaluation indicated that the application had a positive effect on improving students BPMN modelling practices. The usability of the application was assessed as very good, scoring an average of 85.8 using the System Usability

Scale (SUS), and participants of the trial expressed pleasure at the intuitive design and ease of use of the application. The design incorporating rewards based game elements was found to be the most motivational for students, performing consistently strongly in all criteria when compared to the progress and competition based designs. Individual game elements were also assessed and compared, with the following elements determined to be the most motivational:

1. rewards,
2. levels,
3. progress bars, and
4. aesthetics.

This study provided a preliminary assessment of the effectiveness of different game elements when incorporated into a tool for learning BPMN. Further analysis is recommended to confirm the results of this study with a larger sample of students within a classroom environment. It is envisaged that BIPMIN will be incorporated into the teaching program of information systems technology, and this would allow for a more comprehensive and quantitative assessment of the effectiveness of the tool and of gamification as a teaching strategy.

Acknowledgements

I would like to thank my supervisors for their assistance in formulating and developing my thesis. In particular I would to thank Dr. Riccardo Coppola for his guidance, support and availability throughout the development of my thesis despite his temporary relocation to another country.

I would also like to thank Mr Tommaso Fulcini for his help facilitating the trial program.

Finally a special thank you to the engineering students from the Politecnico di Torino who volunteered to participate in the trial program, enabling the evaluation of the prototype application.

Kylie Bedwell

Contents

List of Tables

List of Figures

Acronyms

API
Application Programming Interface

BPMN
Business Process Model and Notation

GQM
Goal Question Metric

GUI
Graphical User Interface

JSON
JavaScript Object Notation

PBL
Points, Badges and Leaderboards

PC
Personal Computer

SDT
Self-Determination Theory

SE
Software engineer

SUS
System Usability Scale

XP
Experience points

Chapter 1

Introduction

Computer engineering is consistently one of the most highly demanded fields in the workplace, with computer engineering related jobs appearing frequently in the 10 most in-demand jobs in Europe [1]. Recently these skills have become even more sought after due to the digital workplace transformation accelerated by the pandemic. Part of becoming a computer engineer is understanding business processes and how they relate to information systems. In being able to accurately model business processes computer engineers can more effectively design, evaluate and implement information systems that support business needs.

At the Politecnico di Torino these skills are taught as part of the Master of Computer Engineering course. In particular, students are taught how to model and analyse organisational processes using Business Process Model and Notation (BPMN). BPMN is a standard for the graphical representation of business processes. It can be used both at a high level representing process implementation, and at the medium level during process analysis. It describes the functional and organisational aspects, i.e. who does what and when.

Students at the Politecnico often under-perform on BPMN related exercises. The modelling of business processes and their implementation with BPMN is not well understood. BPMN is currently taught at the Politecnico using traditional teaching methods such as lectures and laboratories. However these teaching methods are being reviewed in the hope of improving student performance. Teachers of the Information Systems course are considering the potential augmentation of new teaching methods such as gamification into their curriculum.

Gamification is a relatively new field of research aimed at applying game-like elements to non-game scenarios. Games are well designed to capture players interest and motivations, and by applying elements of games to non-game contexts such as the education environment, researchers hope to harness and direct their motivational power.

Recent studies on the effectiveness of gamification have reported success at using

gamification to increase the motivation and participation of students [2, 3, 4, 5]. Many of these studies also reported an increase in performance by students that participated in the gamified version of their experiment [3, 4, 6, 7, 8]. However, other studies have reported mixed results [9, 10, 11], deducing that the success of the gamified system is highly dependent on the design and implementation of the game elements. From an analysis of the literature available it is clear that further research on the suitability of gamification to different scenarios and how to design an effective gamified system is required.

1.1 Goal

The main goal of this study was to design a gamified tool for the teaching of BPMN and to analyse its effectiveness as a strategy for the education of BPMN. This study also had a secondary goal of analysing the effectiveness of different game elements at increasing student motivation, which was identified as a gap in the current literature.

An experiment was conducted on several gamification designs, to both analyse their effectiveness at increasing student motivation and their potential for increasing student performance with regard to creating accurate BPMN diagrams. Several different game elements were assessed and compared with each other, and potential integrations identified.

At the completion of the study a recommendation was made on whether or not to incorporate gamification into the teaching of BPMN, as well as proposals for the design of the gamified system.

1.2 Scope

This study involved the implementation of a prototype web application. The development part of this study was limited to the application of gamification to existing methods. Consequently, existing tools were incorporated into the application for managing the BPMN diagram creation and linting.

Three different versions of the web application were developed, each designed using different game elements. Since the number of game elements and their combinations is large, this study limited its assessment of game elements to the three different designs, which paired related game elements together. The three types of game elements assessed were those related to progress, competition, and rewards.

The web application designs were assessed by conducting a trial on student volunteers from the Master of Computer Engineering course at the Politecnico di Torino.

1.3 BPMN Tools

Several tools exist in the market for creating BPMN diagrams. Signavio [12] is the tool currently in use by professors of the Information Systems course at the Politecnico di Torino. It is a professional software that provides a clear and intuitive layout for creating BPMN diagrams, as well as incorporating error checking with notification to the user (linting). Other professional software packages offering BPMN modelling include Adonis [13], Bizagi [14] and Cardanit [15], which also offer cloud based services. However all of these tools are closed-source applications and do not offer the ability to implement extensions.

The Eclipse Foundation offers a BPMN2 Modeler [16], which is available as a plug-in for eclipse. It also provides extension points for developers to customise its appearance and behaviour. Camunda also offers several BPMN solutions. BPMN modelling is incorporated as part of the Camunda Modeler [17], which is a stand-alone desktop application. Camunda has published an Application Programming Interface (API) giving developers the ability to develop plug-ins for Camunda Modeler. They also offer their BPMN modelling toolkit BPMN.io [18] as a free web-based tool for developing diagrams. Additionally, their underlying engine bpmn.js is provided open source and is available for directly embedding in custom made web applications.

Out of the available options, bpmn.js was chosen as the BPMN modelling tool to use for this study. It provided the ability to design a custom web application, incorporating the BPMN modeler component as an embedded application. In this way the gamification design elements could become the focus of the application, and the interface could therefore be the clearest. Bpmn.js was also deemed the simplest to interact with, providing developers with more control over its functionality. Being an open source tool, bpmn.js also has a community of developers which have published various extensions and implementations. One such extension is the incorporation of a linting tool based on standard BPMN rules, which was also able to be included in the custom made web application for this study.

Chapter 2

Background and Related Work

2.1 Gamification

Gamification is commonly defined as "the use of game design elements in non-game contexts" [19, 20, 9, 21], as proposed by Deterding [22]. It involves the application of game principles and mechanics to enhance the user experience of tools that were designed for non-game purposes.

The main goal of gamification is to increase the motivation of users to interact with a system or use a given process [23, 24]. It does so by addressing the three basic human needs from self-determination theory: the need for competence, the need for autonomy and the need for relatedness [24, 25, 26].

Gamification learns from the experiences and research developments of the game industry, identifying and extracting those features of games which motivate players and make the experience enjoyable, and applying them to different industries and environments [20]. The game industry over the years has refined techniques for optimising human motivation and engagement [23], resulting in a set of game elements tailored to human motivation. For example: the need for competence has been address by providing the player with opportunities to earn points, awards and badges and compare their competence with other players through leaderboards [24]; the need for autonomy has been addressed by providing players with choice of avatars, diverging story paths, choice of ways to play [27]; and the need for connection has been addressed with meaningful story lines centred around the player, cooperative game play (with real or simulated players) [24], and through game related discussion forums [27]. These game elements over the last decade have been increasingly applied to non-game contexts.

Games have been around for centuries, however gamification as a concept was

only recently formally established, with the term's first documented use in 2008 [22]. Gamification initially emerged from the marketing and digital media industry, then experienced widespread adoption in mid-2010 [22, 19]. The idea that gamification could be used to improve motivation of users was widely accepted [24], however conclusive evidence to support this hypothesis was lacking [25, 20].

In the workplace, gamification has been identified as a useful tool for improving the usability of complex systems, enhancing social interaction among colleagues, and increasing the motivation of staff to perform their assigned tasks [21]. It has been adopted in many different industries, including: the health sector; government; and education [28].

2.1.1 Gamification in Education

Gamification has been increasingly used in the education sector as a tool to motivate student learning [25]. In the classroom, gamification has been an effective tool for lowering the learning curve of complex topics [29, 2], increasing student motivation to complete tasks [5], and also as a tool for countering boredom and feelings of loneliness for users of online learning platforms [9]. It is seen as a solution for meeting the needs of next generation students [19].

Gamification and gamified learning is not to be confused with game-based learning. Game-based learning involves the specific development of a game that is designed for educational purposes, i.e. has the goal of teaching students about a particular subject [19]. Gamified learning on the other hand is not a complete game, but rather uses some game-like elements to enhance existing learning processes [25], for example an online learning tool.

Methods for applying gamification techniques to education practices are still being researched and developed. The process for their application can be time-consuming for educators and their effectiveness is varied, with some gamification studies showing detrimental effect on learning outcomes [19]. The challenges of designing an effective gamified learning system are complex, requiring a deep understanding of motivational mechanisms, which are not well understood or implemented [30]. In response to the need for a more robust gamification design process, and to ease the burden on educators, several gamification frameworks have been proposed [30, 31, 32, 33].

2.1.2 Gamification in Computer Engineering

The use of gamification in education is especially suited to material that is difficult, tedious, or requires intensive collaboration [20]. Applying gamification techniques to repetitive or monotonous tasks can help make these tasks move engaging to students [21, 34]. For this reason gamification has been considered particularly suitable

for the education of computer engineering subjects [19]. Computer engineering requires students to learn a number of different programming languages. For many students, learning computer programming is a difficult task [2, 35]. They also lack motivation and interest in the subject due to its monotonous nature [34, 3].

Employing gamification techniques to the education of computer engineering is still in its infancy [19]. However, over the last decade studies have emerged regarding the effectiveness of gamification in the field, in particular for learning computer programming. For example, Marin et. al. [2] applied gamification to the teaching of C programming at university, and found that it had a statistically significant positive effect on student learning performance. Prabawa et.al. [3] created a gamified media application to support the learning of basic programming concepts, finding that students were more engaged in the learning process and showed better understanding of the concepts. Tasadduq et. al. [6] explored the effects of gamification on students with a rote learning background, and found no significant effect of gamification on the motivation of students, however the students in the gamified track performed significantly better in the assessments. These studies all concede however that further research in the field on the effectiveness of gamification and its method of application to computer engineering is required.

Software testing is another area of computer engineering that has been found to benefit from gamification. The testing phase of software development is hugely important in preventing costly software bugs. It requires developers to invest significant time and effort into creating and running thorough tests, a task that is often perceived as boring and repetitive [36, 7]. Gamification has been proposed as a tool to increase the engagement of developers in the testing phase. For example, Cacciotto et. al. [36] proposed a set of metrics, visuals and a scoring scheme to gamify graphical user interface system testing for web and mobile applications. Fraser et. al. [37] made use of the Code Defenders tool [38] in a software testing university course. Students were split into teams: one team behaving as the attackers with the goal of introducing bugs into the code; the other team behaving as the defenders writing tests to catch the bugs. The study found that students engaged actively in the gamification aspects of the course and their testing skills improved over the semester with its use. Rojas et. al. [8] in a separate study on a crowdsourcing scenario also found that using the Code Defenders tool resulted in stronger test suites with higher coverage than automated test generation tools.

Online learning has also been identified as an area for improvement through gamification techniques. Virtual learning environments have been found to create a sense of loneliness for students, with a consequent reduction in student involvement [9, 39]. Olsson et. al. [9] proposed the use of game inspired visualisations, such as progress bars and digital badges, to increase student motivation to participate in

online learning for programming education. The study found that progress bars were beneficial in aiding participants to navigate the online environment. The effectiveness of badges on student motivation however varied, with the authors acknowledging that the main driver for student participation in the learning process was course grades.

2.2 Principles

Gamification principles are the broad aspects of games which make them appealing and motivate players to continue playing the game. When extracted from games these principles can be used in non-game scenarios with the same effect of creating an appealing system which users are motivated to engage with. Various authors have attempted to formalise and label these principles, Reeves and Read [40] proposed ten ingredients for great games, Chou [41] created a framework for gamification based on eight principles, Oprescu et. al. [42] proposed ten principles of gamification for transforming work practices , and Rojas-López and Rincón-Flores [4] summarised the principles into a set of four dynamics. The proposed principles are listed in Table 2.1. Each of these principles was proposed with different goals in mind, however some trends and similarities can be identified. There are common themes regarding individual representation, social engagement, sense of achievement and entertainment. All of these principles attempt to comprehend the human motivational psychology and how games have achieved such desirable effects on people.

2.2.1 Psychology

To fully comprehend how gamification principles motivate people it is necessary to study human psychology. In the field of psychology, human motivation can be described by self-determination theory (SDT). Though it covers a broad area, when applied to gamification SDT has been summarised as the human psychological need for autonomy, competence and relatedness [24, 25, 26].

Autonomy regards the freedom to make decisions independently, and also willingness to engage in a task [24, 43]. The need for autonomy can be satisfied by providing users with choice and non-controlling instructions [43], e.g. offering different ways to complete a task, or providing guides on how to complete a task but not enforcing the procedure be followed. Conversely, restricting choice or freedom can interfere with the sense of autonomy and undermine user motivation [43]. In the context of gamification, game elements that address the need for autonomy can include: the creation of personal profiles or avatars; experiencing a meaningful story; and providing a non-fixed structure [27, 24].

Reeves and Read [40]	**Chou** [41]
Self-representation with avatars Three-dimensional environments Narrative context Feedback Reputations, ranks and levels Marketplaces and economies Teams Competition under rules that are explicit and enforced Parallel communication systems that can be easily reconfigured Time pressure	Epic meaning Accomplishment Ownership Scarcity Avoidance Unpredictability Social Influence Empowerment
Oprescu et. al. [42]	**Rojas-López and Rincón-Flores** [4]
I orientation Persuasive elements Learning orientation Achievement based rewards Y generation adaptable Amusement factors Transformative Well-being oriented Research generating Knowledge-based	Emotive Narrative Progression Social

Table 2.1: Principles of gamification.

Competence is the feeling of effectiveness, being able to overcome a challenge and enjoying a sense of accomplishment. The need for competence can be satisfied by providing users with the opportunity to learn new skills, offering challenging tasks, or giving positive feedback [43]. Game elements that can be used to create the feeling of competence include: intuitive controls; immediate positive feedback; optimal challenges; and a progressive learning curve [43, 25, 26].

Relatedness refers to the feeling of connection with people, of belonging to a group or society, and being part of something bigger than oneself [24, 26]. The need for relatedness can by satisfied by incorporating ways of interacting, or comparing achievements with other users into a system. These interactions can be achieved by social media elements such as ratings, commenting and sharing, or by game elements such as badges, levels and leaderboards [26]. It can also be achieved by providing means to compete directly with other users, or to work cooperatively

and collaborate on a task or given objective [27].

Theoretically, a gamified system will be successful if it can effectively satisfy all three of the SDT psychological needs. It should be noted however that although multi-player games, or games with multi-player or social elements, which address these three needs have proven successful in the game industry, there is still a significant portion of successful games that are single player only, with no social elements (apart from those provided by external parties, such as discussion forums and trophy systems) [44, 45, 46]. Either these single player games satisfy well the needs of autonomy and competence, without the need for relatedness, or they are able to satisfy the need for relatedness by connecting players with fictional characters and communities.

2.2.2 Motivators

Satisfying human psychological needs is a key tactic for gamifying systems, however it is also important to understand users motivations for using the system in the first instance. Motivations can be categorised a number of ways: intrinsic vs. extrinsic motivators; or positive vs. negative motivators.

Extrinsic motivators are external to the system, providing users with rewards for interacting with the system. For example, when using a system for university education purposes the extrinsic motivation for students is to pass their university course with high grades, and to successfully obtain their degree [9]. Extrinsic motivators can also come in the form of monetary incentives, extra credits, physical gifts, or even status among peers. Intrinsic motivators on the other hand are internal to the system and also internal to the user, i.e. the system provides rewards that are intangible, and users seek feelings of satisfaction and accomplishment simply by performing tasks within the system. For example, the majority of video game players do so for fun, and do not receive any tangible rewards from their achievements [43]. In some instances video game players can even receive negative external outcomes [47], suggesting that intrinsic motivation in games can be very strong. In gamification the focus is on adding intrinsic motivators to systems, learning from the strong intrinsic motivations that video games can induce. However, commonly users will already have an extrinsic motivation to use the system. These two forms of motivators can interfere with each other [9], and so a balance should be found.

Positive motivators are those which provide the user with a reward for accomplishing a task, for example, providing a dog with a treat for performing a handshake when requested by a trainer. Negative motivators on the other hand punish the user if they do not accomplish their task, for example, removing access to play time from a student that has not completed their homework on time. The argument for the use of positive vs. negative motivators is the proverbial “carrot or the stick”

discussion: are rewards more effective motivational tools than punishments? A study by Andreoni et. al. [48] found that rewards on their own were relatively ineffective, punishments were somewhat effective, but the best results were achieved by combining both rewards and punishments. They found that simply having punishments exist was enough of an incentive for participants to seek the rewards. Podczervinski et. al. [49] also conducted a study on the effectiveness of incentives vs. disincentives in a medical employee influenza vaccination campaign. Though both motivations improved the vaccination rates of staff at the center, they found the disincentives to be more effective at improving the vaccination rate. In gaming, both positive and negative motivators can exist. Examples of positive motivators include rewards, prizes and badges for completing tasks [23]; examples of negative motivators include seeing your in-game pets wither due to neglect [50] or having non-playable characters complain that they haven't seen you around for awhile [51]. Achieving the right balance between positive and negative motivators is important to ensuring an enjoyable and productive experience for users.

2.3 Game Elements

Game elements are those components of games which have been created to meet the motivational needs of players. There is not a strict definition of what constitutes a game element compared to merely an element of digital applications, nor a strict boundary between what constitutes a game principle compared to a game element [22, 24]. For the purposes of this study game elements are considered to be those components of games which can be extracted and applied to applications in non-game contexts, and which are noticeably repeated in many successful games, such as the existence of a point system or a reward scheme.

Many studies have characterised the game elements in different ways, with various different lists and descriptions of the elements [24, 21, 20, 52]. The following sections provide a list of common game elements and their use in scientific studies on the effectiveness of gamification[1]. This list is not exhaustive but represents those elements which were considered for use in this study. The game elements have been categorised into five separate themes: those relating to rewards, accomplishment, social engagement, adventure, and design.

[1]It should be noted that many of the studies reported here used a combination of multiple game elements. Each study has been discussed under the game element of most relevance to the study, however their results should not be considered indicative of the effectiveness of a single game element alone.

2.3.1 Rewards

Rewards entail game elements that give something to the user in exchange for them completing a task. These rewards are often intangible in the real world but provide intrinsic motivation to the user.

Points are a basic element of many games. They are in essence a numerical counter that grows as players complete tasks. Points can come in many formats, e.g. experience points (XP), skill points, or reputation, and serve as an indicator of player progress through the game [24]. Points can be simply a progress indicator, or used as a form of currency for buying in-game items or unlockables.

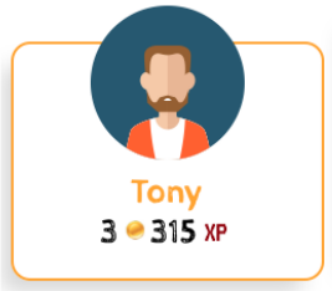


Figure 2.1: Example of points (source: Bucchiarone et. al. [29]).

Point-based systems have been used in many gamification studies [29, 2, 6, 53]. Bucchiarone et. al. [29] created a point based gamified version of the Papyrus [54] modelling tool. In their gamified version of the tool students can earn both experience points and gold coins for completing exercises within Papyrus. Experience points can be exchanged for gold coins, and the coins can be used to reduce the task load for their assignments. Their display of user's points and gold coins is shown in Figure 2.1.

Badges, achievements and medals are all different terms for a similar concept: a reward for achieving a specific goal. They are a visible indicator of the players accomplishments, commonly represented with a specific picture or icon relevant to the accomplished task. Badges are usually optional to obtain but encourage players to perform additional tasks or experiment with different ways of interacting with the system [21, 24]. Badges can also be a form of social motivation by creating the essence of belonging to an exclusive club, especially if the badges are difficult to earn [24].

Badges are a common tool in gamification studies [2, 9, 6, 34, 4, 7]. A study by Marin et. al. [2] analysed a number of past studies that used badges and found that whilst some studies reported improvements in understanding and interaction

of students using gamified versions, other studies reported gamification had no significant effect on student behaviour. Marin et. al. also then incorporated medals into their gamified application for the teaching of a programming course. These medals were tied to images of related content and were awarded for correctly completing challenges. The study reported statistically significant improvement in the academic results of students using the gamified application compared to the control group.

Prizes are items that users receive for achieving a task or goal. These items can be tangible, such as extra marks for a graded course for the student at the top of the leaderboard, or intangible, such as in-game items or currency. Prizes can provide either extrinsic or intrinsic motivation for users of a system depending on their nature. In this study gamification is being assessed as a tool for inciting motivational behaviours in users, and therefore only intangible prizes are considered (tangible prizes are considered as a separate motivational tool to gamification). Intangible prizes are in-game rewards that provide either an improvement to the user's abilities or are coveted items that are simply a pleasure to own, for example a special costume for the user's avatar.

Intangible prizes have not been explored by many gamification studies, however Matsubara and da Silva [10] proposed the use of virtual currency to purchase virtual goods for use within their gamified system. In their proposal students could either buy the goods directly using currency they had earned through completing tasks, or exchange the goods as gifts among other students.

2.3.2 Accomplishment

Creating a sense of accomplishment is one method in which games satisfy the human psychological need for competence. This can be achieved a number of different ways, for example by clearly displaying user progress and development, or by providing specific challenging tasks for users to overcome.

Progress bars are one method of displaying user progress through a system. Similar to those seen when loading a web page, progress bars are horizontal rectangles that are filled to a certain point to indicate how much of a task a user has completed. Applications can make use of many progress bars, some indicating completion of a specific tasks, with others indicating overall progress for a larger exercise.

Olsson et. al. [9] implemented progress bars as a feature in their study on the gamification of e-learning. They found that overall the visualisation of progress was appreciated by the participants, allowing them to more easily track their progress and see what exercises still needed to be completed. However some participants

didn't notice the progress bar, or felt that more feedback was required, indicating that careful design of the progress bars is an important factor in its effectiveness. Additionally, they discovered that the progress bar proved to be a useful tool for teachers of the course to analyse student engagement, and could be used as an early warning sign of issues to be addressed.

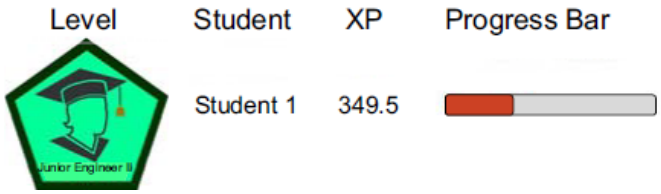


Figure 2.2: Example of levels and progress bars (source: Matsubara and daSilva [10]).

Levels are attached to the user's profile or avatar, and are a method of indicating the user's experience with using a system. Commonly, there are a fixed number of levels available, which could be either numbered sequentially or labelled according to experience, for example from novice to master. As the user completes tasks their experience improves and this is indicated by a transition to the next level. Levels are generally tied to experience points (XP) but any counter can be used to indicate progress to the next level.

Levels have been used in various gamification studies [6, 36, 10]. Matsubara and da Silva [10] used a set of five levels ranging from Junior Software Engineer (SE) to Senior SE in their case study on the effect of game elements in a software engineering study group. To transition between levels the students were required to earn a specified amount of XP and in some cases complete a relevant quest. Figure 2.2 shows these levels and their associated progress bars connected to XP. The results of the study shows that the completion of quests was a significant hurdle for many students, who did not manage to progress past the second level, which required the completion of a quest. Student did not have the time required to complete the quests, and preferred to complete the more efficient quizzes instead. A recommendation of the study is to ensure that the points gained from activities are appropriate for their difficulty and time requirements.

Challenges are difficult tasks that require persistence, dedication and the display of skill to overcome. Challenges are a key element of gaming, allowing players to test their skills and prove their competence at the game-play. In games, challenges are typically labelled as 'boss fights' and consist of a larger and longer challenge than experienced during regular game-play.

In the field of gamification, challenges can also be used as a method for testing participant's skills, providing them with an arena for proving their competence at a given activity. Similarly to games, challenges in gamified applications consist of completing a larger task than would be required during regular use of the application. Challenges can be commonly tied with badges and achievements, given as rewards for completing the challenges.

A study by Rojas-López and Rincón-Flores [4] on the effects of gamification applied to a university programming course made use of challenges coupled with points, badges and a leaderboard. Students were splits into teams and asked to complete challenges to earn points. Results of the study found that students' understanding of the topic was improved by participating in the team challenges, and that students were motivated to see their achievements displayed on the leaderboard. The study also recommended careful design of the challenges with respect to time required and ability of the students so as to optimise the outcomes.

2.3.3 Social Engagement

Social engagement involves interactions with other people, nurturing a feeling of belonging to society. Game elements that employ social engagement techniques aim to satisfy the human psychological need for relatedness. These game elements are generally secondary to the main interactions of the user, providing incentives for the user to interact further with the application or task.

Discussion forums provide a way for users to discuss their interactions with a system. They can be either external to the system, or integrated within the system. Discussion forums are an online place for users to post questions and seek answers from other community members, enabling the discussion of various topics. In games, discussion forums are usually external to the game but provide players with a place to explore a shared experience, gaining a sense of belonging to a community of other players, and giving them motivation and assistance to progress further in the game. In an e-learning environment these forums can help students to overcome difficult problems together, and can reduce the feeling of loneliness that some students may experience due to their participation in online-only learning courses [9].

A study by Tasadduq et. al. [6] included the use of a discussion forum to promote collaboration in their study on the use of gamification in learning computer programming. They found that student interaction with the forum was tentative at first, and due to low responses the use of the forum declined over time. These findings were contrary to those of Knutas et. al. [55] who found that students actively participated in discussion forums.

Leaderboards compare the performance of users against their peers. They are generally shown as a table of rankings, using a given performance metric (such as points or badges earned) to sort users from highest to lowest ranked. For systems with a large number of users the leaderboards often only display a portion of the top users, for example the top ten highest ranked. Leaderboards make use of the competitive nature in humans, displaying users performance compared to their peers with the goal of motivating them to improve their performance and climb the leaderboard [24].

Leaderboards have been used in many gamification studies [5, 2, 4, 36, 53, 56]. Marin et. al. [2] did a study on the use of a gamified platform in a university programming course. They found that the existence of the leaderboard was successful in engaging the student's competitive nature, with students actively wanting to obtain a higher ranking to beat their peers. A study by Ayub et. al. [5] on gamification in blended learning also found that leaderboards provided extra motivation for students to complete tasks because they wished to compete with one another. In the study by Rojas-López and Rincón-Flores [4] however some students did not like the leaderboard. As in the study by Hanus and Fox [11] leaderboards were found to have the potential for harming motivation, because students low on the leaderboard can become disinterested from the extra pressure.

Competition and Cooperation involves users working directly either against one another or with each other to achieve a shared task. Separately from leaderboards, competition in this game element refers to direct competition with a peer in a one versus one scenario for individual competition, or as a group against another group of peers for team based competitions. Cooperation refers to users working with other users to achieve a common goal. This can be either as a member of an explicitly defined team, or as part of a fluid collective.

The element of competition and cooperation was used by Fraser et. al. [37] in their study on gamification in a software testing course. As reported in section 2.1.2, they made use of the Code Defenders tool [38] to pit student teams against each other to develop comprehensive software tests. The use of both competition and cooperation was successful in improving student performance.

A study by Dubois and Tamburrelli [32] used competition as a game element in a software engineering course by allowing student teams in one experiment to see the live performance metrics of other teams. The results from this experiment were compared to a baseline experiment where students could not see the other teams' metrics and were found to perform slightly better, especially in terms of test coverage and documentation.

Akpolat and Slany [57] made use of both competition and cooperation in their study on student engagement in an extreme programming course. In the study students were split into teams of 10, and competed against other teams in weekly

challenges. An overall winner was declared at the end of the course as the team who won the most challenges. Their study found that students engaged more with topics that were part of the weekly challenge, and skills learned from those challenges remained present in future challenges. A key recommendation from the study was to properly design the gamification techniques, by ensuring the creation of a rating scheme that is easy to understand and also providing challenges that have a balanced difficulty level. It was acknowledged that further study in the field is required to better develop appropriate design guidelines.

2.3.4 Adventure

Game elements under the adventure theme aim to motivate users through entertainment. This can be achieved by providing an interesting narrative, compelling users to continue their use of the system to progress through a story. Developers can also use aspects of mystery and the discovery of secrets to encourage users to thoroughly explore their systems.

Story telling applies a narrative to the experience of using a system. Also referred to as meaningful stories, they give meaning to the use of a gamified system beyond merely the pursuit of points and achievements [24]. These stories can be included directly with descriptions or audio-visual narratives, and also contextualised in elements of the gamified system. An example of narrative-based gamification is the popular running mobile application Zombies Run [58]. The main purpose of the app is for health and fitness, it tracks workouts and provides statistics and training programs. However on top of the fitness application is a detailed story portraying the user as a survivor of a zombie epidemic, whose role is to gather supplies as a runner for the remaining human outposts. This story is provided to the user mainly through audio files, however further aspects of the narrative are contextualised in interactive elements of the application such as a base builder where users can upgrade their base using supplies gathered during their run.

The importance of including narrative-based elements in gamification systems was identified by Trinidad et. al. [59]. They identified the need for including narrative to enhance the effectiveness of other game elements. Trinidad et. al. developed a narrative-based gamification suite called GoRace which immerses participants in an ancient Olympic race to achieve immortality. Participants complete real-life activities to earn rewards in GoRace which they can use to purchase virtual items to compete in the race. The system makes use of both a video trailer to introduce the story, and contextual elements to enhance the users immersion. GoRace has been tested in various scenarios in the educational domain, and the results from user questionnaires proved the system performed well

in usability, social interaction and fun.

Quests are tasks to be completed by the user. They are similar to the challenges game element mentioned previously, however quests expand on these by providing a narrative aspect to the challenge. These narrative aspects provide a fictional reason for users to complete the tasks. They can be either independent stories or part of the overarching narrative for a system.

Sheth et. al. [56] made use of quests in their study on using gamification to improve the engagement of students in the software testing process. They developed a plugin for Eclipse called HALO which provides students with quests as incentives to thoroughly complete their assignments. These quests contained a narrative element that was themed to popular culture at the time. Feedback from students revealed that the quests helped them in making sure they did everything required for the assignment, and they also appreciated the links to popular culture. However some students found the quests too trivial and were a distraction to completing the tasks. The study therefore recommends implementing quests that are dynamically adaptable to the skill of the student to be a more effective engagement tool.

Avatars are visual representations of users displayed within a gamified system [24]. They can either be selected by the user from a set list of avatar choices, or created and designed by the user. Avatars give users the opportunity to express their personality and character separate from their physical appearance. In this way they can provide a means of social interaction with a potentially different experience compared to the real world.

Avatars have been present in many gamification experiments [29, 6, 4, 11, 59]. Tasadduq et. al. [6] allowed students to change their avatar pictures and names such that students could be anonymous if desired, yet still display their character. Rojas-López and Rincón-Flores allowed teams to design their own avatar, enhancing each members sense of belonging to the team. They did not use avatars for individual students, and found that students would have preferred to use avatars rather than their own names. Trinidad et. al. [59] also found success by the use of avatars, with feedback from users of their system requesting more features to customize their avatars.

Easter Eggs are hidden surprises that can be discovered by users of a system. They are generally camouflaged and require users to search deeply within a system to uncover them. Easter eggs are used to encourage exploration and reward dedicated users.

Easter eggs were used in a proposal by Cacciotto et. al. [36] on the gamification of graphical user interface testing. In their gamification tool Easter eggs would appear to users after interacting with randomly chosen elements, with the purpose

of encouraging users to interact with as many elements as possible. In their experiment the eggs would help to make the testing procedure more thorough. In their follow up study [60] the gamification mechanics were indeed found to encourage more thorough exploratory testing.

2.3.5 Design

The final theme of game elements considered in this study is that of design. Design game elements are those elements that make a system feel like a game environment even if it is not. This covers higher level attributes such as the aesthetics, responsiveness and behaviour of the interface. These design elements can trigger recognition and comfort from users with game experience, as well as create those feelings for new users as they would in games.

Aesthetics covers the look and feel of a user interface. This includes, but is not limited to, the colour scheme, layout of components, font choices and animations. The aesthetics of a user interface are of major importance when it comes to the effective use of gamification concepts [24].

Prabawa et. al. [3] made use of aesthetic elements in their study on using gamification to teach basic programming. They incorporated themes in their application that harmonised colour and picture, using attributes of nature and adventure to immerse students in the feel of the game. Their gamified platform received a positive response from students and had a positive impact on their learning.

In contrast, a study by Mekler et. al. [61] which did not focus on aesthetics found reduced effectiveness of gamification elements on student motivation. This study concluded that a more appealing presentation of the gamification elements could have improved their effectiveness. This reinforces the importance of design and aesthetics in successful implementation of gamification concepts.

Feedback covers a broad design aspect which is particularly important when used in an educational environment. Feedback in a computer application includes interactive tutorials, error warnings, correction suggestions and notifications for correct completions of tasks. These types of immediate feedback which can be provided by a computer application to many students at once, as opposed to students waiting their turn for individual feedback from a teacher, can enable an accelerated learning environment.

A study by Buisman and Eekelen [53] noted the potential of immediate feedback, as used by the video game industry, in the learning environment. Their study on the application of gamification to educational software development made use of immediate feedback elements to guide students towards important actions. They

found that the use of positive feedback in their gamified platform was effective at increasing student's use of their system.

2.3.6 Summary

A total of 15 different game elements across 25 separate studies have been analysed. The usage of each game element in the 25 considered studies is shown in Figure 2.3. Points, badges and leaderboards are shown to be the most common game elements used in the gamification studies analysed. This trio of game elements is commonly referred to as PBL (Points, Badges and Leaderboards) and is considered by some authors to be an over-simplification of the elements that make games attractive [59, 61]. Although many authors apply the PBL trio to gamification studies, their effectiveness at increasing motivation and suitability for different scenarios has not been well proven [19].

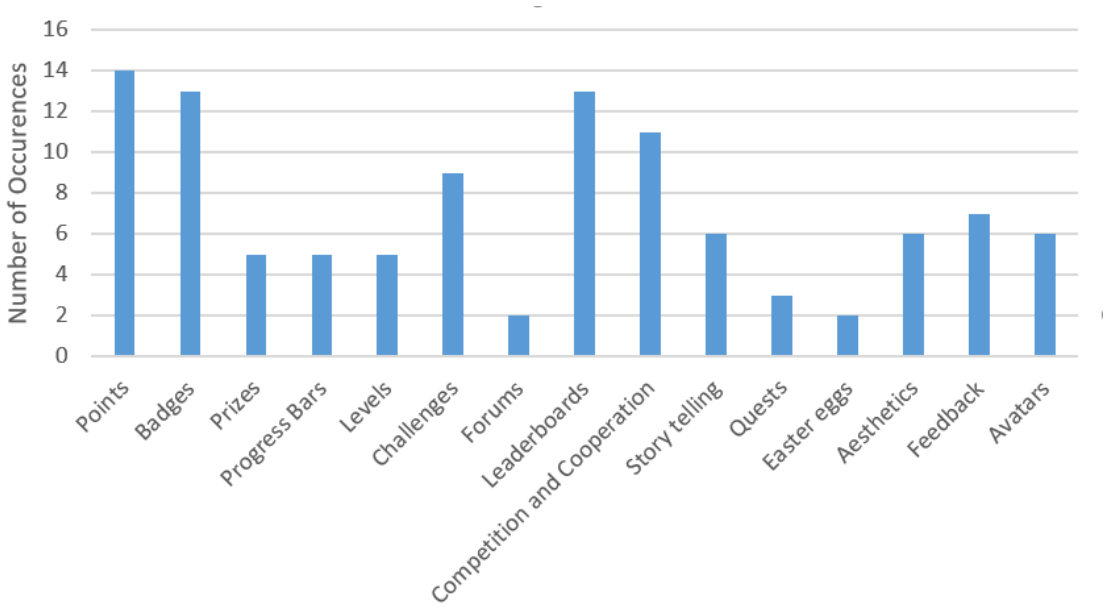


Figure 2.3: Occurrences of game elements in analysed literature.

Additionally, many of the studies analysed use a combination of multiple game elements, therefore it is difficult to assess the effectiveness of any one particular game element on its own. Many game elements are also interdependent, relying on the existence of each other to function. For example, leaderboards need a point or achievement based system to compare performance; levels require a measure of experience; and progress requires tasks to complete (quizzes, challenges or quests). Although some authors have attempted to analyse the effectiveness of different game elements [24, 61] the results so far have been inconclusive.

From the analysis of the literature it is apparent that further research is needed on which game elements are crucial for gamified applications, which elements pair well together, how each element affects users need, and how to best select appropriate game elements for a gamified system.

Chapter 3

Web Application Design

The design of the gamified web application followed software engineering design principles. Firstly the requirements were developed and available technological instruments selected. The gamification elements to be implemented were then selected with reference to the studied literature. An evaluation engine was also designed to enable the automatic assessment of the BPMN diagrams. The architecture of the software was then developed, planning the layout and integration of the software components. Finally the graphical user interface was designed using human computer interaction principles and underwent a testing process.

BIPMIN was chosen as the name for the developed web application, and is used in subsequent references to the application.

3.1 Requirements

To develop the requirements the stakeholders first needed to be identified. Table 3.1 lists the stakeholders for the prototype web application that was developed.

Stakeholder	**Description**
Student	Learns business process modelling.
Teacher	Teaches business process modelling to the students.
Developer	Develops the software used for teaching.
Third Party Software Provider	Provides tools integrated into the software.

Table 3.1: Stakeholders.

The stakeholders are paired with a context diagram shown in Figure 3.1 displaying the interaction of the key stakeholders with the system. The logical interface for

interaction is through the graphical user interface (GUI) and the physical interface is through the keyboard and mouse on a computer.

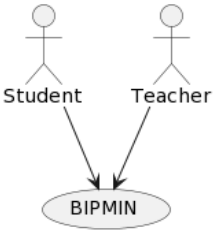


Figure 3.1: Context diagram.

The high level functional requirements for the application were defined through a use case diagram as shown in Figure 3.2. Teachers have the ability to manage account access for their students, as well as set the exercises to be completed by the students.

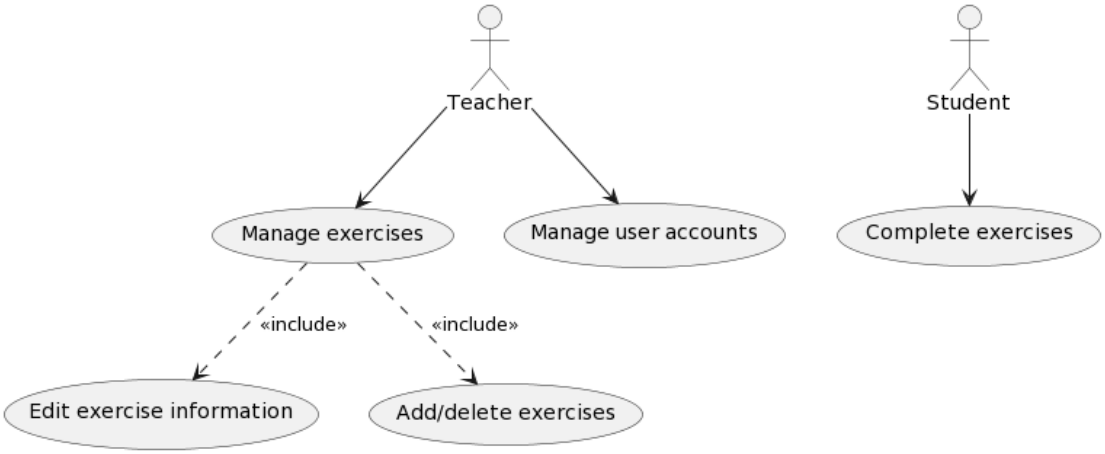


Figure 3.2: Use case diagram.

3.2 Tools

To develop the web application a number of different software tools were utilised. As mentioned in Section 1.3 bpmn.js was chosen as the BPMN modelling tool. It provides the functionality to interactively create BPMN diagrams and can be embedded into existing web applications. Figure 3.3 shows the user interface of bpmn.js. Users can click on elements in the left hand menu to add components to the diagram. There is also a quick menu which is displayed when a component is

selected, which can be used to easily add connecting components. Components of the diagram can also be easily modified and moved within the process.

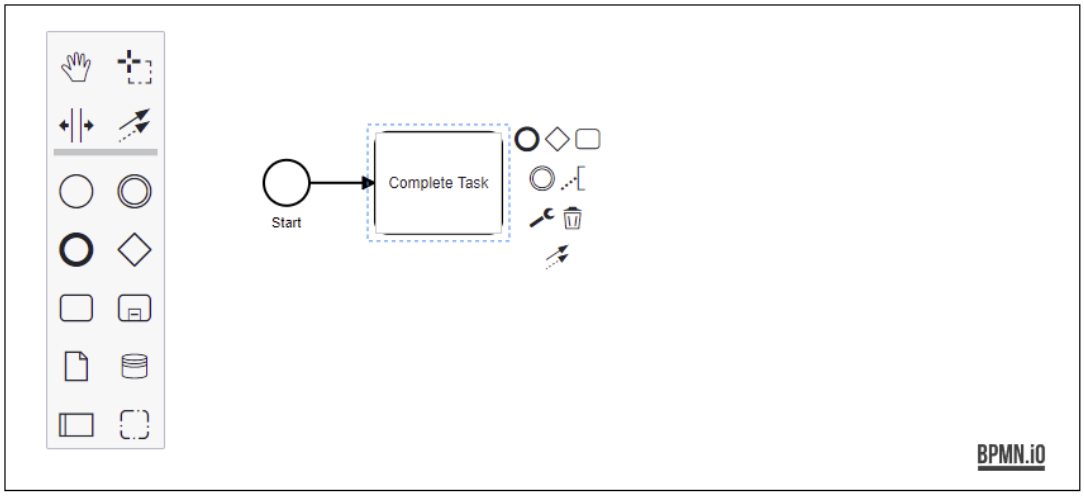


Figure 3.3: Bpmn.js graphical user interface.

Bpmn.js is written in JavaScript and provides a version for embedding that allows access to the individual components of its library. As part of the core services bpmn.js provides access to its ElementRegistry, which lists all of the components existing in the currently displayed diagram. The ElementRegistry also includes a number of APIs to retrieve elements based on different criteria, as well as providing access to their properties. This functionality was used in the BIPMIN application to create custom bpmn diagram evaluation rules, explained further in Section 3.4.1.

Being an open source project, bpmn.js as part of bpmn.io has an online community [62] where developers share examples of their usage of bpmn.js and propose extensions to the library. One extension available in the community is the bpmn-js-bpmnlint extension [63], which provides a linting functionality to the bpmn modeller. This linting functionality will validate the currently displayed diagram against a set of standard BPMN diagram rules, and display errors on the diagram when any rules have been broken. An example of the bpmn-js-bpmnlint extension incorporated into bpmn.js is shown in Figure 3.4. The bpmn-js-bpmnlint extension was also incorporated into the BIPMIN web application. It was used to provide students with feedback on their diagrams and encourage good modelling practices.

React [64] was used for the development of the front end of the BIPMIN web application. React is a component based library for creating interactive user interfaces based on JavaScript, and interacts with HTML and CSS. In particular, React was used with Bootstrap (React-Bootstrap [65]) to render bootstrap styled

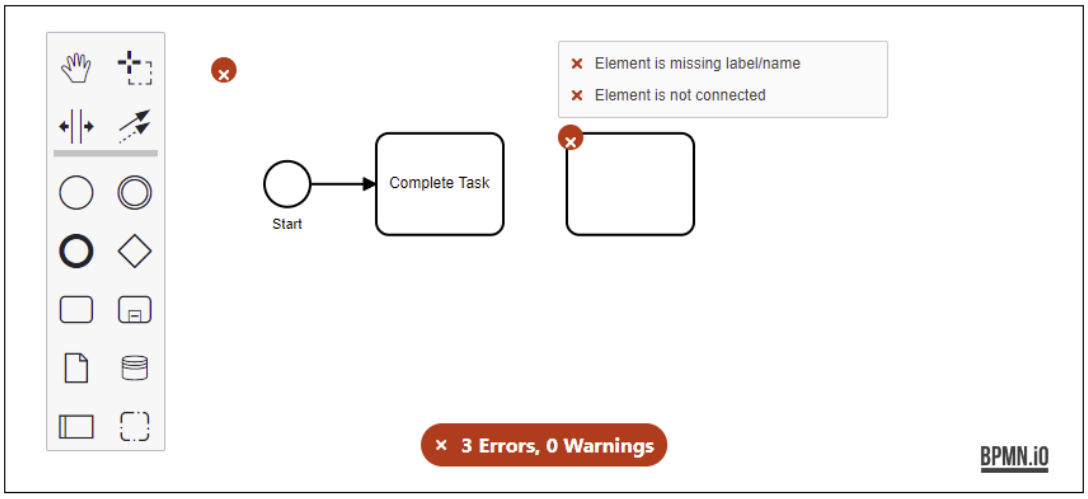


Figure 3.4: Bpmnlint incorporated into bpmn.js.

components.

Express [66] was used for the server back end of the web application. Express is a web framework for Node.js providing methods to develop a simple HTTP server. A database was also developed using SQLite [67] for storing the persistent data.

3.3 Gamification Elements

The goal of this study was to analyse the effectiveness of gamification as a strategy for the education of BPMN, with the secondary goal of analysing the effectiveness of different game elements. To achieve these goals three different versions of the gamified web application were developed, each utilising different gamification elements. The gamification elements were grouped according to motivational themes, with reference to the psychology of human motivation as discussed in Section 2.2.1. The three versions were related to:

- progress,
- competition, and
- rewards,

and were identified accordingly. These themes were chosen to better understand the importance and effectiveness of the different motivational concepts as represented in the different game elements. In the literature a common theme emerged that considered points, badges and leaderboards (PBL) as the key game elements to use

when gamifying a system (see Section 2.3.6), however this assessment has not been thoroughly investigated and other game elements may be more effective [19, 59, 61].

Progress focuses on game elements that display the users progression through a set of tasks. In this study the use of progress bars was adopted, such as the one shown in Figure 3.5. Progress can also refer to an increasing level of competence for the user. In games this competence level is often represented by a skill level. In this study a skill level was also included in this version of the web application, with users being able to progress through four different skill levels: from "Noob" to "Padawan" to "Genius" and finally to "Grandmaster". The labels of these skill levels were chosen with reference to popular culture, in an effort to be more appealing to students of Computer Engineering.

Figure 3.5: Example of a progress bar.

Competition focuses on game elements that compare users to one another. These elements provide a form of social relatedness, allowing users to assess their competence in relation to their peers. This version of the web application made use of a leaderboard to display and rank the progress of all users of the application, encouraging users to seek out the top position. In conjunction with the leaderboard it was also necessary to implement a point based system, with users earning experience points upon completion of exercises. These experience points (XP) were then used as the metric for ranking users on the leaderboard. User avatars were also included in this version, providing users with a simple way to project their personality into the system, which was also shared with their peers in the leaderboard display. Users were provided with the option of selecting from a set of 12 different avatars, each of a caricatured animal. An example of these three game elements in use is shown in Figure 3.6.

Rewards focus on awarding the user with prizes for completing tasks. These rewards can be intangible (having only meaning within the gamified system) or tangible (having real world consequences). Rewards incentivise users to complete tasks for the joy of receiving the reward. In this version of the web application rewards are intangible and are represented by pieces of a jigsaw puzzle. Upon completion of exercises users are rewarded with a number of jigsaw pieces proportional

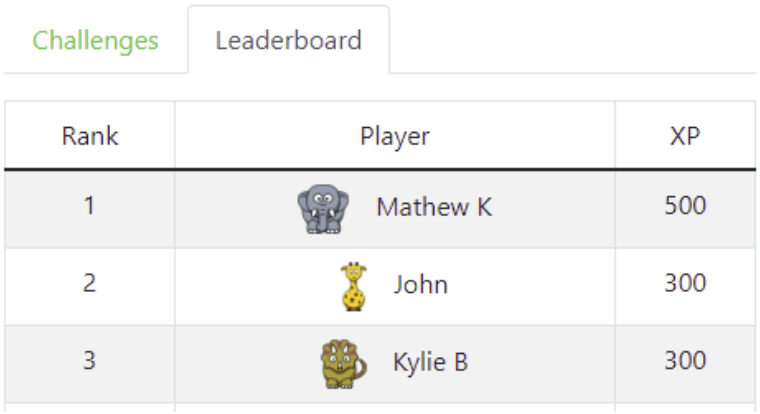


Figure 3.6: Example of a leaderboard using points and avatars.

to the difficulty of the exercise. These jigsaw pieces come together to form a hidden image, with users only able to view the portions of the image shown on the pieces they have collected. This version also implements unlockables, which is another game element related to rewards. In the web application subsequent exercises are locked and can not be attempted until a sufficient number of previous exercises have been successfully completed.

Shared elements spanning all three versions of the application include the aesthetic design and use of immediate feedback. The aesthetic design of the application endeavoured to be clear and pleasant to view, following the principles of user interface design as proposed by Benyon [68]. Users should be able to quickly understand the layout of the application and easily navigate and interact with the components. Visual components were chosen based on their ease of use and consistency with expected norms. The React-Boostrap library was used to provide visual elements consistent with modern material design [65]. A colour scheme using a lime green as the primary colour was chosen for the application. The green was chosen as it represented correctness, as a colour often used for showing success, with the goal of making users feel more successful. Gold was chosen as the colour representing the rewards, because of its association with treasure.

Immediate feedback was identified as a game element that would be beneficial for inclusion in a gamified education tool. With immediate feedback users can quickly learn from their mistakes, without having to wait for a traditional review by a teacher. Immediate feedback was implemented in the BIPMIN application through the use of a "check solution" button, which when pressed analysed the current diagram and displayed any errors to the user. If no errors were found the user is notified of their successful completion of the exercise.

3.4 Implemented Exercises

A set of exercises related to the creation of BPMN diagrams needed to be developed for use in testing the BIPMIN web application. A study of relevant literature included recommendations that exercises in gamified systems be designed with increasing difficulty level and adapted to the skills of the students [4]. The design should also consider the time required to complete the exercises, too long and the students may not have the time to participate, too short and the students may find the exercises too trivial and meaningless [56]. For this study the exercises were designed to be short, with experienced users able to complete each exercise in under 5 minutes. In this way the prototype could be more efficiently evaluated, focusing on the effectiveness of the gamification components, with testers able to complete multiple exercises during the testing period. The exercises were also designed with increasing difficulty level, introducing new BPMN concepts as users progressed through the system.

An example of a developed exercise is given in Table 3.2. This exercise is the introductory exercise introducing the basic BPMN diagram components. It consists of the following components:

- Title - summarising the topic of the exercise
- Description - describing the scenario and the relevant components required in the diagram
- Starting Diagram - the initial diagram displayed to the users, to be built upon
- Complete Diagram - the solution to the exercise
- Completion Rules - rules embedded into the application that must be satisfied to consider the exercise complete

The procedure used for evaluating the exercises is described in Section 3.4.1. The exercises were designed with topics that would appeal to students, some referencing popular culture, some related to local cuisine, and others referring to social media. The complete list of exercises and their components are listed in Appendix A. The BIPMIN web application also implements an API that allows teachers to add their own exercises to the tool. The full set of APIs developed for the web application is listed in Appendix B. In future developments of the application the ability to manage exercises will be implemented in a graphical user interface.

3.4.1 Evaluation Engine

BPMN diagrams have traditionally been assessed by teachers directly in the Information Systems course at the Politecnico di Torino. This assessment process

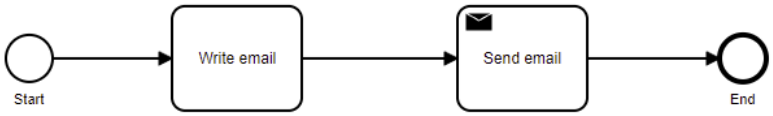
Title	Send an email
Description	Let's create your first model! In this exercise you will create a simple process for sending an email. Your process should consist of: • a start event, • a task for writing the email, • a task for sending the email, • an end event.
Starting Diagram	
Completed Diagram	
Completion Rules	Must have: • 1 start event, • 1 normal task, • 1 send message task, • 1 end event, • all in sequence, • and abide by linting rules.

Table 3.2: Exercise 1 - Task Creation (Easy).

is time consuming and students receive feedback about their diagrams in a delayed manner. A goal in the development of the BIPMIN web application was to implement immediate feedback mechanism, to allow students to improve their skills more efficiently and increase engagement. This required the development of a BPMN diagram evaluation engine, to allow the web application to programmatically

assess the BPMN diagrams. This tool would not only assess the diagrams against the standard rule set (as implemented using the bpmn-js-bpmnlint extension), but also against a set of definable assessment criteria provided by the teacher for each exercise. These additional rules define the success criteria for completing the exercise.

Grammar

A specific grammar was developed to compose the assessment criteria such that the web application was able to assess the diagrams appropriately. A list of six different criteria were accepted by the application. The criteria list is not exhaustive, but was developed to provide a good breadth of assessment criteria sufficient to guide students to the right solution and improve their BPMN diagram creation practices. Further programmatic assessment criteria could be developed in the future to improve the capability of the BIPMIN application.

The list of criteria and their corresponding grammar definition are listed below. When using the API to define new exercises the rules must be defined using the appropriate grammar related to the intended rule. The API accepts objects in the JSON (JavaScript Object Notation) format. Components listed in the grammar rules must be labelled according to their specific bpmn.js type, as used in the element registry of the bpmn Modeler.

Criteria:

1. Specific bpmn components must be present in the diagram.

    - This grammar defines the number of each component that must be present in the completed diagram.
      For example:

      ```
      {"StartEvent" : 1, "Task" : 2, "EndEvent" : 1}
      ```

      requires the diagram to have exactly one start event, two tasks and one end event present in the diagram.

2. Connections required between components of a specified type.

    - This grammar defines which connections between components (also known as sequence flows) are required to be present in the completed diagram. The connection is defined by specifying a target of a given component type.
      For example:

      ```
      {"Target_ExclusiveGateway" : "Task"}
      ```

requires an exclusive gateway to be connected to a task. These components are evaluated in order, i.e. in this example the task must follow the exclusive gateway in flow sequence.

3. A component with a specific type definition must be present.

   - This grammar defines which type definitions must exist for specific components in the diagram.
     For example:

     ```
     {"Definition_EndEvent" : "TerminateEventDefinition"}
     ```

     requires an end event to be of type terminate end event.

4. A required message flow from one element to another.

   - This grammar defines the message flow connections required in diagrams that have multiple pools.
     For example:

     ```
     {"MessageFlow_Task" : "StartEvent"}
     ```

     requires a message flow connection from a task in one pool to a start event in another pool.

5. Number of outgoing connections on a specific component type.

   - This grammar defines the number of subsequent sequence flows coming from a component in the diagram.
     For example:

     ```
     {"Outgoing_ExclusiveGateway" : 2}
     ```

     requires than an exclusive gateway has exactly 2 outgoing connections to other components.

6. Number of incoming connections on a specific component type.

   - This grammar defines the number of prior sequence flows coming into a component in the diagram.
     For example:

     ```
     {"Incoming_ExclusiveGateway" : 2}
     ```

     requires than an exclusive gateway has exactly 2 incoming connections from other components.

Programmatic Evaluation

The assessment criteria defined using the proposed grammar was then used by the evaluation engine of the BIPMIN web application. This engine works by loading the element registry provided by bpmn.js which lists all the components present in the current diagram along with their properties. For this reason the specific bpmn.js component types must be specified so that the evaluation engine can compare the assessment criteria to those components listed in the registry. For each criteria the evaluation engine filters the registry for the relevant components, and checks that the criteria is satisfied. For example for criteria 5 it will check that at least one of the components has the correct number of outgoing connections. A snippet of this behaviour in code is shown below:

Listing 3.1: Evaluation engine code snippet.

```
1    const componentNode = elementRegistry.filter ( (e) =>  e.type ===
     "bpmn:" + component )
2                for (let comp of componentNode) {
3                    if (comp.outgoing.length == numberOut) {
4                        satisfied = true
5                    }
6                }
```

Upon evaluation of an exercise the application will then provide students with feedback on criteria that are not satisfied, allowing them to review their solution and correct any mistakes. An example of the error dialog shown to students is given in Figure 3.7.

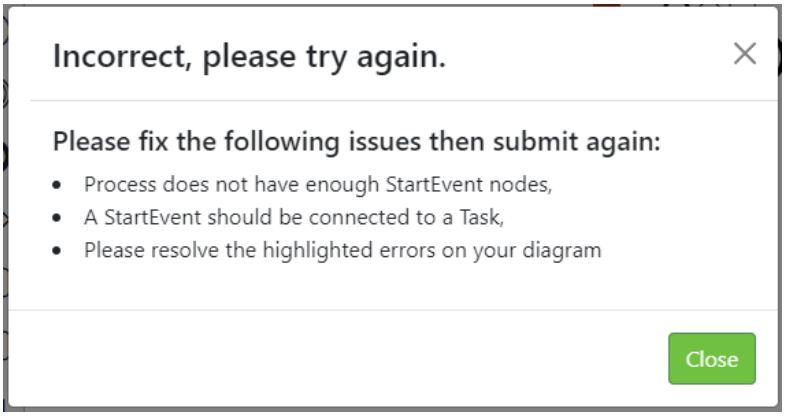


Figure 3.7: Example of an error dialog.

Limitations

The evaluation engine was developed as an example of the potential for automatic assessment of BPMN diagrams. This example does not cover all errors that could be made by students during the creation of diagrams and the interpretation of the exercise description. BPMN diagrams are also inherently subjective, with multiple correct solutions being possible depending on the description of the task. In the BIPMIN application the exercises were designed to provide clarity on which components are required in the diagram, specifically listing each of the components to help students create diagrams that would satisfy the evaluation criteria. The evaluation engine is therefore useful for simple exercises to teach students the basic concepts of BPMN modelling, but it does not scale well to complex solutions.

In addition, it was not possible for the evaluation engine to easily identify specific nodes on a diagram, because the ID of components could not be guaranteed. It was only able to check for the existence of node types and their connections. It was therefore difficult to check the specific ordering of components of a diagram if that diagram included multiple nodes of the same type. This constraint could possibly lead to incorrect diagrams being assessed by the engine as correct. Further development on the capability of the evaluation engine and the addition of more detailed criteria definitions is recommended if the application is to be deployed in a classroom environment.

3.5 User Interface

The web application graphical user interface was designed to be simple and intuitive. Users of the application should be able to immediately understand the layout, interact with its components and navigate to their desired views.

A logo was developed for the BIPMIN application shown in Figure 3.8. The logo uses components of a BPMN diagram, with the two circles representing a start and end event, and the cog in the middle representing the inner workings of a complete process.

Figure 3.8: BIPMIN logo.

During the design of the user interface a set of wireframes were first developed.

These wireframes were used to decide on the layout of components for the application, and were also used during the subsequent heuristic testing phase to refine the design of the user interface. The initial design wireframe for the main page of BIPMIN is shown in Figure 3.9 for the rewards version of the application. The page included the BPMN modeler as its main focus, as well as the following sub components:

- buttons at the bottom of the page for navigating to different exercises and checking the diagram solution,
- a side bar on the left for selecting between different exercises,
- a tab in the sidebar for viewing the user's reward collection,
- a navigation bar at the top of the screen, and
- a header including the current exercise title and a button for reviewing the description of the current exercise.

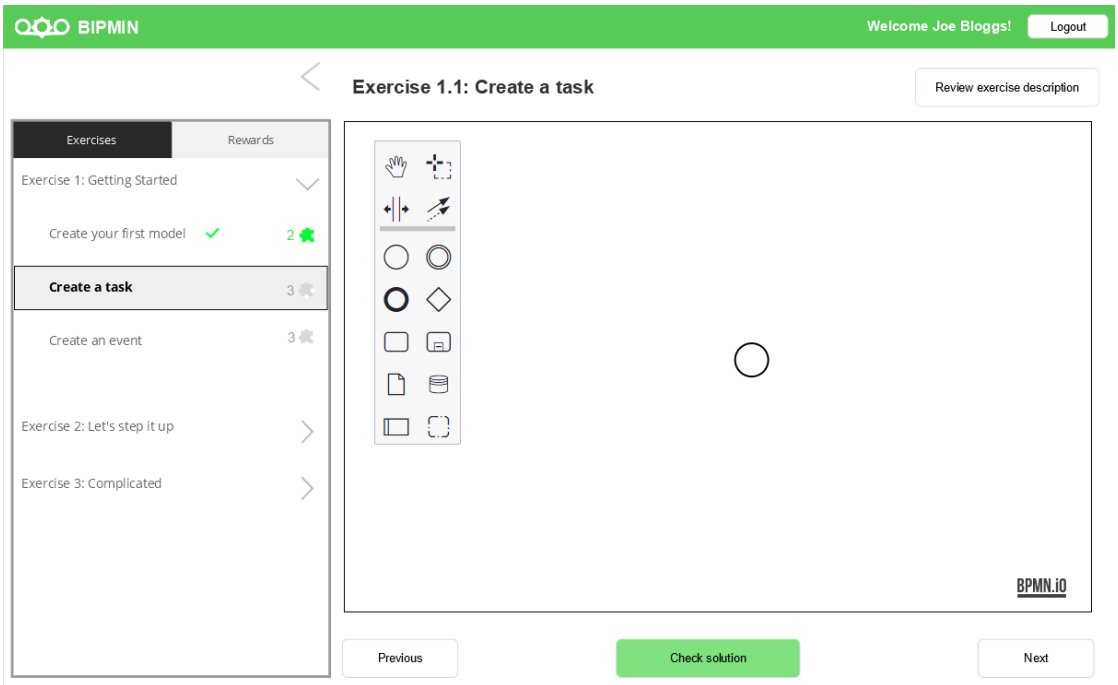
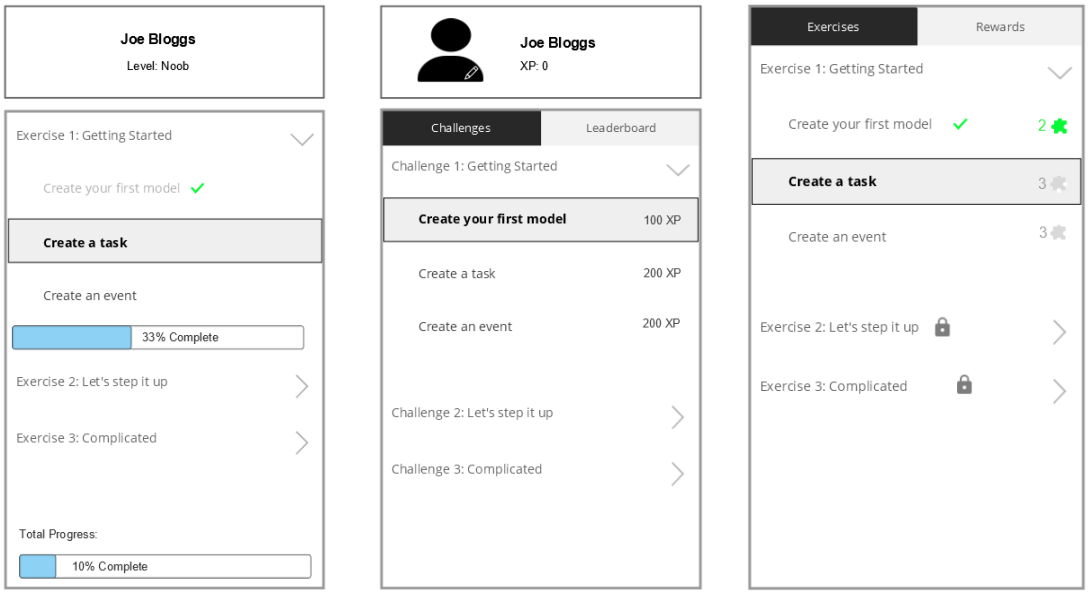


Figure 3.9: Initial design wireframe of the application's main page.

The three versions of the application were designed with a similar user interface. Each version having instead it's own flavour of gamification elements. For example, each was designed with different attributes applied to the side bar of the application. These differences are shown in Figure 3.10. The progress version includes progress

bars showing both the progress through each group of exercises, and also the overall progress through the complete list of exercises. This version also included user levels, shown in a brief user summary at the top of the sidebar. The competition version shows the experience points earned by completing each exercise, and includes a tab showing the leaderboard. This version also includes a user profile summary at the top, listing the users points and providing the option for users to select a new avatar image. The rewards version shows how many pieces will be rewarded for the completion of each exercise, as well as showing that exercises are locked until the user completes enough exercises. In the competition version the exercises were referred to as challenges to add to the sense of competition.

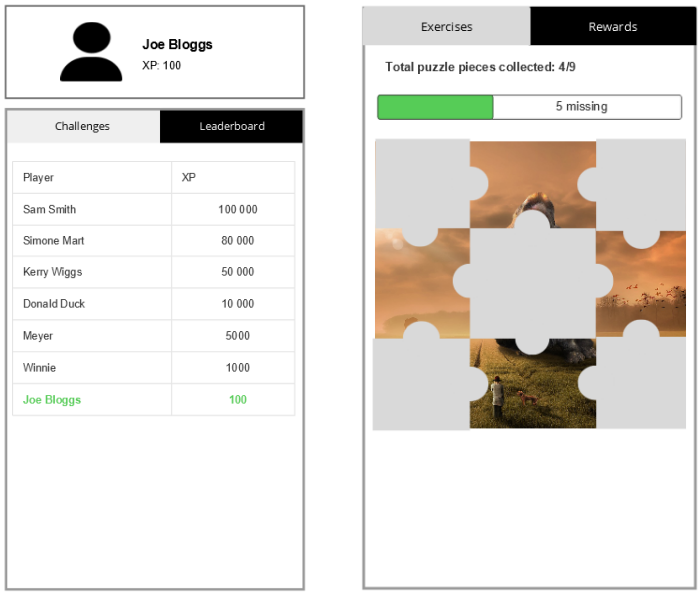


(a) Progress **(b)** Competition **(c)** Rewards

Figure 3.10: Sidebar wireframe designs.

The alternative tabs of the sidebar available in the competition and rewards versions are shown in Figure 3.11. The leaderboard ranks all the users of the application according to the number of experience points they have earned, and shows both their name and their number of points. The rewards tab in the rewards version lists the number of puzzle pieces the user has collected, as well as how many remain to be collected. The puzzle pieces collected so far by the user are displayed, partially revealing an image which will be completely revealed upon collection of all pieces.

The user interface components of the BIPMIN application designed for this study focus on the use case of students completing exercises, referenced in Figure 3.2. The remaining use cases focusing on the teacher's interactions (i.e. the management



(a) Progress **(b)** Rewards

Figure 3.11: Sidebar wireframe designs - Leaderboard and Rewards tabs.

of exercises and user accounts) are currently provided for by the use of APIs, as listed in Appendix B. These remaining use cases however will be provided for by a separate user interface to be implemented in future developments of the BIPMIN application. The focus of this study is instead on the design of the interface for completing exercises, which will be used to determine the effectiveness of the gamification elements tested.

3.5.1 Heuristic Testing

Heuristic testing was conducted on the wireframes of the user interface to discover any usability issues with the design of the application. The heuristic evaluation involved the generation of a paper prototype of the application, based on the previously generated wireframes. The paper prototype mimics the interaction of users with the web application by replicating the various pages and components of the application onto paper. Evaluators interact with the paper in a similar manner to how they would interact with a computer, however the feedback to these interactions (such as button clicks) is realised by a person playing the role of the computer. This person switches in and out the appropriate paper pages in front of the evaluator. A portion of the developed paper prototype is shown in Figure 3.12. This portion shows the paper pages for the rewards version of the application, with cut-outs of the various components which can be overlain on the main paper page

to simulate the application's response to user interactions.

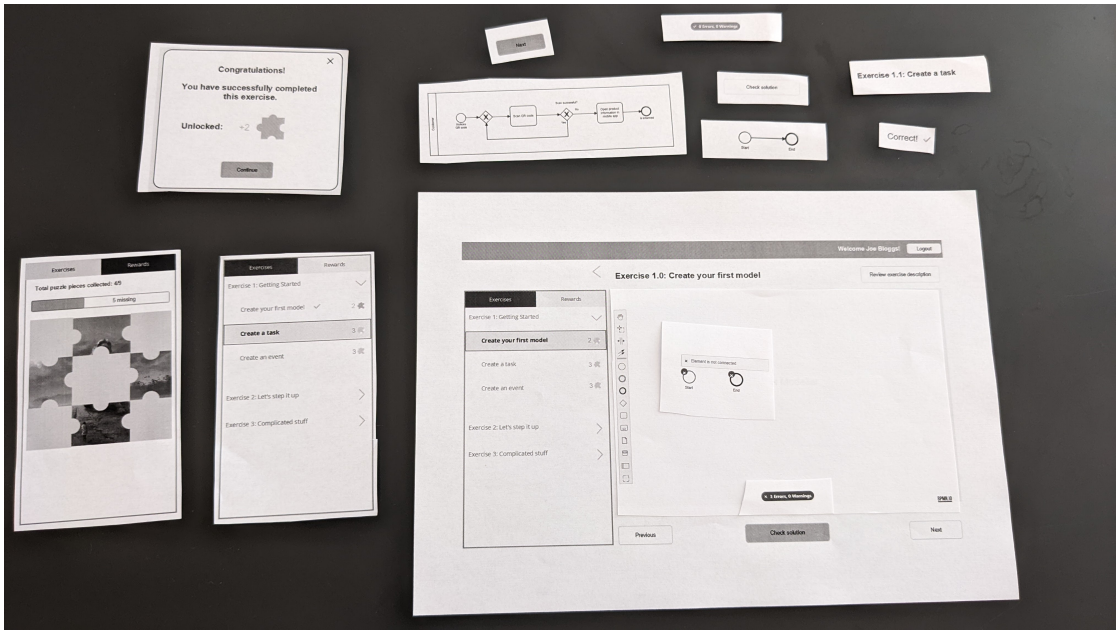


Figure 3.12: Paper prototype.

To conduct the heuristic test three types of roles were performed. The first role was the facilitator, who was in charge of coordinating the test. The second was the evaluator, who was asked to interact with the paper prototype and assess it against a set of usability related evaluation criteria. The third was the computer, who was responsible for arranging the components of the paper prototype to correctly mimic the response of the application to the evaluator's inputs.

Three evaluators were sourced to conduct the test. The number of evaluators selected was based on recommendations by the Nielsen Norman Group [69] which suggest that three to five is the optimal number of evaluators based on the number of issues discovered versus the cost of conducting the testing.

The evaluators were given a set of tasks to complete, and whilst completing them were asked to assess the application against Nielsen's usability heuristics for user interface design [70]. These heuristics are listed in Table 3.3, and are used to assess the usability of applications across a range of general principles that should be adhered to for providing positive user experiences. If an evaluator discovered an issue they were then also asked to rate the issue using Nielson's severity ratings [71], listed in Table 3.4. These ratings are used to determine how serious the issue was, with priority given to fixing the most severe issues.

Nielsen's Heuristics	
H1	Visibility of system status
H2	Match between system and the real world
H3	User control and freedom
H4	Consistency and standards
H5	Error prevention
H6	Recognition rather than recall
H7	Flexibility and efficiency of use
H8	Aesthetic and minimalist design
H9	Help users recognize, diagnose, and recover from errors
H10	Help and documentation
NH	Non-heuristic issue

Table 3.3: Heuristic evaluation criteria [70].

Nielsen's Severity Ratings	
0	I don't agree that this is a usability problem at all
1	Cosmetic problem only: need not be fixed unless extra time is available on project
2	Minor usability problem: fixing this should be given low priority
3	Major usability problem: important to fix, so should be given high priority
4	Usability catastrophe: imperative to fix this before product can be released

Table 3.4: Severity ratings [71].

Outcomes

The findings from each of the evaluators were combined to give a holistic overview of the usability design issues. The following design issues were identified from the heuristic testing and rectified in the subsequent development of the application:

- It was difficult to understand if the sub parts to the exercises in the side panel were steps to each exercise or exercises in their own right. This also added to confusion with what functionality the "next" and "previous" buttons should provide. As a consequence to this feedback it was decided to re-label the groups of exercises as "Parts" and each sub part being referred to as an independent exercise.
- It was suggested that the sub tasks should have numbers. This feedback was incorporated.

- Evaluators did not readily notice the "review exercise description" button in the top right of the screen, which was needed to understand how to complete the exercise. In response to this observation the content from the exercise description dialog box was instead moved and incorporated into the side panel. In this way users could more easily see the instructions for the current exercise, and reference this content quickly whilst completing the exercise.

- Feedback for providing incorrect login details was required.

- The numbering of exercises should start from 1 instead of 0.

- The edit icon for changing the avatar was not easily visible where it was located overlain on the user's profile picture. To rectify this issue it was offset to the right of the image, and feedback provided to the user during mouse hover over to indicate that this area is an interactive button.

- It was not clear that the user needed to confirm the change of their avatar image. The design of this dialog was update to make the confirm button clearer.

- There was confusion over seeing a "continue" button displayed in a dialog box after the completion of an exercise, and whether that button would provide different behaviour to the "next" button displayed on the main screen. As a consequence, the continue button was removed, and instead an "OK" button left in the dialog box which simply closes the dialog.

The evaluators also offered general suggestions for improving the design of the application. These suggestions included:

- Add loading feedback so that the user is aware of the state of the system if the connection speeds are low.

- Adding a registration link for new users. For this application however it was decided the user accounts should only be created by administrators of the system and self sign-up would not be available. Instead some text was added to the login page to explain to users how to receive an account if they did not have one.

- Centre content in the leaderboard for aesthetic purposes.

The design issues identified by the evaluators and their suggestions were used to improved the design of the application.

3.5.2 Final Design

The final design of the BIPMIN application was generated using components from the React-Bootstrap [65] library, with the layout based on the designs from the wireframe prototypes and incorporating feedback from the heuristic testing. The user login page is shown in Figure 3.13. This page displays the logo prominently at the centre of the screen, and provides input for the user email and password to facilitate logging in to the application. Users are redirected to this page if they are not logged in.

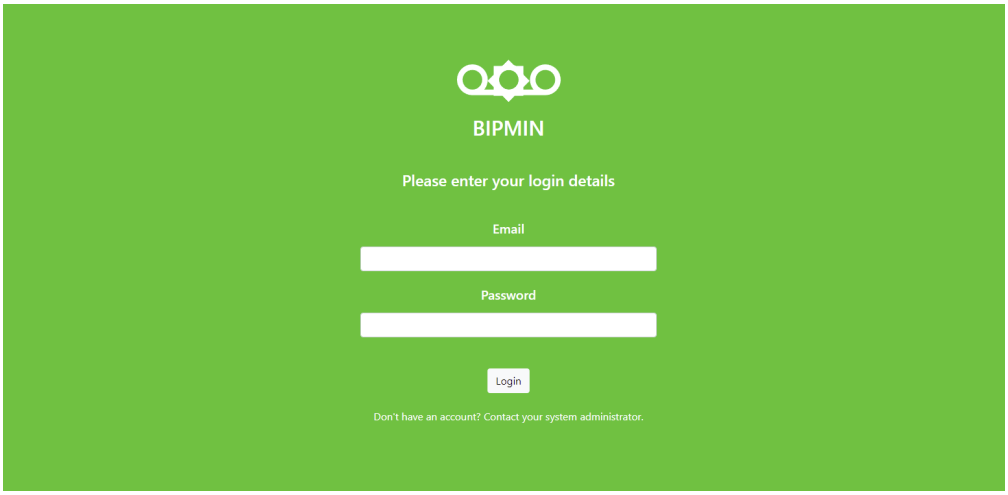


Figure 3.13: Login page.

For the preliminary evaluation of the BIPMIN tool an extra page was created to allow testers to select between the three different versions of the application. This page is shown in Figure 3.14. Users can return to this page at any time by clicking on the logo or application name in the navigation bar. This page was used during the evaluation stage of this study to allow the test participants to efficiently evaluate the different versions without having to log in separately to three versions of the application.

An example of the main page of the BIPMIN application is shown in Figure 3.15, which displays the progress version of the application. The page includes a navigation bar at the top of the screen, which allows users to log out of their accounts. The main part of this page is allocated to the BPMN modeler, with the title of the current selected exercise displayed at the top, and buttons below the modeler to check the solution of the current exercise or navigate to the next or previous exercise. On the left is a side panel which allows users to select directly which exercise they wish to complete, and also shows the exercise instructions. This panel also includes progress bars indicating how many exercises the user

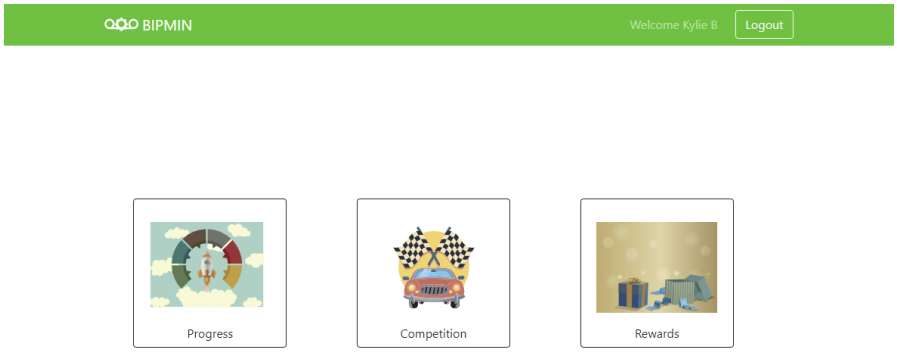


Figure 3.14: Version selection screen.

has completed for each of the parts, as well as the total progress on all exercises displayed at the bottom. At the top of this side panel the user's current level is displayed, with guidance on how to progress to the next level.

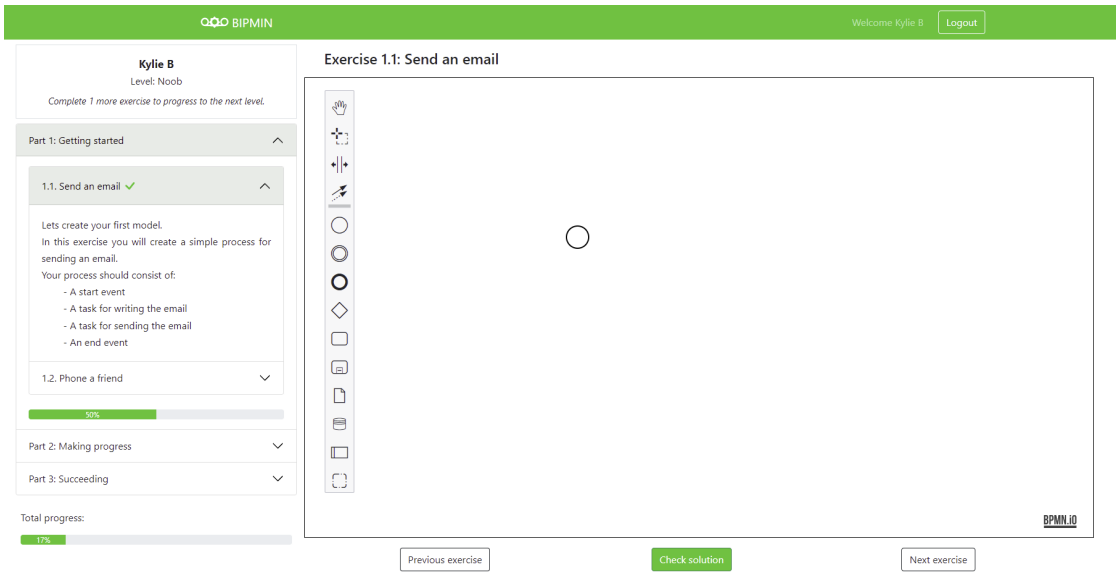
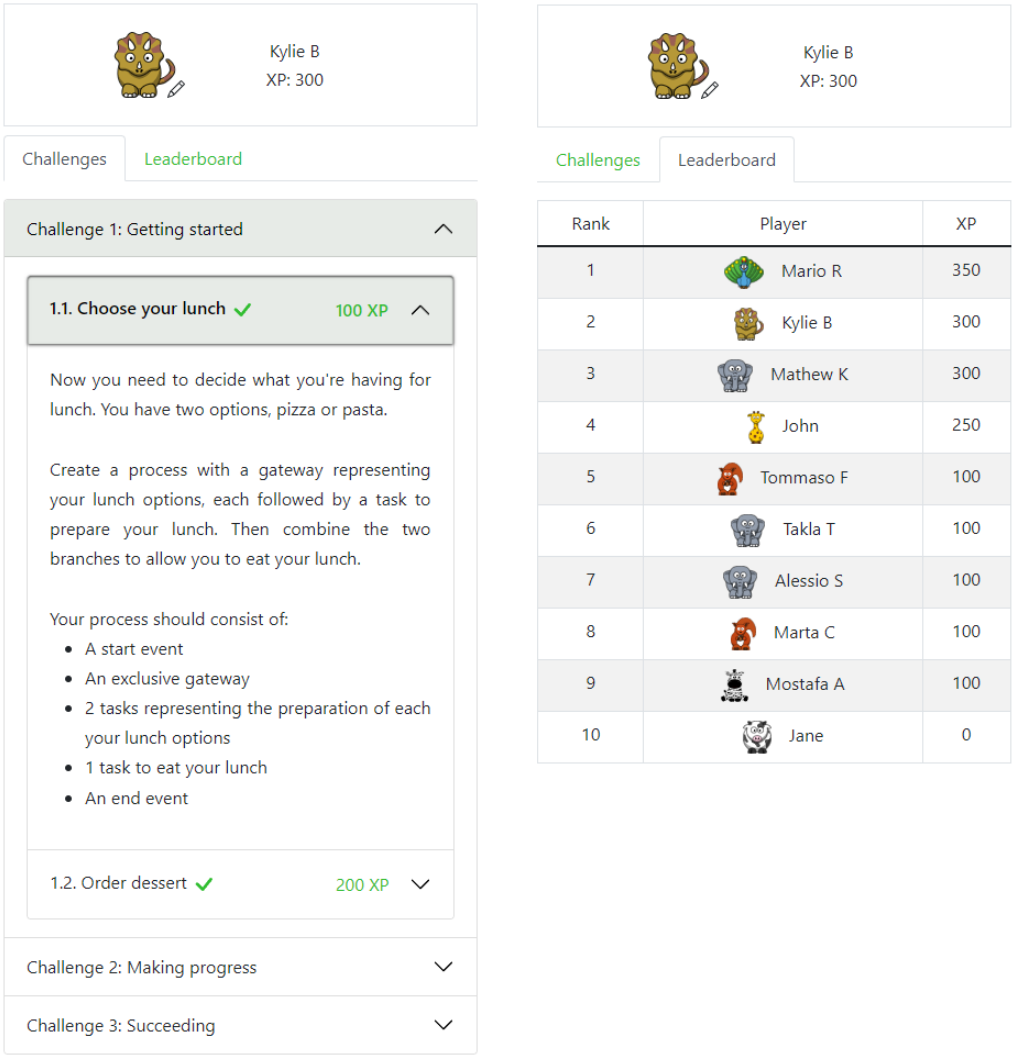


Figure 3.15: Progress version main page.

All three versions of the BIPMIN application share a similar main screen as in Figure 3.15, however each version has its own flavour for the side panel. For the competition version the side panel includes two tabs, one showing the list

of available exercises, and the other showing the leaderboard. The competition version side panels are shown in Figure 3.16. The exercise list is similar to that of the progress version however the competition version displayed the amount of experience points the user will earn upon completion of each exercise. It also includes a tab for viewing the current state of the leaderboard, listing the rank of all users based on the experience points they have collected. At the top of the side panel users can see their total experience points and their chosen avatar.



(a) Exercise list **(b)** Leaderboard

Figure 3.16: Competition version main page - exercise list view and leaderboard tabs.

Users of the competition version are able to change their avatar image by clicking

on their avatar at the top of the side panel. Upon clicking on their avatar users are presented with the avatar selection dialog, shown in Figure 3.17. Twelve different avatar images are available for users to choose between.

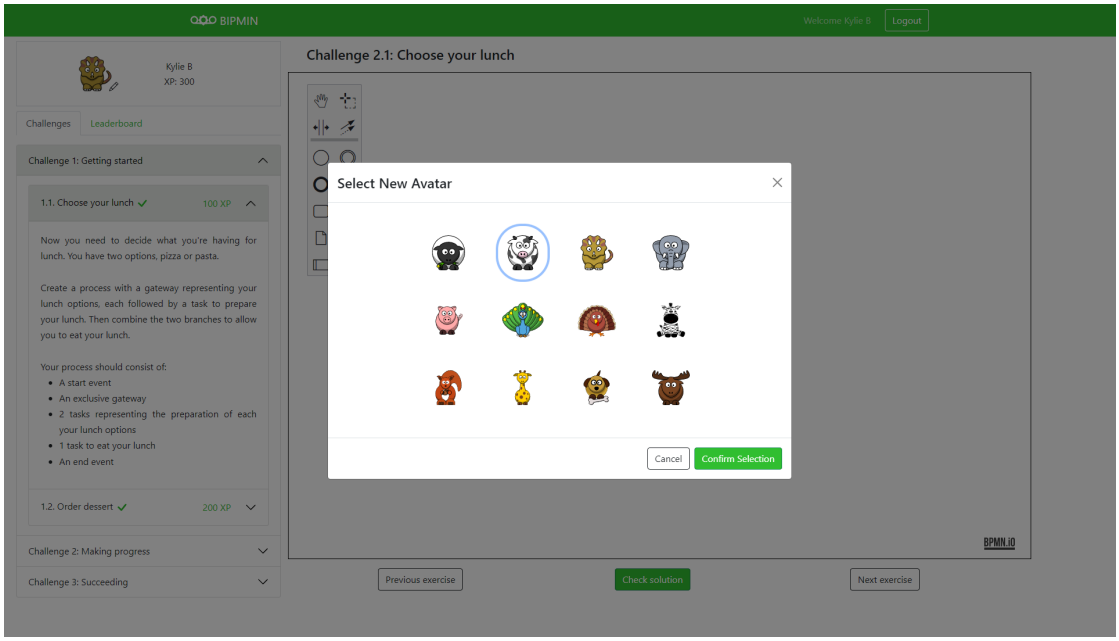
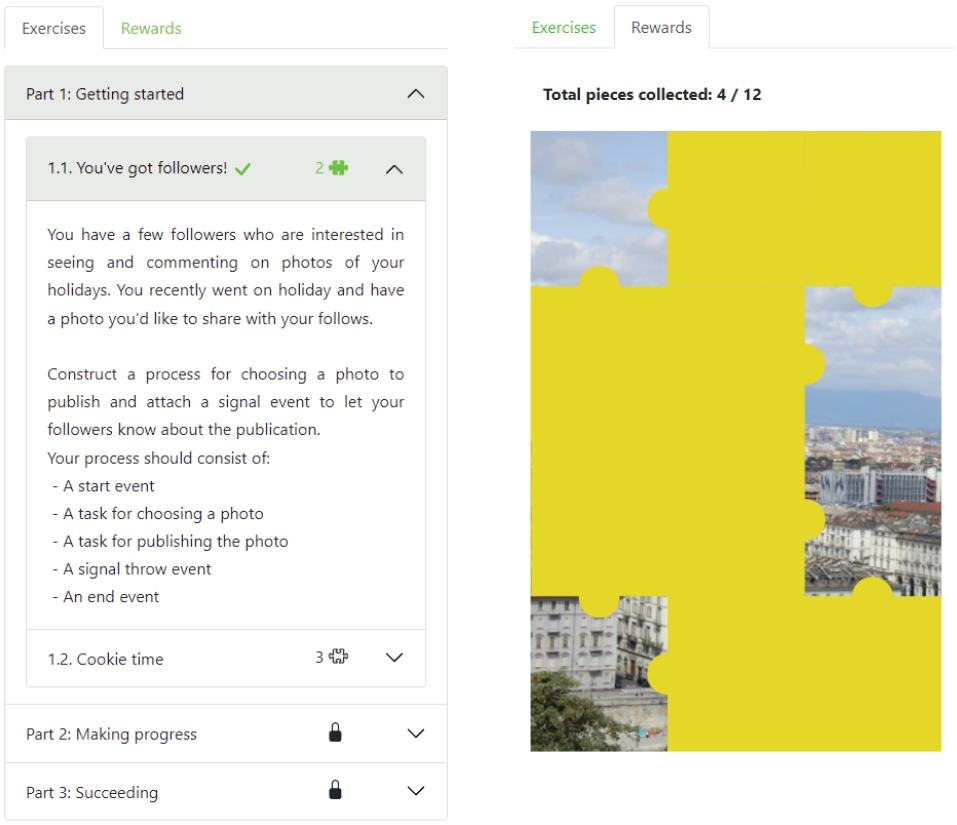


Figure 3.17: Competition version avatar selection dialog window.

The rewards version side panel includes two tabs: one showing the exercise list similar to the competition version; and the other showing the users reward collection. These tabs are shown in Figure 3.18. The exercise list in this version displayed the number of jigsaw pieces the user will be rewarded with upon completion of each exercise. This version also includes unlockables, such that subsequent parts in the exercise list are locked until completion of the previous exercises. This is displayed using a padlock icon, and users cannot view the exercise descriptions until the parts are unlocked. The rewards tab lists the number of pieces collected by the user so far, and also shows their portion of the image in the hidden jigsaw puzzle.



(a) Exercise list **(b)** Rewards collection

Figure 3.18: Rewards version main page - exercise list view and rewards tabs.

Finally, an example of the dialog window presented to users upon successful completion of an exercise in the rewards version is shown in Figure 3.19. This dialog congratulates the user for their success, and shows them the rewards they have earned for completing the exercise. Similar congratulations dialog windows are shown for the other two versions of the application, with the competition version instead showing the number of experiences points the user has earned.

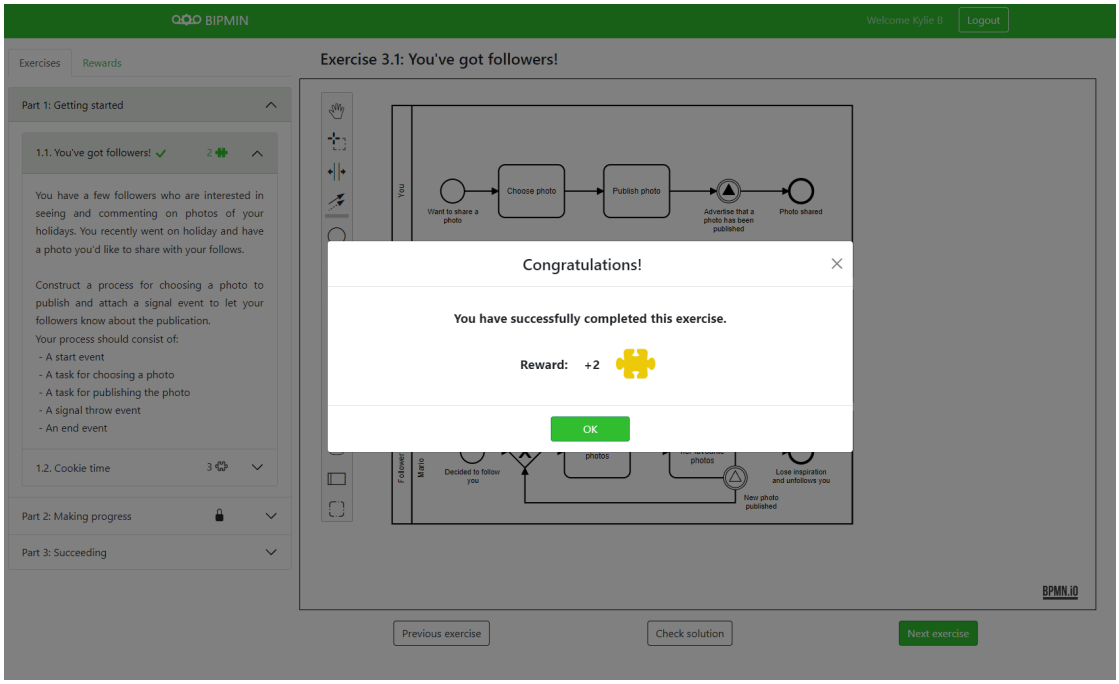


Figure 3.19: Rewards version successful exercise completion dialog window.

3.6 Software Architecture

The BIPMIN application was developed using web based technologies, with the aim of being able to deploy the application as a website for use in future Information Systems courses. The deployment diagram shown in Figure 3.20 represents the deployment plan for the BIPMIN web application. Alongside the application exists a server which hosts the application's data in a database. The application can be deployed to both personal computers (PCs) and tablet clients.

The database contains data on the users of the application, necessary to set up the student user accounts. It also stores data on the exercises to be completed, as well as the progress of each user through the three different versions of the application. The data is stored in an SQLite database file, with the tables and properties given in Figure 3.21.

The data stored by the server can be accessed by the web application through use of an API. The list of API methods along with their interaction with components of the BIPMIN application are included in the class diagram shown in Figure 3.22. The web application was broken up into a number of components based on the user interface design and the functionality to be provided by the different parts. The App component is the entry point of the application hosting the login form and functionalities, as well as the navigation bar. The Version component hosts

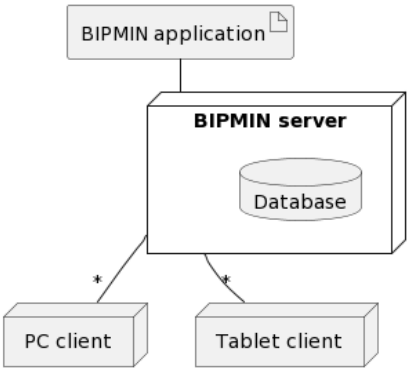


Figure 3.20: Deployment diagram.

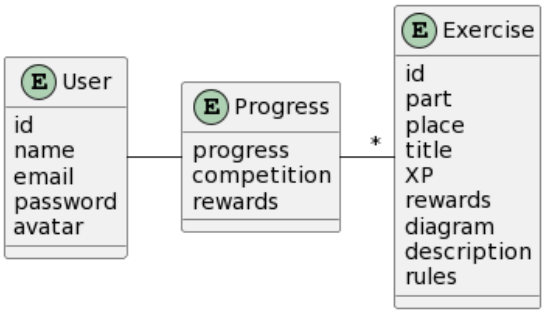


Figure 3.21: Database glossary.

the BPMN Modeler instance and compiles the various components relative to the appropriate version; be it progress, competition or rewards based gamification elements. The Sidebar provides the navigation between the different exercises, and hosts the majority of the gamification elements, such as the leaderboard, rewards collection and the user profile. The Footer component is responsible for checking the solution of the BPMN diagram, and contains the evaluation engine for assessing the diagram against the exercise's assessment criteria.

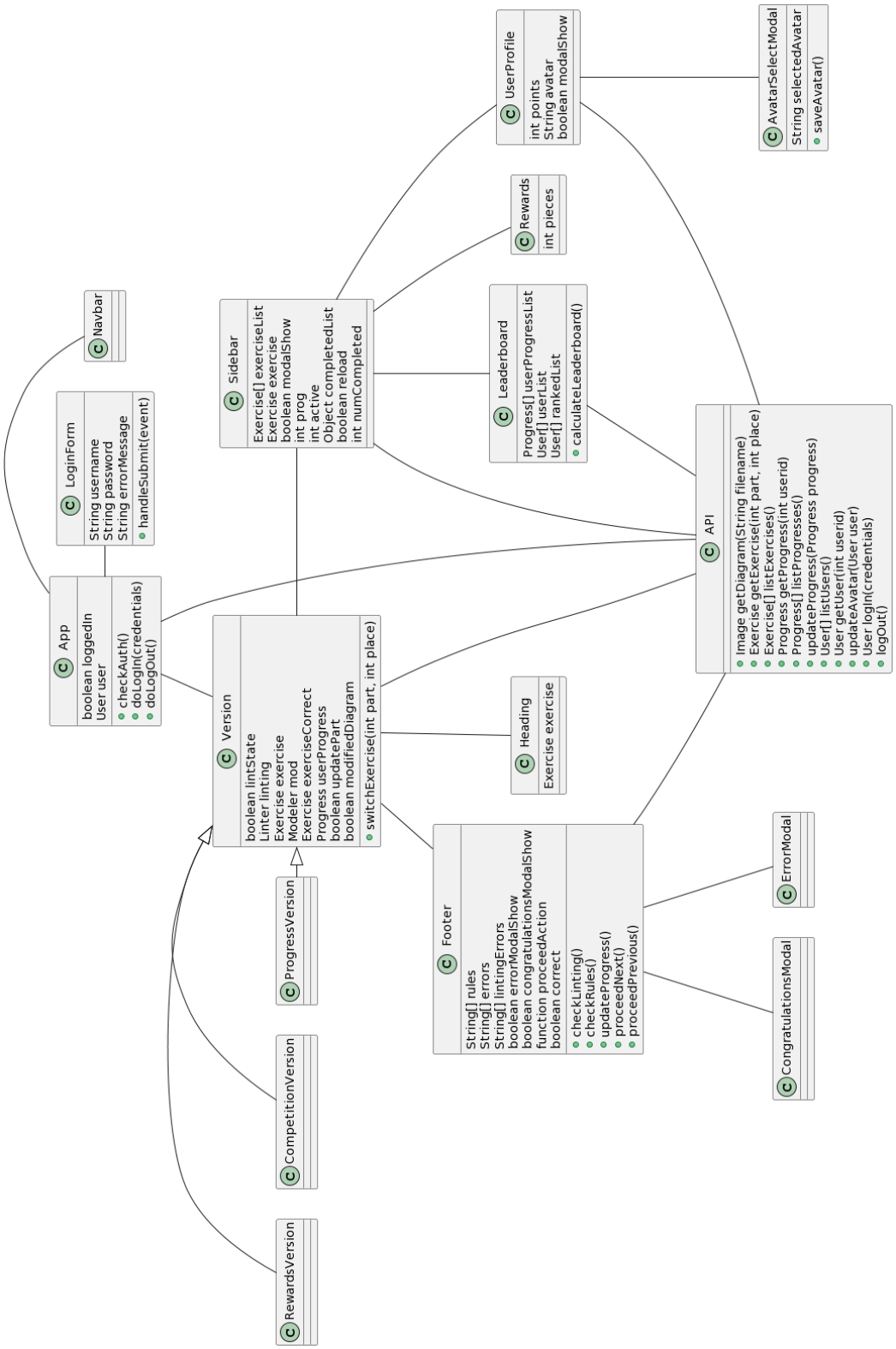


Figure 3.22: Class Diagram.

Chapter 4

Evaluation

The evaluation of the BIPMIN tool consisted of two parts: one part assessed the usability of the tool; and another part evaluated the effectiveness of the different game elements represented in the three different versions of the application. The assessment of both parts was conducted during a single trial program.

4.1 Design

The design of the trial program followed the Goal Question Metric (GQM) template [72] by determining first the goal of the trial, then the associated research questions to be answered by the trial, and finally the metrics with which to measure the outcomes of the trial and answer the corresponding research questions.

4.1.1 Goal

The trial program conducted for this study was a preliminary evaluation of the usability of the tool and of the effectiveness of the various game elements. The GQM template, shown in Table 4.1, was used to formulate the goal. The goal can be expressed as follows:

> *The purpose of this study is to evaluate and improve the effectiveness of different game elements at motivating students to interact with a gamified BPMN modelling application from the point of view of software development researchers in the context of an educational environment.*

Gathering preliminary results on the effectiveness of the various game elements will help inform future gamification studies on the importance of each of the assessed game elements, helping to focus the design of future systems on game elements and combinations that are more crucial to designing successful applications.

Object of study	gamified BPMN modelling application
Purpose	evaluate and improve
Focus	effectiveness at encouraging student interaction
Context	educational environment
Stakeholders	developers, researchers, teachers

Table 4.1: GQM Template.

The evaluation also included an analysis of the usability of the BIPMIN application to enable improvements to the tool for use in a subsequent larger experiment. A larger experiment is planned to be conducted during the teaching of the Information Systems course at the Politecnico di Torino. This preliminary evaluation will be used to improve the tool so that it is ready for deployment for use in the course experiment, which is planned to be run during the next semester of the university course program.

This trial program also provided a proof of concept for the utility of the technology in computer engineering educational environments.

4.1.2 Participants

Participants in the trial program were sought using convenience sampling from the cohort of computer engineering students at the Politecnico. The participants were selected as representative of masters level students who would learn or use BPMN as part of their studies. Due to this being a preliminary trial program, only a small number of participants were arranged, with a larger experiment containing many more participants expected to be conducted during the Information Systems course in the next semester. A total of 12 volunteers were found to participate in the trial. The volunteers were rewarded with free lunches or snacks, and the possibility of reciprocating the arrangement in subsequent trials for their studies.

4.1.3 Procedure

To conduct the evaluation trial program three roles were performed: a facilitator, an observer and an evaluator. The facilitator coordinated the trial program, welcomed the participants and explained the conduct of the trial. A script was prepared for the facilitator to use during the conduct of the trial to ensure consistency between the trials from each participant, the full script is available in Appendix D. Participants during their trial performed the role of the evaluator, following the instructions provided by the facilitator to assess the tool. The observer recorded any observations made regarding the use of the tool and related game elements, providing supplementary material for the assessment of the application.

The trial required participants to complete a number of tasks using a web-based prototype of the BIPMIN application. The full list of tasks is shown in Table 4.2. The first task was to complete a tutorial regarding the use of the BPMN Modeler bpmn.io, with participants accessing the public website of bpmn.io [18] to complete the tutorial. The task represented the non-gamified version of the tool, reflecting how students would have previously created BPMN diagrams before the creation of the BIPMIN tool, and served as a baseline for comparisons with the gamified versions. This tutorial task was also an opportunity for participants of the test to get acquainted with the BPMN Modeler if they had not previously used it. The instructions for the tutorial task are provided in Appendix C.

Subsequent tasks involved the participant completing one exercise from each of the three versions of the BIPMIN application. During the completion of these exercises participants were asked to identify and interact the various gamification elements used, to familiarise themselves with the differences between the three versions. After each of these exercises were complete the participant was then asked to complete one further exercise from a version of their choice. Finally participants were encouraged to complete further exercises from any version if desired, and then asked to complete two post-test questionnaires.

Task	**Description**
T1	Complete the tutorial. Once you have finished ask the facilitator to check your solution.
T2	Log in to your account using the credentials provided.
T3	1. Enter the progress version and complete the first exercise. 2. Note your current skill level. 3. Return to the main screen.
T4	1. Enter the competition version and complete the first exercise. 2. Note your position on the leaderboard. 3. Choose your avatar. 4. Return to the main screen.
T5	1. Enter the rewards version and complete the first exercise. 2. Note your reward collection. 3. Return to the main screen.
T6	Complete 1 extra exercise from the version of your choice.
T7	Complete further exercises if desired, then please fill out the post-experiment surveys.

Table 4.2: Participant task list.

4.1.4 Methods

A within-subjects experimental technique was employed for this trial program. In this way each participant performed the trial for each version of the application. This method was preferred over a between-subjects technique (where each participant performs the trial on only one version of the application) due to the small number of participants available for the trial program. This technique will be reviewed for future experiments involving a larger number of participants.

To counter the effects of order biases experienced when utilising the within-subject technique a counter-balancing approach was adopted. Counter-balancing involved modifying the order of tasks completed by the participants, such that participants experienced the different versions of the application in different orders. By adopting this approach any efficiencies learned by participants during their completion of previous tasks in the trial were balanced across the three versions. The order of tasks was determined using a balanced Latin square [73], specifically to prescribe the order of tasks T3, T4, and T5 (as listed in Table 4.2) which corresponded to the completion of exercises in the progress, competition and rewards versions of the application respectively. With three versions of the application to be tested, the balanced Latin square consisted of 6 different variations to the order of task completion, these orders are listed in Table 4.3. With 12 volunteers participating in the trial program each order was used exactly twice.

	Task Order		
Participant	**First**	**Second**	**Third**
1	T3	T4	T5
2	T4	T5	T3
3	T5	T3	T4
4	T3	T5	T4
5	T4	T3	T5
6	T5	T4	T3

Table 4.3: Task order based on a balanced Latin square.

4.1.5 Materials

The following equipment was prepared to conduct the evaluation:

- computer,
- stopwatch,
- camera,

- pens,
- note paper,
- participant instructions,
- consent form, and
- post-trial questionnaires.

The trial was conducted on a single computer, with participants scheduled one at a time to perform the evaluation. The computer was pre-loaded with the BIPMIN application already running, along with a separate tab open for access to the bpmn.io website for use during the tutorial task. A list of user accounts was created before the trial, one for each of the participants. A list of exercises were also prepared, listed in Appendix A, and pre-loaded into the BIPMIN application. Prior to the first user evaluation a number of default user accounts were also created, and used to pre-populate the leaderboard displaying users with a variety of experience points. This pre-population was used to provide the first testers with some users to compete against.

4.1.6 Research Questions

Following the GQM technique a set of research questions were developed to represent the intent of the evaluation. The trial was designed to answers the following two research questions.

Usability (RQ1)

The first research question, referred to as RQ1, related to the usability of the BIPMIN application. It was formulated as follows:

> **RQ1:** *Is the system usable by students of computer engineering?*

In designing the BIPMIN application the intention was to create a system that could be easily understood and interacted with by the students of the Information Systems course. The design had to be such that students could:

- successfully login to the application,
- easily navigate to their desired location,
- understand how to complete exercises within the application,
- understand the feedback provided by the application to easily recover from any errors, and
- interact positively with the game elements implemented.

Metrics

Task	Success Criteria	Metrics
T1	The participant follows the instructions provided and is able to complete the exercise [in 5 mins]	- Time to complete - Number of requests to check the solution
T2	The participant logs in to the tool successfully [in 30 secs]	- Time to complete
T3	1. The participant completes the first exercise [in 5 mins] 2. The participant records their level [in 30 secs] 3. The participant returns to the home screen [in 30 secs]	- Time to complete - Number of clicks on the check solution button.
T4	1. The participant completes the first exercise [in 5 mins] 2. The participant records their rank [in 30 secs] 3. The participant selects a new avatar [in 2 mins] 4. The participant returns to the home screen [in 30 secs]	- Time to complete - Number of clicks on the check solution button.
T5	1. The participant completes the first exercise [in 5 mins] 2. The participant records their number of pieces collected [in 1 min] 3. The participant returns to the home screen [in 30 secs]	- Time to complete - Number of clicks on the check solution button.
T6	The participant completes an exercise [in 5 mins]	- Time to complete - Number of clicks on the check solution button.
T7	N/A	

Table 4.4: Usability task success criteria.

To assess the usability of the BIPMIN application two methods were used. The first was to measure the time it took participants to complete certain tasks relating to navigation of the web application. Each task listed in Table 4.2 (a number of which were included to answer this research question) was assigned a success criteria along with corresponding metrics to measure the success. The list of success criteria for each task is listed in Table 4.4. To evaluate the comprehension of the

exercise error feedback a metric was also included counting the number of times the participant checked their solution when completing exercise related tasks (this check also displayed the list of errors to the user).

The second method used to assess the usability of the BIPMIN application was to ask participants to complete the System Usability Scale (SUS) survey [74] upon completion of the trial. The SUS is a common tool used to assess the usability of software applications. It consists of 10 standard statements about the user's experience using the application, with users asked to rate their agreement with each statement ranging from 1 (strongly disagree) to 5 (strongly agree) using a Likert-scale. The phrasing of statements alternate between positive and negative to remove any biases possible if any user simply ticked strongly agree to every statement without reading the survey. The complete survey is provided in Appendix E.2.

The results from the SUS are combined to calculate a score ranging from 0 to 100. A score above 68 is considered above average. The score is calculated using the following equation:

$$Score = 2.5(\sum(Q_{odd} - 1) + \sum(5 - Q_{even})) \tag{4.1}$$

where Q_{odd} is the value for odd numbered questions and Q_{even} is the value for even numbered questions.

Game Elements (RQ2)

The second research question, referred to as RQ2, related to the effectiveness of different game elements. It was formulated as follows:

> **RQ2:** *Which game elements are the most important for motivating students?*

RQ2 relates to the secondary goal of this study in analysing the effectiveness of different game elements at increasing student motivation, which was identified as a gap in the current literature.

Metrics To answer this question the three different version of the BIPMIN application were developed, each including different game elements. The game elements studied and their use in the corresponding versions of the application are listed in Table 4.5. All versions employed similar aesthetics.

Two sets of metrics were created to answer RQ2. The first related to directly observing student behaviour when faced with a choice between the different game elements. As part of the trial participants were asked to complete one exercise in each of the three version and afterwards asked to complete one exercise in

Version	Game Element
Progress	Progress bars Levels
Competition	Leaderboard Avatars Points
Rewards	Rewards Unlockables
All	Aesthetics

Table 4.5: Game elements present in each version of BIPMIN.

the version of their choice (T6). This task was included to clearly show student preference for particular game elements, which might have differed from their responses to a related survey question. A final optional task (T7) was also provided encouraging participants to complete further exercises in their chosen or other versions. The results from the final task were used to assess whether the game elements provided high enough motivation for participants to complete optional exercises.

The second set of metrics involved the formulation of a post-trial questionnaire. The questionnaire, the full contents of which can be found in Appendix E, included questions relating to participant preferences between the three versions, and also between the eight game elements studied. The questions were designed using a ranking system, with participants asked to rank the different versions and game elements in terms of both their enjoyment and motivation levels. This ranking system was used as it offered a clear understanding of the relative effectiveness and importance of the different game elements compared to each other. Finally a section for open comments was provided to better understand participant responses and gather feedback on the tool.

4.2 Results

The results of the evaluation trial program are reported herein, including both the results of the recorded metrics for the two research questions analysed, as well as general observations about the trial and the utility of the BIPMIN application.

4.2.1 Usability (RQ1)

RQ1 related to the usability of the BIPMIN application, and included two sets of metrics: one relating to the tasks performed by the evaluators during the trial; and

another relating to the survey completed by participants at the conclusion of the trial.

Task Metrics

The task metrics included assessing the time it took participants to complete each of the tasks performed during the trial. The average time for the 12 participants to complete each task is given in Table 4.6 alongside the success criteria for completing the task. In all instances the average time taken by participants was less than the specified success criteria, indicating that the application was able to be successfully used by the evaluators.

Task	**Criteria**	**Result**
T1	5:00	3:33
T2	0:30	0:14
T3.1	5:00	2:50
T3.2	0:30	0:07
T4.1	5:00	4:32
T4.2	0:30	0:08
T4.3	2:00	0:06
T5.1	5:00	4:58
T5.2	1:00	0:06
T6	5:00	4:50
T3.3/4.4/5.3	0:30	0:14

Table 4.6: Average time (m:ss) to complete tasks.

Tasks T3.3, T4.4 and T5.3 all related to returning to the main screen. Since the order of these tasks varied depending on the participant task order (as defined in Table 4.3) they were combined, and the reported value represents the time taken to return to the main screen the first time the participant was requested to do so. In the subsequent related tasks the participants already knew how to return to the main screen and generally would only take 1-2 seconds to complete the task. Although the average for this task is well within the success criteria it is noted that there were 3 instances during the trial where the facilitator had to assist participants to return to the main screen. This was not considered a major issue because this main screen was implemented for trial purposes only and is not planned to be present in the final application. For the purposes of the trial however it was suggested to include a home icon in the navigation bar beside the logo to more clearly indicate its use as a button to return to the main screen.

During the trial program there were however 13 instances where participants took longer than 5 minutes to complete an exercise related task (T3.1, T4.1, T5.1

or T6). 6 of these instances were experienced during the two remote trials which were conducted online, and the longer times attributed to the lag experienced with the interactions. 5 of the instances were also during task 6 which, by designing exercises with incremental difficulty, would always be a slightly more complicated exercise than those experienced previously. Of the in-presence trials however all times remained below 8 minutes per exercise.

A second task metric measured the number of times a participant clicked on the "check solution" button when completing an exercise task. This metric was used to determine the usefulness of the evaluation engine and the ability of users to recover from errors present in their submitted diagrams. The results of this metric are given in Table 4.7. The majority of participants checked their solutions between 1 and 3 times before the solution was considered correct by the application. In a few instances participants had to check more times, but only up to a maximum of 6 times. This low number paired with observations of the participants during their interaction with the evaluation engine proved its usability for interactive BPMN exercises.

Participant	**T1**	**T3**	**T4**	**T5**	**T6**
1	2	1	3	4	3
2	1	5	3	1	3
3	1	2	3	2	1
4	1	3	3	3	1
5	1	3	2	2	2
6	2	1	2	2	1
7	1	3	1	1	2
8	1	2	2	2	2
9	1	1	2	1	1
10	1	2	2	1	1
11	1	1	2	2	2
12	1	4	2	2	6

Table 4.7: Number of requests to check solution during exercise related tasks.

SUS Metric

Once the trial tasks were completed participants were requested to fill out the SUS survey, as given in Appendix E.2. The score for each participant was calculated using Equation 4.1, and then the final score was calculated as the average amongst all participant responses. The results from the SUS survey are listed in Table 4.8. The average score for the BIPMIN application was 85.8, well above the 68 which is considered to be the average usability of software applications. This indicates that

the BIPMIN application exhibits good usability characteristics.

Participant	1	2	3	4	5	6	7	8	9	10	11	12
Score	90	70	90	97.5	65	92.5	90	85	80	97.5	92.5	80
Average	85.8											

Table 4.8: SUS scores.

Observations

A number of observation were noted regarding the usability of the application during the conduct of the trial program.

Many of the exercises included a single start event as the starting diagram. Multiple participants added a new start event as their first action, but then realised the start event already existed and had to remove their start event. This is considered a minor usability issue but could be easily fixed by the removal of the initial start event, providing instead a blank canvas as the starting diagram for those exercises.

The design of the BIPMIN application for the trial separated the rules for exercise completion from the BPMN rules assessed by the linting module. The errors from the linting module were displayed directly on the diagram, whereas any violations of the exercise related rules were listed in the modal shown upon checking the solution. One evaluator showed confusion as to why there were errors listed in the modal that weren't shown directly on the diagram, not understanding why the solution was incorrect even though no errors were shown by the linting module. The evaluator was able to recover and correct their solution after further investigations. For future versions of the application it is recommended to either modify the linting module, or add an additional layer to the diagram, such that any violations of exercise rules are also indicated directly on the diagram.

There was also some confusion noted for participants reviewing the errors in the modal for bpmn.io component names (displayed in the modal) relating to the event definitions. For example when an intermediate timer event was missing the error was labelled as *IntermediateCatchEvent should be of type TimerEventDefinition*. This description is how the timer events are represented within the BPMN modeller, however when presenting the error to users the description could be adapted to use more commonly understood terminology.

Other observations relating to the use of the bpmn.js components are listed below. These observations relate to the plug-in components used in the BIPMIN tool, the functionality of which is provided by external parties.

- A participant accidentally navigated to the previous web page because they

expected to be able to use a context menu connected to the mouse right-click. In bpmn.js the right-click functionality does not exist, and relevant menus are instead shown beside components once selected.

- A participant entered a label onto a component then immediately pressed the "check solution" button. This should have been considered correct but the linting module did not recognise the label until the component had been deselected, i.e. once the edit had been finalised.
- A participant desired a copy functionality to be able to copy and paste components on the diagram. They searched for this functionality in the context menus but were unable to find it. This functionality is possible in bpmn.js by using the "Ctrl + C" aand "Ctrl + V" keyboard shortcuts but that was not realised by the participant.
- At least 5 participants realised they could use the component context menu as a shortcut for creating and connecting components, improving the efficiency of their diagram productions.

Finally, with regard to the usability and design of the BIPMIN application, many participants commented during the trial about how pleasant they found the design of the application, how it was intuitive and easy to use, and how they would be happy to interact with the application further as a learning tool for creating BPMN diagrams.

4.2.2 Game Elements (RQ2)

RQ2 related to the effectiveness of the different game elements at motivating students to learn BPMN. Two sets of metrics were used to answer this question: the first directly observed participants choices during the trial; and the second analysed the responses to a post-trial questionnaire.

Task Metrics

During the trial participants were given a task which required them to complete one extra exercise from the version of their choice (task T6). Figure 4.1 shows which version was chosen by participants to complete this task. The rewards version of the application was overwhelmingly the most chosen version, with 8 out of 12 participants selecting this version. The progress and competition versions each were chosen by 2 participants. This is a particularly interesting result because the rewards version did not contain any of the key game elements popularly associated with gamification, being the PBL trio of points, badges and leaderboards. It instead focused on providing rewards for tasks and showing a collection of pieces to unlock.

An element of mystery was also provided in this version with users encouraged to discover the hidden image.

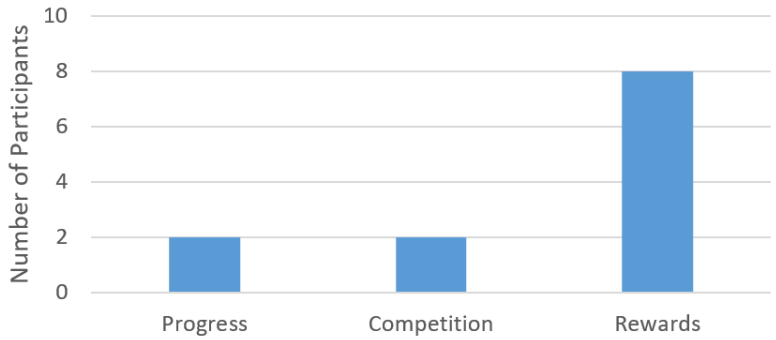


Figure 4.1: Version chosen during task T6.

An optional task (T7) was also included in the trial which encouraged participants to complete further exercises at the end of the trial if so desired. 3 participants elected to complete this task, with 2 continuing on to complete exercises in the version chosen for T6, and the other decided to complete exercises in a different version (changing from competition to rewards). Additionally, many participants indicated that they would complete more exercises were they to use the application during the course and outside of a trial environment.

Post-Trial Questionnaire

Upon completion of the trial participants were requested to also fill out a post-trial questionnaire, as detailed in Appendix E.1. This questionnaire aimed to discover the effect of the different elements on participant's feelings of enjoyment and motivation, and also determine their preferences.

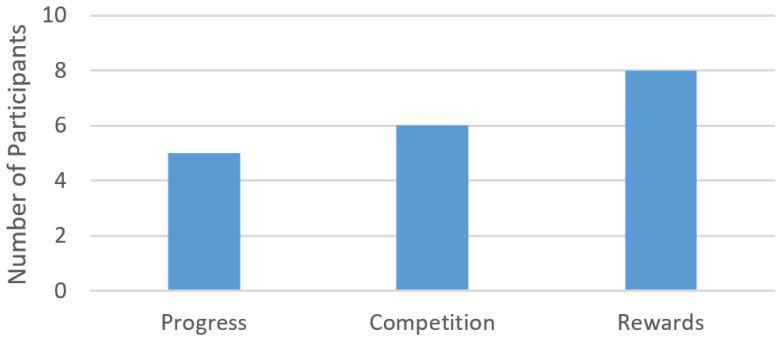


Figure 4.2: Version chosen as most likely to use to study BPMN.

One question asked participants which version of the BIPMIN application they would most likely use if they were to study BPMN further. The responses to this question are shown in Figure 4.2, noting that some participants chose multiple versions in response to this question. The results are consistent with the observations from task T6 in that the rewards version was chosen by the most participants. This chart also shows that the progress and competition versions were appreciated by participants more than Figure 4.1 would suggest, however when forced to choose the rewards version proved to be the most motivational.

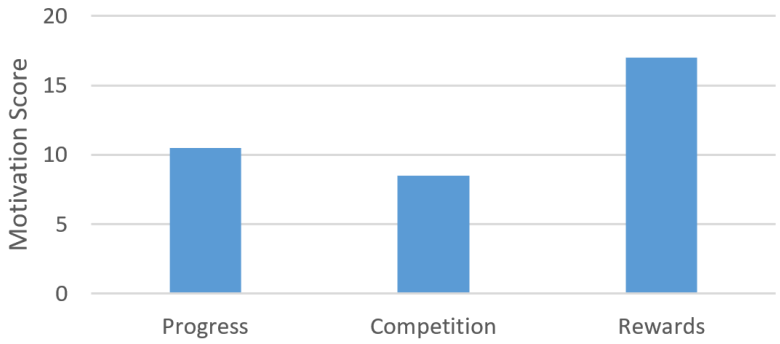


Figure 4.3: Motivational score for each version of BIPMIN.

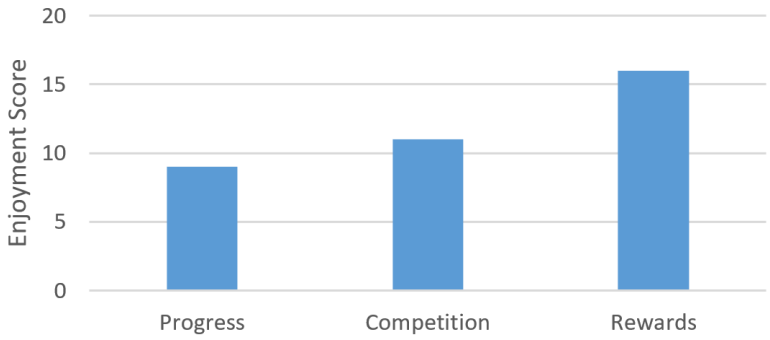


Figure 4.4: Enjoyment score for each version of BIPMIN.

Two questions asked participants to rank the three versions according to which motivated them to complete more exercises, and which they enjoyed using the most respectively. The versions were numbered from 1 to 3 with 1 being the most motivational/enjoyable, and 3 the least. These rankings were converted into a score: a rank of 1 was assigned 2 points; a rank of 2 assigned 1 point; and a rank of 3 given 0 points. The maximum points thus available, considering the trial had 12 participants, was 24 points. The score calculated from these two questions for each of the versions is displayed in Figures 4.3 and 4.4. For both questions the rewards

version proved to be both most motivational and enjoyable for the participants. The competition version was seen to be the least motivational, suggesting that participants were not driven by a competitive nature. Interestingly however, the competition version was found to be more enjoyable than the progress version, even if less motivational.

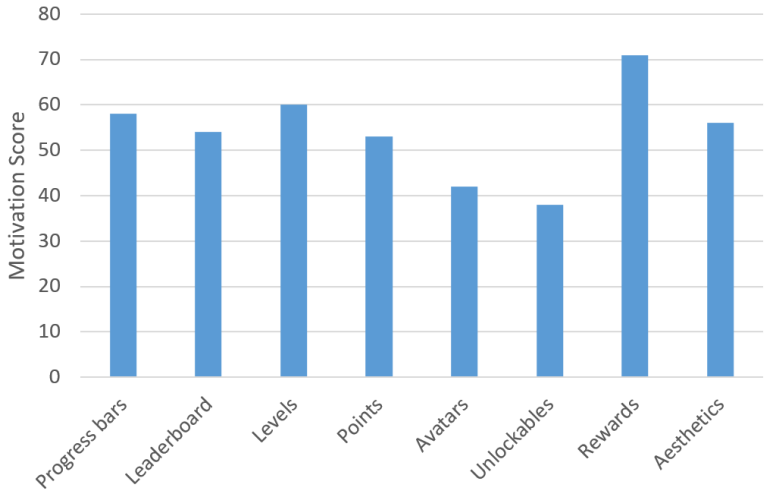


Figure 4.5: Motivational score for each game element.

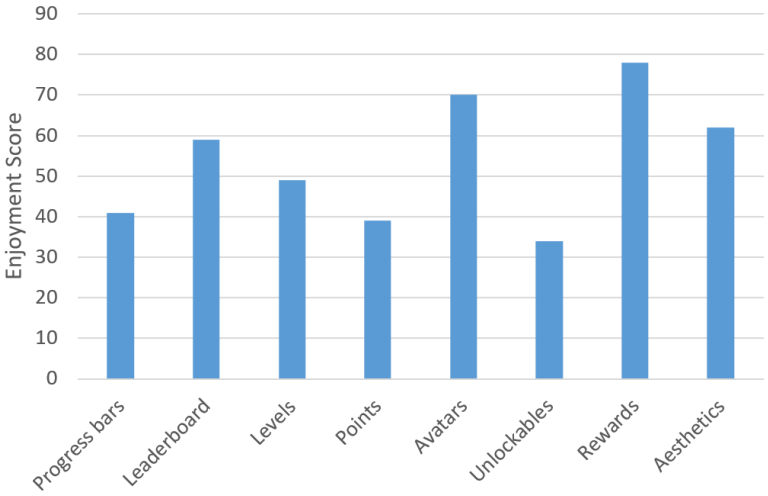


Figure 4.6: Enjoyment score for each game element.

Two similar ranking questions were asked relating to the game elements included in the BIPMIN application versions. Participants were asked to rank each game element according to which motivated them the most and which they enjoyed using

the most respectively. The elements were numbered from 1 to 8, and 1 being the most motivating/enjoyable and 8 the least. The rankings were converted to a score using a reverse points system, where rank 1 = 8 points, rank 2 = 7 points, and so on down to rank 8 = 1 point. The maximum points attainable by a single element was 96 points. The results for these two questions are shown in Figures 4.5 and 4.6 respectively.

The most motivational elements were found to be, in order:

1. rewards,
2. levels,
3. progress bars, and
4. aesthetics.

The most enjoyable elements were found to be, in order:

1. rewards,
2. avatars,
3. aesthetics, and
4. leaderboard.

Rewards were found to be both the most motivational and most enjoyable component, consistent with the findings for the different versions. The rewards version of the application also included the unlockables game element, however this element performed poorly for both motivation and enjoyment, indicating that the success of the rewards version was due to the implementation of the rewards game element. Avatars were found to be not particularly motivating for participants but were one of the most enjoyable elements. The aesthetics were also appreciated by participants as being one of the most important elements, being included as one of the top elements for both motivation and enjoyment.

A question was also asked regarding which game elements participants would recommend be included in the final version of the BIPMIN application. The results are shown in Figure 4.7. Avatars were the most recommended element, even though they were not identified as the most enjoyable or motivating. Points and unlockables were not deemed necessary by the majority of participants.

The most recommended elements were found to be, in order:

1. avatars,
2. levels and rewards, and
3. progress bars.

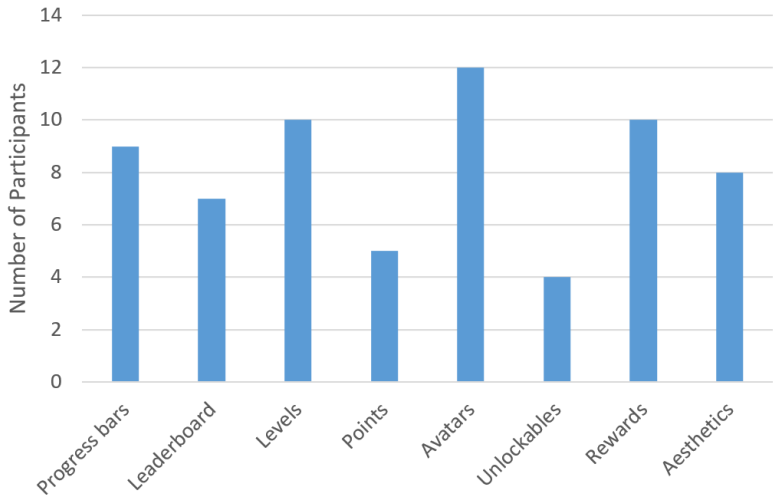


Figure 4.7: Game element recommended for use in final version of BIPMIN.

A final question allowed participants to enter free text comments providing any feedback or suggestions relating to the BIPMIN application. The responses to this question included comments about how participants found the features in the tool useful and stimulating. They appreciated the visuals and novelty of the rewards collection provided in the rewards version. There was also an acknowledgement by a participant that they were not competitive and didn't care about the leaderboard, but appreciated that other people might find it more motivating.

Included in the final comments were some suggestions by participants on methods to improve the tool for future use. These suggestions are summarised below:

- It was suggested to add a tutorial to introduce users to the BPMN components. The BIPMIN application was a useful practice tool, however could not be used alone to teach BPMN since it required pairing with supplementary teaching material. The application could however be converted into a complete BPMN teaching tool with the addition of a tutorial and further guidance or reference material.
- In addition to the game elements present in BIPMIN it was suggested to add an achievements or badges element, as additional techniques for motivating students.
- Another suggested additional game element was the introduction of a duelling system, such that users not only compete with the rest of the class on a leaderboard but directly with one another in duel-like scenarios.
- In the progress version it was suggested to update the congratulations modal to also show the progress of the user to the next level.

Observations

A number of observations regarding the use of the different game elements were noted during the conduct of the trial program.

The competition version of the application was not assessed to be as motivating or enjoyable by the participants when compared to the rewards version. However it was acknowledged by participants that the competition version might be more appealing when deployed in a classroom environment and when users are competing against known colleagues. One participant in particular admitted that they wanted to compete with their colleagues, and if they used the application while attending the Information Systems course they envisaged using the competition version the most (even though in the experiment they chose the rewards version). The lower performance of the competition version could therefore be due to the evaluation being conducted in an independent trial environment. This possibility warrants further investigation, and is recommended to be considered during future experiments.

The interactions of participants with the application was also limited by time constraints. One participant indicated that they would have continued completing exercises until they were top of the leaderboard, however they were mindful of the time and their other commitments. Other participants also indicated desires to continue completing exercises in the rewards version so that they could collect all the puzzle pieces, but they didn't have the time. The trial program was conducted in the lead up to the summer examination session at the Politecnico di Torino and many of the volunteer participants were preparing for exams. More accurate data on the behaviour of students and their interactions with the BIPMIN application should however be obtainable during the larger experiment planned to be conducted during the next semester.

General comments from participants during their use of the tool also indicated that they were pleased with the way the game elements had been incorporated into the application, enjoying the look and feel of the elements. Participants were particularly pleased with the choice of avatars, and the display of the rewards collection.

4.2.3 General Observations

Separate from the two formulated research questions, this study also aimed to design a tool that was effective at improving student's understanding of BPMN modelling. Observations relating to this goal were made during the evaluation session, aimed at assessing the participants development of their BPMN modelling skills during the trial. These observations are summarised below:

- The majority of participants were noted to improve their component labelling

practices during their use of the tool. After their first error notification about a component missing a label they remembered in subsequent exercises to label all their components. Some participants even labelled more components than were deemed necessary by the linting module. Other participants already had good labelling practices and never experienced errors relating to missing labels.

- During the trial there were some participants that initially used the wrong type of component required for the exercise. Upon being notified and correcting their error, in subsequent exercises these participants learnt to consider the types of components before submitting their solutions.
- Generally participants were noted to learn from previous errors, and did not repeat any mistakes.

These observations suggest that the BIPMIN application had a positive effect on improving the trial participants BPMN modelling practices. Further research is however required to quantitatively prove its effectiveness, which will be conducted in the next semester.

Observations were also made regarding the usefulness of the evaluation engine, which was developed to assess the accuracy of the BPMN diagram exercise solutions. There were several instances during the trial where participants added extra components to the diagram, which were flagged as an error by the evaluation engine, however when assessed by a teacher would have been considered as correct. There were however other instances where extra components were added and the evaluation engine considered the solutions correct. The flexibility of the evaluation engine depended on the specific rules selected to assess a particular exercise. In some instances these rules were restrictive, not allowing other correct solutions. When using the evaluation engine in the future teachers would therefore need to carefully consider their exercise rule definitions to ensure both accuracy and sufficient flexibility. The evaluation engine is not a perfect substitute for traditional teacher assessment and feedback, however it's use with the BIPMIN application was deemed useful as a support tool for providing practice material to improve BPMN modelling practices.

4.3 Recommendations

The following section provides recommendations for future development of the BIPMIN application based on the outcomes of the evaluation. This includes recommendations for: improvements to the usability of the application; the implementation of game elements within the application; and also general recommendations for future experiments to be conducted in this field.

It is envisaged that the BIPMIN application will be developed further for use in the Information Systems course to be held in the next semester. In preparing the application for use in the course a single version of the application is planned to be developed, merging the best aspects from all three versions of the application, and potentially providing additional capability. The following recommendations assume that the three versions will be merged into one, and are phrased accordingly.

4.3.1 Application Usability

According to the results from the SUS survey the usability of BIPMIN was very good, however, good applications can still be improved.

Based on analysis of the results of the evaluation the following recommendations are made relating to improving the usability of the BIPMIN application:

1. It is recommended to remove the initial start event from exercises with otherwise empty starting diagrams to remove the minor confusion experienced by some participants of the evaluation. This will also foster user experience with developing diagrams from scratch.

2. Violations of exercise rules are currently listed in an error modal displayed to the users upon checking their exercise solutions. Errors displayed directly on the diagram are limited to those identified by the linting module plug-in. It would be beneficial to users if the violations to the exercise rules were also displayed directly on the diagram. This could be achieved by either modifying the linting module to include custom error notifications, or by adding an additional display layer on top of the diagram to indicate the exercise rule violations.

3. When presenting the violations of exercise rules in the modal it is also recommended to adapt the description of the error to use more commonly understood terminology.

4. If the final version of BIPMIN is to include a home screen, separate from the main screen used to complete exercises, it is recommended to include a clear home button in the navigation bar. This button should either be labelled as "HOME" or use a commonly understood home icon, to enable clearer navigation to the home screen.

5. The final version is envisaged to be deployed as a website hosted by the Politecnico di Torino. It is therefore recommended to conduct a response time analysis and performance testing on the website to investigate methods to improve the efficiency of the application and reduce load on the server. In general the response times are expected to be good, with the majority of

interactions and feedback performed on the client side, however it is possible that certain data updates or features could be slow in this environment. Appropriate feedback should therefore be provided to the user to display the status of the application whilst waiting for server responses.

4.3.2 Gamification Design

This study analysed the effectiveness of 8 different game elements at motivating students to learn BPMN modelling. With the plan to combine the three versions of the BIPMIN application into one version to be used by future courses, the following recommendations are made relating to the choice and implementation of the gamification elements:

1. Results from this study found the top most motivational and enjoyable game elements to be: rewards, levels, progress bars, aesthetics, avatars and leaderboards. It is therefore recommended to include these game elements in the final version of the application. In particular the rewards element was deemed to be both the most motivational and enjoyable by the participants in the evaluation for this study.

2. Aesthetics were also found to be a key attribute that was important for both motivation and enjoyment. The general aesthetics of BIPMIN were found to be pleasing to participants of the trial program, and should be retained in future versions of the application. If any changes to the aesthetic design are proposed they should be carefully considered.

3. This study only considered 8 game elements, however many more game elements exist that could be incorporated into the application. Of the elements analysed in Chapter 2 the following could be suitably incorporated into BIPMIN:

   - Story telling
   - Badges
   - Quests

   To assess the effectiveness of the different elements in a combined application future studies could measure which elements are most interacted with by users.

4. Observations from the trial program indicated that the competition version may perform better in a classroom environment. It is therefore recommended to keep the game elements from the competition version in the final version of the application, and to design an experiment to further test its motivational potential.

5. The exercises in BIPMIN were designed with incremental difficulty, however during the trial program the order of the exercises were shuffled such that the first exercise in each version was different. This was done so that participants could complete new exercises when completing tasks in the different versions of the application, rather than re-doing the same first exercise three times. It is therefore recommended to restore the order of the exercises in the final version.

6. Finally, within the congratulations model it is recommended to show additional details relating to the progress of the user for all relevant game elements, such as their progress through the levels, points gained, rewards earned, and rank increase.

4.3.3 Further Work

This study was a preliminary assessment of the effectiveness of different game elements when incorporated into a tool for learning BPMN. Outcomes from this study suggested that gamification has the potential to improve students understanding and skills related to BPMN modelling, however further study is required to better understand and quantitatively prove its effectiveness. To this end, a larger experiment is planned to incorporate the use BIPMIN into the curriculum of the Information Systems course to be conducted next semester. This next experiment could potentially include over 100 participants, with volunteers sought from masters level students completing the course. In conducting the experiment researchers will be able to gather better statistical data due to the number of participants envisaged. The planned experiment will also not be as limited by the timing constraints as experienced during the trial program for this study, which will allow a greater understanding of the behaviour of the cohort.

The following recommendations are made relating to the conduct of future trials evaluating the effectiveness of the BIPMIN application:

1. To analyse whether the tool has had a positive effect on student understanding of BPMN concepts it is recommended to split the trial participants into two groups: one group which uses the BIPMIN tool during their studies; and a separate group which completes their studies traditionally, without access to BIPMIN. At the end of the course the performance of the two groups at completing the BPMN related exercise assessments can be compared, and used to directly analyse the effectiveness of BIPMIN.

2. It is also recommended to add a tutorial to the application introducing the use of the tool and the BPMN components, as well as providing additional reference material accessible within the tool. In this way BIPMIN could

become more self-contained and be used more efficiently by students wishing to study BPMN content.

3. Currently BIPMIN includes 6 different exercises for creating BPMN diagrams, which only cover some aspects of BPMN modelling. In a course environment further exercises will need to be developed introducing further BPMN concepts. This will provide more depth and content to the application, increasing its utility.

4. Lastly, its is recommended to improve the capability and flexibility of the evaluation engine to increase its applicability for use as a supplementary BPMN diagram assessment tool. Further discussions with teachers of BPMN are suggested to better understand the common pitfalls experienced by students, and design evaluation rules accordingly. It is also recommended to investigate ways to make the existing rules less restrictive or more prescriptive, adapting the capability to that required to correctly assess different diagrams.

Chapter 5

Conclusion

This study applied gamification principles to computer engineering education by designing a gamified tool for the teaching of BPMN practices. The effectiveness of different game elements was then analysed to determine which elements were the most important for improving student motivation and engagement with the tool, and by extensions the subject.

A prototype web application was developed, named BIPMIN, which implemented three different designs, each incorporating different game elements relating to either progress, competition or rewards. The web application was designed following software engineering design principles. Additionally for this study an evaluation engine was developed to enable the automatic assessment of BPMN diagrams, and its suitability analysed.

A trial program was then conducted to evaluate the usability of the tool and the effectiveness of the various game elements. The program involved 12 volunteer participants from the cohort of computer engineering students, who were asked to complete a number of tasks using the web application. Participants choices and performance was recorded during the trial, and used to assess the usability of the tool and effectiveness of the game elements at increasing motivation.

The usability of the application performed well, scoring an average of 85.8 on the System Usability Scale. Participants were generally pleased with the aesthetics, layout and intuitiveness of the user interface design. Despite the application's good performance on usability, a number of recommendations were proposed to improve the usability further. These recommendations included adding extra feedback to users relating to any errors found with their submitted exercise solutions, and adapting terminology used to be more broadly understandable by students. It was also suggested to implement additional reference material within the web application, including a tutorial to introduce the BPMN components and their usage.

Of the three different designs analysed the rewards version was found to be

both the most motivational and enjoyable by students. It performed strongly in all criteria when compared to the progress and competition based designs. From feedback received during the trial it was however noted that the competition version could perform better in a classroom environment, where students would be able to directly compete against their classmates. Further analysis of these elements was therefore recommended to better understand the behaviour of the cohort in a learning environment.

The effectiveness of individual game elements was also assessed. The results are shown in Table 5.1 for the top three most motivational, most enjoyable, and most recommended game elements of the eight included in this study. Rewards were found to be both the most motivational and enjoyable element, however avatars were the most recommended. Elements relating to progress also performed well (levels and progress bars). The elements listed in Table 5.1 were therefore recommended to be included in future versions of the application.

Most Motivational	**Most Enjoyable**	**Most Recommended**
1. Rewards	1. Rewards	1. Avatars
2. Levels	2. Avatars	2. Levels & Rewards
3. Progress bars	3. Aesthetics	3. Progress bars

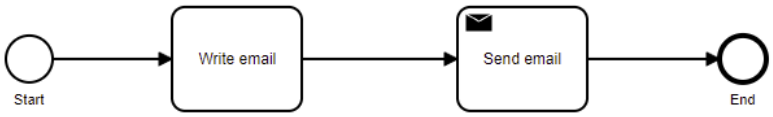
Table 5.1: Top 3 individual game elements.

The effectiveness of the tool at improving student's understanding of BPMN modelling was also assessed. Participants were observed during the conduct of the trial program to: improve their component labelling practices; consider types of components in their diagrams; and learn from their previous errors responding to notifications from the evaluation engine. These observations suggest that the BIPMIN application had a positive effect on improving the trial participants BPMN modelling practices.

This study demonstrated the potential of gamification and its components at motivating students to engage with a BPMN teaching tool. Further analysis is however recommended to better understand and quantitatively prove its effectiveness, by conducting a larger experiment which uses the BIPMIN application within a classroom environment.

Appendix A

Exercises

Title	Send an email
Description	Let's create your first model! In this exercise you will create a simple process for sending an email. Your process should consist of: • a start event, • a task for writing the email, • a task for sending the email, • an end event.
Starting Diagram	
Completed Diagram	

Completion Rules	Must have: • 1 start event, • 1 normal task, • 1 send message task, • 1 end event, • all in sequence, • and abide by linting rules.

Table A.1: Exercise 1 - Task Creation (Easy).

Title	Choose your lunch
Description	Now you need to decide what you're having for lunch. You have two options, pizza or pasta. Create a process with a gateway representing your lunch options, each followed by a task to prepare your lunch. Then combine the two branches allow you to eat your lunch. Your process should consist of: • a start event, • an exclusive gateway, • 2 tasks representing the preparation of each your lunch options • 1 task to eat your lunch • an end event.
Starting Diagram	

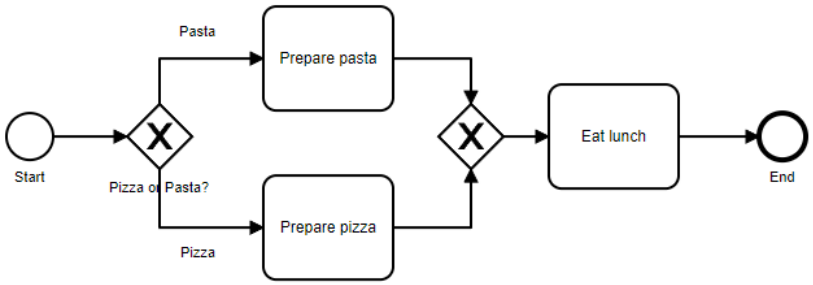
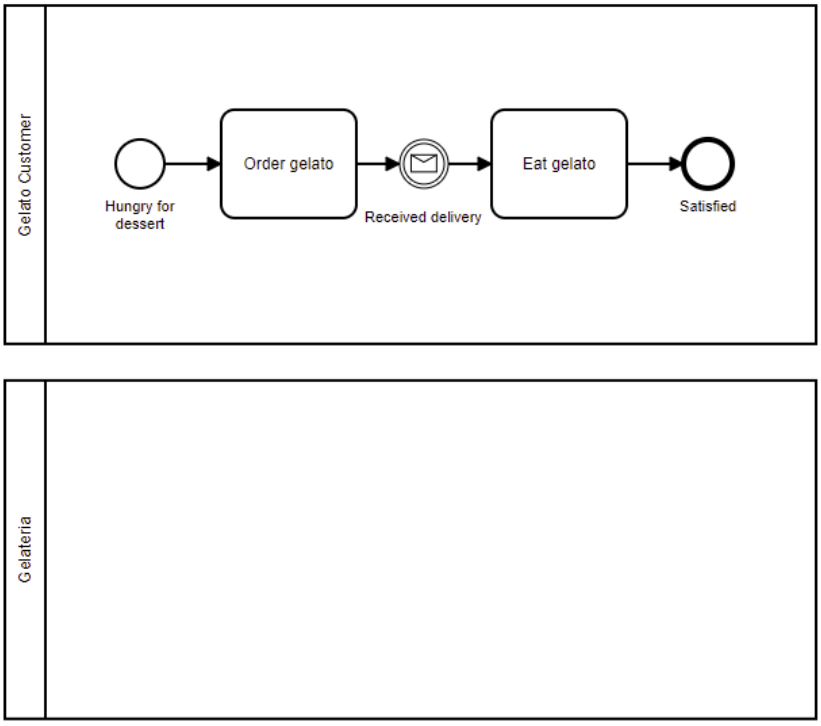
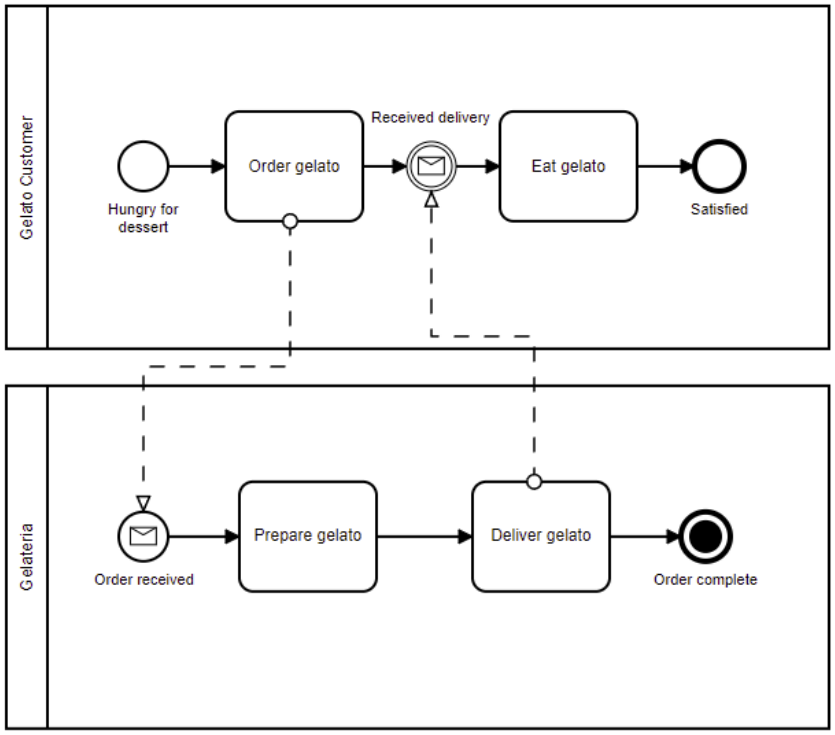
Completed Diagram	
Completion Rules	Must have: • 1 start event, • 3 normal tasks, • 2 exclusive gateways, • 1 end event, • second exclusive gateway has two incoming tasks and one outgoing task, • first exclusive gateway has two outputs, • and abide by linting rules.

Table A.2: Exercise 2 – Exclusive Gateway (Easy).

Title	Order dessert
Description	Now that you've finished lunch you're craving a gelato, but you have none at home so you order one from your local gelateria. Complete the given diagram by adding a process to the gelateria which responds to the "Order gelato" task, by preparing the gelato and then delivering it. To complete this exercise you will need to add: • a message start event, • a task for preparing the gelato, • a task for delivering the gelato, • a terminate end event, • a message flow from the "Order gelato" task and another to the "Received delivery" intermediate event.

Starting Diagram	
Completed Diagram	

Completion Rules	Must have: • 1 message start event with source as order gelato task, • 1 normal task with a message flow connection target as received delivery, • 1 terminate end event, • and abide by linting rules.

Table A.3: Exercise 3 – Pools (Medium)

Title	Phone a friend
Description	You're thinking about adopting a cat and you'd like your friend's opinion. Unfortunately they accidentally threw their phone into a river yesterday and are now using a temporary number. Create a process with a task for calling your friend, attaching an error event for when you can't reach your friend because you've called the wrong number. Your process should consist of: • a start event, • a task for calling your friend, • an end boundary event, • a task for the error, • 2 end events, one for success and one for failure.
Starting Diagram	

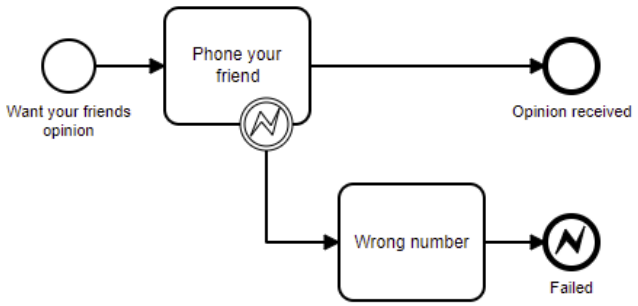
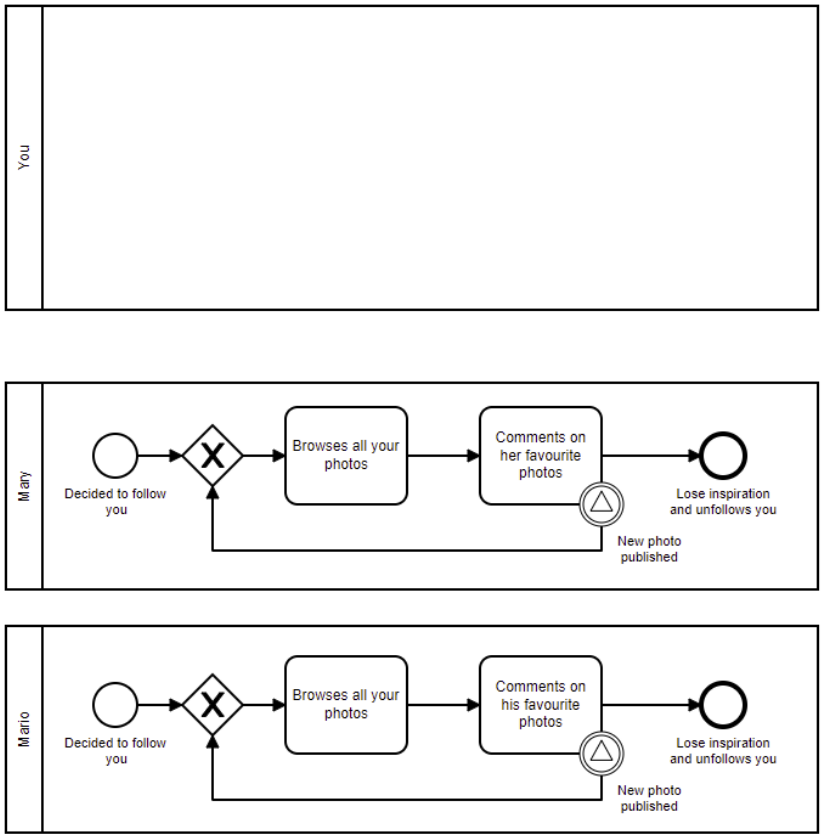
Completed Diagram	
Completion Rules	Must have: • 1 start event, • 2 normal tasks, • 1 error boundary, • 1 end event, • 1 error end event, • sequence shown in solution, • and abide by linting rules.

Table A.4: Exercise 4 – Error event (Easy)

Title	You've got followers!
Description	You have a few followers who are interested in seeing and commenting on photos of your holidays. You recently went on holiday and have a photo you'd like to share with your follows. Construct a process for choosing a photo to publish and attach a signal event to let your followers know about the publication. Your process should consist of: • a start event, • a task for choosing a photo, • a task for publishing the photo, • a signal throw event, • an end event.

Starting Diagram



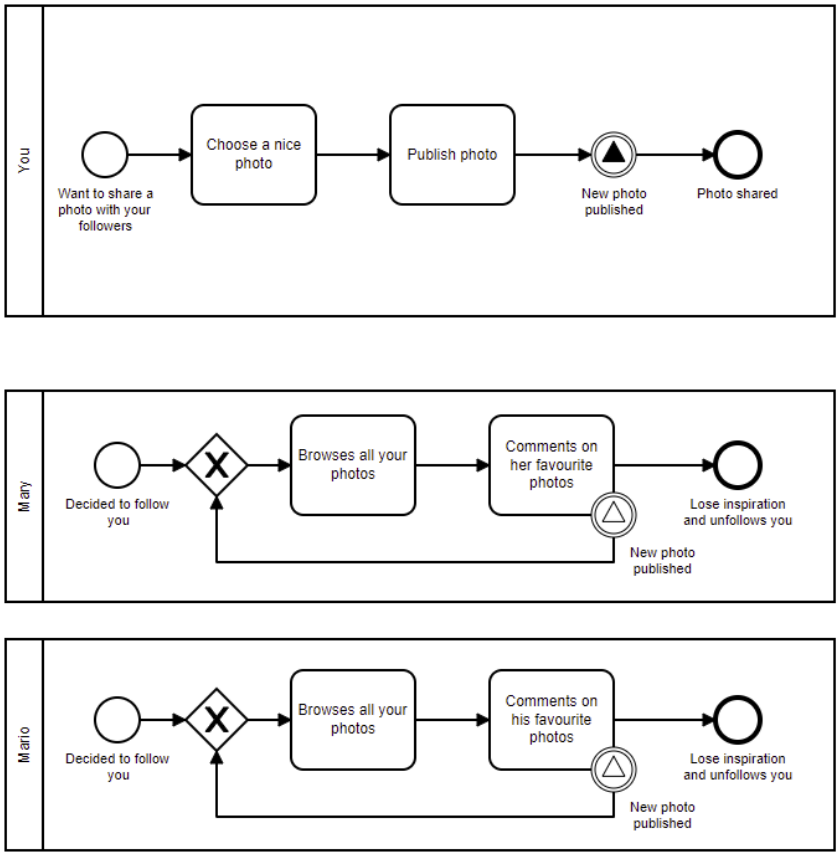
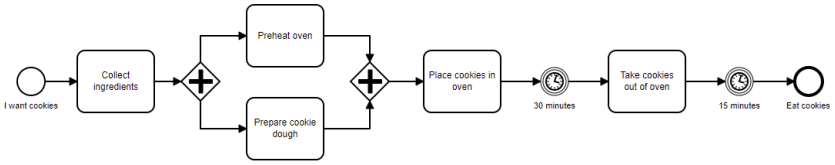
Completed Diagram	
Completion Rules	Must have: • 3 start events, • 6 normal tasks, • 1 signal throw event, • 3 end events, • sequence shown in solution, • and abide by linting rules.

Table A.5: Exercise 5 – Signal (Medium)

Title	Cookie time

Description	You really really really want to eat some cookies, but you have none. So let's bake some! Create a process for baking some cookies. Your process will involve: collecting ingredients; then preparing the dough while the oven is preheating; putting the cookies in the oven then waiting for them to bake; taking the cookies out of the oven then waiting for them to cool. Your process should consist of: • a start event, • a task for collecting ingredients, • a parallel gateway with two tasks, one for preheating the oven and one for preparing the dough, • a task for putting the cookies in the oven, • a timer event for the baking, • a task for taking the cookies out of the oven, • a timer event for waiting for the cookies to cool, • an end event to finally eat your cookies.
Starting Diagram	
Completed Diagram	

Completion Rules	Must have: • 1 start event, • 5 normal tasks, • 2 parallel gateways, • 2 timer events, • 1 end event, • sequence shown in solution, • and abide by linting rules.

Table A.6: Exercise 6 – Parallel Gateway and Timer (Medium)

Appendix B

BIPMIN APIs

B.1 Exercise APIs

Usage: Retrieve exercise starting diagrams.
Method: GET
Address: /api/diagram/resources/<filename>
Body: null
Response: XML file

Usage: Retrieve the exercise of a specified part and place.
Method: GET
Address: /api/exercise/<part>/<place>
Body: null
Response: JSON object

Usage: Retrieve all exercises.
Method: GET
Address: /api/exercises
Body: null
Response: JSON object

Usage: Create a new exercise.
Method: POST
Address: /api/exercise
Body: JSON exercise object
Response: HTTP Status Code

Usage: Update an exercise.

Method: PUT
Address: /api/exercise/<part>/<place>
Body: JSON exercise object
Response: HTTP Status Code

B.2 User Progress APIs

Usage: Get the progress of a user.
Method: GET
Address: /api/progress/<user>
Body: null
Response: JSON progress object

Usage: Get the progress of all users.
Method: GET
Address: /api/progresses
Body: null
Response: JSON progress list object

Usage: Update the progress of a user.
Method: PUT
Address: /api/progress/<user>
Body: JSON progress object
Response: HTTP Status Code

B.3 User APIs

Usage: Get all users.
Method: GET
Address: /api/users
Body: null
Response: JSON user list object

Usage: Get a user.
Method: GET
Address: /api/user/<user>
Body: null
Response: JSON user object

Usage: Update a user's avatar.
Method: PUT
Address: /api/user/<user>
Body: JSON avatar object
Response: HTTP Status Code

Usage: Create new user.
Method: POST
Address: /api/user
Body: JSON user object
Response: HTTP Status Code

Appendix C

Tutorial Task

Head to `https://demo.bpmn.io/new` if you're not there already.

Let's create your first model!

You've just woken up in the morning and you need a coffee. Let's create a simple process for making your coffee. Please follow the following steps to create the BPMN diagram:

1. Label the start event by double clicking on the start event () and typing "Woke up".

2. Add a task to the right of the start event by clicking on the "Create Task" icon () on the left, then clicking to the right of the start event. Label this task "Boil kettle".

3. Add a sequence flow by clicking on the "Activate the global connect tool" () icon on the left, then clicking on the start event and then the "Boil kettle" task.

4. Next we have to wait for the kettle to boil. Create a Timer Intermediate Catch Event by clicking on the "Create Intermediate/Boundary Event" () icon on the left, then clicking to the right of the "Boil kettle" task. Now click on the wrench icon () attached to the intermediate event and select "Timer Intermediate Catch Event". Double click on the event and label it "Wait for kettle to boil". Finally add a sequence flow like before from the "Boil kettle" task to the timer event.

5. Next create a "Make coffee" task by adding another task to the right of the

"Wait for kettle to boil" event and labelling it "Make coffee". Connect it with a sequence flow coming from the "Wait for kettle to boil" event.

6. Finally add an end event by clicking on the "Create End Event" icon () and label it "Coffee ready". Connect the "Make coffee" task to the end event.

7. You're done! Now ask the facilitator to check your solution.

Appendix D

Test Script

Hi, <name of the participant>. I am <name of the facilitator> and today we'd like you to help us assess our new BPMN modelling tool. This application uses gamification elements to improve the experience of learning how to create BPMN diagrams. The application has three different versions, one focusing on progress related game elements, one focusing on competition, and one focusing on rewards. From this experiment we'd like to assess the effectiveness of different gamification elements and improve the application for use in future courses.

Remember we are here to test the website, not you! So don't worry about whether or not you're able to achieve the tasks we give you, if you can't complete them it is our fault and we would greatly appreciate your feedback to help us improve the application for future users.

Please fill out this document giving us permission to collect data regarding your performance during the experiment, this includes taking photographs of you during the experiment.

<hand participant the consent form>

Thank you.

To begin we're going to go through a tutorial about how to use the BPMN modelling tool. This first task uses a public website that is currently used in the domain for BPMN modelling.

<hand participant tutorial instructions>
<open BPMN website tab on the computer>

Please follow these instructions to create your first BPMN diagram. If you have any questions feel free to ask us, and once you're finished please let us know and we will check your solution.

Next we will begin the tasks on our BPMN gamification tool.

<open BIPMIN on the computer>

Here is the list of tasks we would like you to perform if possible.

<hand participant the list of tasks>

If you're comfortable we kindly request that you talk us through what you're thinking as you work through the tasks, think-aloud so to speak.

If you get stuck at all or need any help please feel free to ask. Do you have any questions before we start?

Please let me know when you're ready to begin the first task.

T2, T3, T4, T5, T6 [Record times]

Thank you for completing those.

Lastly we kindly request you to fill out these two end of experiment questionnaires to help us assess our application.

<Hand participant post-test questionnaires>

If you have any further thoughts or recommendations please feel free to let us know.

Thank you for helping us today.

Appendix E

Post-Trial Questionnaires

E.1 Post-Trial Questionnaire

Post Experiment Survey

We'd like your opinions!

Thank you for participating in our experiment. As one final request we'd appreciate your thoughts on the BIPMIN tool by filling out this short questionnaire. If you have any questions about any of the topics please ask.

Did you attend the Information Systems course?

☐ Yes ☐ No

Which version of the BIPMIN tool would you be most likely to use if you were to study BPMN further?

☐ Progress Version ☐ Competition Version ☐ Reward Version ☐ I wouldn't use it

Please briefly explain your choice:

Please rank each version according to how motivated you were to complete more exercises, with 1 being the most motivated and 3 being the least motivated.

Progress Version ☐ Competition Version ☐ Reward Version ☐

Please rank each version according to which you enjoyed using the most, with 1 being the most enjoyment and 3 being the least enjoyment.

Progress Version ☐ Competition Version ☐ Reward Version ☐

Please rank each of the game features in terms of which motivated you the most, with 1 being the most motivating and 8 being the least motivating.

Progress bars	☐	Levels	☐	Avatars	☐	Rewards	☐
Leaderboard	☐	Points	☐	Unlockables	☐	Aesthetics	☐

Please rank each of the game features in terms of which you found most enjoyable, with 1 being the most enjoyable and 8 being the least enjoyable.

Progress bars	☐	Levels	☐	Avatars	☐	Rewards	☐
Leaderboard	☐	Points	☐	Unlockables	☐	Asthetics	☐

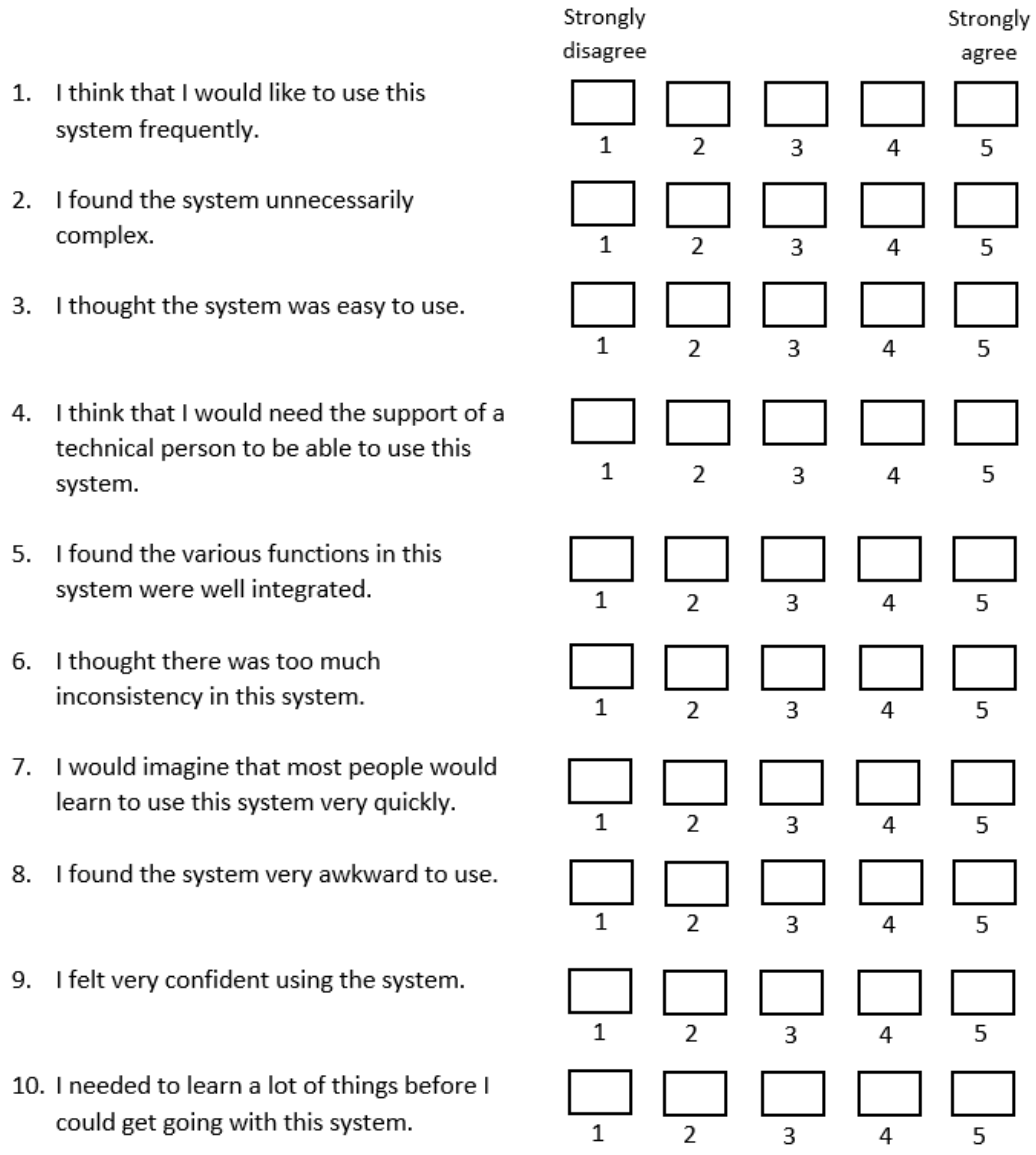
Which of the following game features would you recommend including in the final version of the BIPMIN tool? Please tick all that apply.

Progress bars	☐	Levels	☐	Avatars	☐	Rewards	☐
Leaderboard	☐	Points	☐	Unlockables	☐	Asthetics	☐

Please let us know if you have any additional comments or suggestions.

E.2 System Usability Scale

The standard version of the system usability scale, sourced from [74].



Bibliography

[1] Linkedin. *Most in-demand jobs and industries in Europe & Middle East and Latin America August 2020*. URL: https://business.linkedin.com/talent-solutions/recruiting-tips/thinkinsights-emea/most-in-demand-jobs-and-industries-in-europe-middle-east-and-latin-america/ (cit. on p. 1).

[2] B. Marín, J. Frez, J. Cruz-Lemus, and M. Genero. «An Empirical Investigation on the Benefits of Gamification in Programming Courses». In: *ACM Transactions on Computing Education* 19.1 (2018), p. 4 (cit. on pp. 2, 5, 6, 11, 15).

[3] H W Prabawa, H Sutarno, J Kusnendar, and F Rahmah. «Learning basic programming using CLIS through gamification». In: *Journal of Physics: Conference Series* 1013.1 (2018), p. 12099 (cit. on pp. 2, 6, 18).

[4] Arturo Rojas-López and Elvira G. Rincón-Flores. «Gamification as Learning Scenario in Programming Course of Higher Education». In: *International Conference on Learning and Collaboration Technologies: Learning and Teaching*. LNCS 10925. Las Vegas, USA, 2018, pp. 200–210 (cit. on pp. 2, 7, 8, 11, 14, 15, 17, 27).

[5] Mewati Ayub, Hapnes Toba, Maresha C. Wijanto, Steven Yong, and Bryan Wijaya. «Gamification for blended learning in higher education». In: *World Transactions on Engineering and Technology Education* 17.1 (2019), pp. 76–81 (cit. on pp. 2, 5, 15).

[6] Mamoona Tasadduq, M. Salman Khan, Rao M. A. Nawab, M. Hassan Jamal, and M. Tayyab Chaudhry. «Exploring the effects of gamification on students with rote learning background while learning computer programming». In: *Computer Applications in Engineering Education* 29.6 (2021), pp. 1871–1891 (cit. on pp. 2, 6, 11, 13, 14, 17).

[7] Gordon Fraser. «Gamification of Software Testing». In: *Proceedings of the 12th International Workshop of Automation of Software Testing*. IEEE/ACM. 2017, pp. 2–7 (cit. on pp. 2, 6, 11).

[8] José Miguel Rojas, Thomas D. White, Benjamin S. Clegg, and Gordon Fraser. «Code Defenders: Crowdsourcing Effective Tests and Subtle Mutants with a Mutation Testing Game». In: *IEEE/ACM 39th International Conference on Software Engineering*. IEEE. 2017, pp. 677–688 (cit. on pp. 2, 6).

[9] Marie Olsson, Peter Mozelius, and Jonas Collin. «Visualisation and Gamification of e-Learning and Programming Education». In: *The Electronic Journal of e-Learning* 13.6 (2015), pp. 441–454 (cit. on pp. 2, 4–6, 9, 11, 12, 14).

[10] Patricia Matsubara and Caroline da Silva. «Game elements in a software engineering study group: a case study». In: *Proceedings of the 39th International Conference on software engineering*. IEEE/ACM. 2017, pp. 160–169 (cit. on pp. 2, 12, 13).

[11] Michael D. Hanus and Jesse Fox. «Assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance». In: *Computers & Education* 80 (2015), pp. 152–161 (cit. on pp. 2, 15, 17).

[12] SAP Signavio. *BPMN 2.0 for Efficient Process Design*. URL: `https://www.signavio.com/bpmn-2-0-for-efficient-process-design/` (cit. on p. 3).

[13] BOC Products & Services AG. *ADONIS: Community Edition: Your free cloud BPM tool*. URL: `https://www.adonis-community.com/en/` (cit. on p. 3).

[14] Bizagi. *Bizagi Modeler*. URL: `https://www.bizagi.com/en/platform/modeler` (cit. on p. 3).

[15] ESTECO SpA. *Business Process Management the Cardanit way*. URL: `https://www.cardanit.com/bpmn-editor/` (cit. on p. 3).

[16] Eclipse Foundation. *BPMN2 Modeler*. URL: `https://www.eclipse.org/bpmn2-modeler/` (cit. on p. 3).

[17] Camunda. *Camunda Modeler*. URL: `https://camunda.com/platform/modeler/` (cit. on p. 3).

[18] Camunda. *Web-based tooling for BPMN, DMN and Forms*. URL: `https://bpmn.io/` (cit. on pp. 3, 49).

[19] Manal M. Alhammad and Ana M. Moreno. «Gamification in software engineering: A systematic mapping». In: *The Journal of Systems and Software* 141 (2018), pp. 131–150 (cit. on pp. 4–6, 19, 25).

[20] Oscar Pedreira, Félix García, Nieves Brisaboa, and Mario Piattini. «Gamification in software engineering – A systematic mapping». In: *Information and Software Technology* 57 (2015), pp. 157–168 (cit. on pp. 4, 5, 10).

[21] Dirk Basten. «Gamification». In: *IEEE SOFTWARE* 35.5 (2017), pp. 76–81 (cit. on pp. 4, 5, 10, 11).

[22] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. «From Game Design Elements to Gamefulness: Defining "Gamification"». In: *Proceedings of the 15th International Academic MindTrek Conference*. MindTrek'11. Tampere, Finland, 2011, pp. 9–15 (cit. on pp. 4, 5, 10).

[23] Yu-Kai Chou. *The Octalysis Framework for Gamification & Behavioural Design*. URL: `https://yukaichou.com/gamification-examples/octalysis-complete-gamification-framework/` (cit. on pp. 4, 10).

[24] Michael Sailer, Jan Ulrich Hense, Sarah Katharina Mayr, and Heinz Mandl. «How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction». In: *Computers in Human Behavior* 69 (2017), pp. 371–380 (cit. on pp. 4, 5, 7, 8, 10, 11, 15–19).

[25] Michael Sailer and Lisa Homner. «The Gamification of Learning: a Meta-analysis». In: *Educational Psychology Review* 32 (2020), pp. 77–112 (cit. on pp. 4, 5, 7, 8).

[26] Lei Shi and Alexandra I. Cristea. «Motivational Gamification Strategies Rooted in Self-Determination Theory for Social Adaptive E-Learning». In: *Intelligent Tutoring Systems* 9684 (2016), pp. 294–300 (cit. on pp. 4, 7, 8).

[27] Siaw-Chui Wee and Weng-Wai Choong. «Gamification: Predicting the effectiveness of variety game design elements to intrinsically motivate users' energy conservation behaviour». In: *Journal of Environmental Management* 233 (2019), pp. 97–106 (cit. on pp. 4, 7, 9).

[28] Benedikt Morschheuser, Lobna Hassan, Karl Werder, and Juho Hamari. «How to design gamification? A method for engineering gamified software». In: *Information and Software Technology* 95 (2018), pp. 219–237 (cit. on p. 5).

[29] Antonio Bucchiarone et al. «Papyrus for gamers, let's play modeling». In: *ACM/IEEE 23rd International Conference on Model Driven Engineering Languages and Systems*. MODELS '20 Companion. Canada, 2020, p. 21 (cit. on pp. 5, 11, 17).

[30] Darina Dicheva, Keith Irwin, and Christo Dichev. «Exploring Learners Experience of Gamified Practicing: For Learning or for Fun?» In: *International Journal of Serious Games* 6.3 (2019), pp. 5–21 (cit. on p. 5).

[31] Vladimir Uskov and Bhuvana Sekar. «Gamification of Software Engineering Curriculum». In: *2014 IEEE Frontiers in Education Conference Proceedings*. IEEE. 2014, pp. 1–8 (cit. on p. 5).

[32] Daniel J. Dubois and Giordano Tamburrelli. «Understanding Gamification Mechanisms for Software Development». In: *Proceedings of the 2013 9th Joint Meeting on foundations of software engineering*. ACM. Saint Petersburg, Russian Federation, 2013, pp. 659–662 (cit. on pp. 5, 15).

[33] Bradley J. Morris, Steve Croker, Corinne Zimmerman, Devin Gill, and Connie Romig. «Gaming science: the "Gamification" of scientific thinking». In: *Frontiers in Psychology* 4 (2013), p. 607 (cit. on p. 5).

[34] W N Hidayat, A Fitranti, A F Firdaus, C D I Kartikasari, and T A Sutikno. «Gamification based mobile application as learning media innovation for basic programming lessons». In: *The 1st Annual Technology, Applied Science and Engineering Conference*. IOP Conference Series: Materials Science and Engineering. 2020, p. 12113 (cit. on pp. 5, 6, 11).

[35] Jaouja Maiga and Andi Wahju Rahardjo Emanuel. «Gamification for Teaching and Learning Java Programming for Beginner Students — A Review». In: *Journal of Computers* 14.9 (2019), pp. 590–595 (cit. on p. 6).

[36] Filippo Cacciotto, Tommaso Fulcini, Riccardo Coppola, and Luca Ardito. «A Metric Framework for the Gamification of Web and Mobile GUI Testing». In: *IEEE International Conference on Software Testing, Verification and Validation Workshops*. IEEE. 2021 (cit. on pp. 6, 13, 15, 17).

[37] Gordon Fraser, Alessio Gambi, Marvin Kreis, and José Miguel Rojas. «Gamifying a Software Testing Course with Code Defenders». In: *Proceedings of the 50th ACM Technical Symposium on Computer Science Education*. SIGCSE'19. Minneapolis, USA, 2019, pp. 571–577 (cit. on pp. 6, 15).

[38] *Code Defenders*. URL: `https://github.com/CodeDefenders/CodeDefenders` (cit. on pp. 6, 15).

[39] R Nuravianty, H B Santoso, and K Junus. «Usability evaluation of a Gamification-based programming learning platform: Grasshopper». In: *Journal of Physics: Conference Series* 1898.1 (2020), p. 12020 (cit. on p. 6).

[40] Byron Reeves and J. Leighton Read. *Total Engagement: Using Games and Virtual Worlds to Change the Way People Work and Businesses Compete*. Boston, Massachusetts: Harvard Business Press, 2009 (cit. on pp. 7, 8).

[41] Yu-Kai Chou. *Actionable Gamification: Beyond Points, Badges, and Leaderboards*. Packt Publishing, 2019 (cit. on pp. 7, 8).

[42] Florin Oprescu, Christian Jones, and Mary Katsikitis. «I PLAY AT WORK — ten principles for transforming work processes through gamification». In: *Frontiers in Psychology* 5 (2014), p. 14 (cit. on pp. 7, 8).

[43] Richard M. Ryan, C. Scott Rigby, and Andrew Przybylski. «The Motivational Pull of Video Games: A Self-Determination Theory Approach». In: *Motivation and Emotion* 30 (2006), pp. 347–363 (cit. on pp. 7–9).

[44] Puah Ziwei. *Gamers prefer single-player games, according to Sony's internal data.* URL: https://www.nme.com/news/gaming-news/gamers-prefer-single-player-games-according-to-sony-internal-data-2828991 (cit. on p. 9).

[45] Brendan Sinclair. *Why are AAA single-player games viable again?* URL: https://www.gamesindustry.biz/articles/2018-12-03-why-are-aaa-single-player-games-viable-again (cit. on p. 9).

[46] Access Creative College. *Is Single-Player Gaming Actually Dying?* URL: https://www.accesscreative.ac.uk/is-single-player-gaming-dying/ (cit. on p. 9).

[47] Jory Deleuze, Pierre Maurage, Adriano Schimmenti, Filip Nuyens, André Melzer, and Joël Billieuxa. «Escaping reality through videogames is linked to an implicit preference for virtual over real-life stimuli». In: *Journal of Affective Disorders* 245 (2019), pp. 1024–1031 (cit. on p. 9).

[48] James Andreoni, William Harbaugh, and Lise Vesterlund. «The Carrot or the Sitck: Rewards, Punishments, and Cooperation». In: *The American Economic Review* 93.3 (2003), pp. 893–902 (cit. on p. 10).

[49] Sara Podczervinski, Zach Stednick, Lois Helbert, Judith Davies, Barbara Jagels, Ted Gooley, Corey Casper, and Steven A. Pergam. «Employee influenza vaccination in a large cancer center with high baseline compliance rates: Comparison of carrot versus stick approaches». In: *American Journal of Infection Control* 43 (2015), pp. 228–233 (cit. on p. 10).

[50] Madeleine Morley. *'I Could Never Abandon Them': Neopets Users Play on.* URL: https://www.nytimes.com/interactive/2021/11/03/arts/design/neopets.html (cit. on p. 10).

[51] Victoria Phillips Kennedy. *Do Aniimal Crossing's Villagers Miss You If You Stop Playing.* URL: https://screenrant.com/animal-crossing-villagers-miss-you-stop-playing-leave/ (cit. on p. 10).

[52] Alessandra Antonaci, Roland Klemke, Christian M. Stracke, and Marcus Specht. «Towards Implementing Gamification in MOOCs». In: *International Conference on Games and Learning Alliance: GALA 2017.* LNCS 10653. 2017, pp. 115–125 (cit. on p. 10).

[53] Achilleas Buisman and Marko van Eekelen. «Gamification in educational software development». In: *Proceedings of the Computer Science Education Research Conference.* ACM. 2014, pp. 9–20 (cit. on pp. 11, 15, 18).

[54] The Eclipse Foundation. *Eclipse Papyrus Modeling environment*. URL: https://www.eclipse.org/papyrus/ (cit. on p. 11).

[55] Antti Knutas, Jouni Ikonen, Uolevi Nikula, and Jari Porras. «Increasing collaborative communications in a programming course with gamification: a case study». In: *Proceedings of the 15th International Conference on Computer Systems and Technologies*. CompSysTech 14. 2014, pp. 370–377 (cit. on p. 14).

[56] Swapneel Sheth, Jonathan Bell, and Gail Kaiser. «A competitive-collaborative approach for introducing software engineering in a CS2 class». In: *26th International Conference on Software Engineering Education and Training*. IEEE. 2013, pp. 41–50 (cit. on pp. 15, 17, 27).

[57] Bilal Sercan Akpolat and Wolfgang Slany. «Enhancing software engineering student team engagement in a high-intensity extreme programming course using gamification». In: *27th Conference on Software Engineering Education and Training*. IEEE. 2014, pp. 149–153 (cit. on p. 15).

[58] Six to Start & Naomi Alderman. *ZOMBIES, RUN!* URL: https://zombiesrungame.com/ (cit. on p. 16).

[59] Manuel Trinidad, Alejandro Calderon, and Mercedes Ruiz. «GoRace: A Multi-Context and Narrative-Based Gamification Suite to Overcome Gamification Technological Challenges». In: *IEEE Access* 9 (2021), pp. 65882–65905 (cit. on pp. 16, 17, 19, 25).

[60] Riccardo Coppola, Tommaso Fulcini, Luca Ardito, Marco Torchiano, and Emil Alègroth. «Gamification: the next Silver Bullet for Exploratory GUI Testing». 2022 (cit. on p. 18).

[61] Elisa D. Mekler, Florian Brühlmann, Alexandre N. Tuch, and Klaus Opwis. «Towards understanding the effects of individual gamification elements on intrinsic motivation and performance». In: *Computers in Human Behavior* 71 (2017), pp. 525–534 (cit. on pp. 18, 19, 25).

[62] bpmn.io. *awesome-bpmn-io*. URL: https://github.com/bpmn-io/awesome-bpmn-io (cit. on p. 23).

[63] philippfromme. *bpmn-js-bpmnlint*. URL: https://github.com/bpmn-io/bpmn-js-bpmnlint (cit. on p. 23).

[64] Meta Platforms. *React: A JavaScript library for building user interfaces*. URL: https://reactjs.org/ (cit. on p. 23).

[65] GitHub. *React Bootstrap: The most popular front-end framework Rebuilt for React*. URL: https://react-bootstrap.github.io/ (cit. on pp. 23, 26, 39).

[66] StrongLoop and IBM. *Express: Fast, unopinionated, minimalist web framework for Node.js*. URL: https://expressjs.com/ (cit. on p. 24).

[67] SQLite Consortium. *SQLite*. URL: https://www.sqlite.org/index.html (cit. on p. 24).

[68] David Benyon. *Designing Interactive Systems: A comprehensive guide to HCI, UX and interaction design*. Pearson, 2014 (cit. on p. 26).

[69] Jakob Nielsen. *How to Conduct a Heuristic Evaluation*. URL: https://www.nngroup.com/articles/how-to-conduct-a-heuristic-evaluation/ (cit. on p. 36).

[70] Jakob Nielsen. *10 Usability Heuristics for User Interface Design*. URL: https://www.nngroup.com/articles/ten-usability-heuristics/ (cit. on pp. 36, 37).

[71] Jakob Nielsen. *Severity Ratings for Usability Problems*. URL: https://www.nngroup.com/articles/how-to-rate-the-severity-of-usability-problems/ (cit. on pp. 36, 37).

[72] Rini van Solingen, Vic Basili, Gianluigi Caldiera, and H. Dieter Rombach. «Goal Question Metric (GQM) Approach». In: *Encyclopedia of Software Engineering* (2002) (cit. on p. 47).

[73] Damien Masson. *Balanced Latin Square Generator*. URL: https://cs.uwaterloo.ca/~dmasson/tools/latin_square/ (cit. on p. 50).

[74] James R. Lewis. «The System Usability Scale: Past, Present, and Future». In: *International Journal of Human-Computer Interaction* 34 (2018), pp. 577–590 (cit. on pp. 53, 92).