MASTER'S THESIS

Applying gamification in tools for teaching logic

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APPLYING GAMIFICATION IN TOOLS FOR TEACHING LOGIC

by

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APPLYING GAMIFICATION IN TOOLS FOR TEACHING LOGIC

by

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Contents

Summary iii

Samenvatting iii

1 Introduction 1
- 1.1 Contribution . . . 3

2 Gamification 4
- 2.1 Definition, meaning and types of gamification . . . 5
  - 2.1.1 Definition . . . 5
  - 2.1.2 Meaning . . . 5
  - 2.1.3 Types . . . 6
- 2.2 Games, Game-based learning, and Gamification . . . 7
- 2.3 To gamify or not to gamify . . . 9
- 2.4 Implementation of gamification . . . 10
  - 2.4.1 Past . . . 10
  - 2.4.2 Present . . . 10
- 2.5 Underlying theories . . . 12
  - 2.5.1 Self-Determination Theory (SDT) . . . 12
  - 2.5.2 Flow theory. . . . 13
  - 2.5.3 Self-Efficacy Theory (SET) . . . 14
  - 2.5.4 Scaffolding . . . 15

3 Related Work 16
- 3.1 Overviews and comparisons of studies . . . 16
- 3.2 Empirical investigations . . . 17
- 3.3 Empirical research in university education . . . 18

4 Research 21
- 4.1 Research questions . . . 22
- 4.2 Research methods . . . 24
  - 4.2.1 Overview . . . 24
  - 4.2.2 Search for promising gamification techniques (RQ1) . . . 26
  - 4.2.3 Already in logic tools used gamification mechanics (RQ2) . . . 34
  - 4.2.4 What students like and do not like about gamification (RQ3) . . . 40
  - 4.2.5 Comparison of the usage of prototypes (RQ4) . . . 45
  - 4.2.6 Improvement by scaffolding (RQ5) . . . 50
- 4.3 Results . . . 52
  - 4.3.1 Promising gamification techniques . . . 52
  - 4.3.2 Already, in logic tools used, gamification mechanics . . . 54
  - 4.3.3 Differences in use prototypes and student preferences . . . 55
  - 4.3.4 Scaffolding advice. . . . 57

5 Discussion **58**
5.1 Future research 60

6 Conclusion **61**

Bibliography **i**

Appendices **viii**
A Appeal for participation in the experiments viii
B Invitation sent to the participants ix
C Intrinsic Motivation Inventory x

Summary

Logic tools, as developed in the IDEAS-project, are very useful for students to master logic (better). Nevertheless, the subject of logic remains a real challenge for many students.

Gamification can improve engagement and motivation and is being used more and more in education, often leading to better results. In this study, an inventory was made of which gamification elements are already used in logic tools and which elements could be applied to improve engagement and motivation, with the improvement of results as a consequence.

Some of these elements were then applied to the IDEAS-tool LogEx, and then some experiments were conducted to investigate the results as a consequence of the application of gamification.

The research results do not yet provide hard evidence that motivation and results improve by applying (visible) gamification.

Samenvatting

Logica tools, zoals die ontwikkeld zijn in het IDEAS-project, zijn zeer nuttig voor studenten om logica (beter) onder de knie te krijgen. Desondanks blijft het onderwerp logica een echte uitdaging voor veel studenten.

Gamification kan betrokkenheid en motivatie verbeteren en wordt steeds vaker gebruikt in het onderwijs, waardoor vaak betere eindresultaten worden behaald. In dit onderzoek is geïnventariseerd welke gamification elementen al gebruikt worden in logica tools en welke elementen zouden kunnen worden toegepast ter verbetering van betrokkenheid en motivatie, met verbetering van de resultaten als consequentie.

Enkele van deze elementen zijn vervolgens toegepast op de IDEAS-tool LogEx, en vervolgens zijn enkele experimenten uitgevoerd om de resultaten als gevolg van de toepassing van gamification te onderzoeken.

De onderzoeksresultaten leveren nog niet het keiharde bewijs dat motivatie en resultaten verbeteren door het toepassen van (zichtbare) gamification.

1

INTRODUCTION

Students develop their skills in a logic course, as a part of the curriculum of computer science, philosophy, and mathematics by practising a lot. When the student needs help how to proceed or in understanding errors when solving a problem a teacher can help. However, when a teacher is not available an Intelligent Tutoring System (ITS) can take over the role of the teacher. Three of these ITSs for logic are developed as part of the IDEAS[1]-project. They are described in the PhD thesis of Lodder [2020]: LogEx[2] (figure 1.1), LogAx[3] (figure 1.2), and LogInd[4] [5] (figure 1.3).

IDEAS focuses on providing automatic feedback in ITSs. Within the project, a framework has been developed for creating domain reasoners that can support students in different learning environments by helping them to solve interactive exercises. A domain reasoner generates hints and solutions and analyses student steps for a specific domain. Domain reasoners have been developed for mathematics, but for instance also to support functional and imperative programming.

The Open University is always working on improving the quality of its education. One of the quality improvements involves addressing the aforementioned ITSs, which will continue to be referred to in this thesis as *the IDEAS-tools*. The improvements should help to make logic, which is a difficult subject for many students (Epp [2003], Romano and Strachota [2016]), more accessible, students more motivated to work with it, and result in better grades.

The tools are very promising, but nevertheless, they are still in their pilot phase, while they deserve a better place in logic education. The first step achieving that better place has already taken place to increase user-friendliness and adapt the front end of the various tools to the house style of the Open University.

[1] IDEAS is short for *Interactive Domain-specific Exercise Assistants*, a collaborative project of the Utrecht University and the Open University

[2] http://ideas.cs.uu.nl/logex/

[3] http://ideas.cs.uu.nl/logax/

[4] https://ideastest.science.uu.nl/logind/

[5] https://ideastest.science.uu.nl/logindtext/

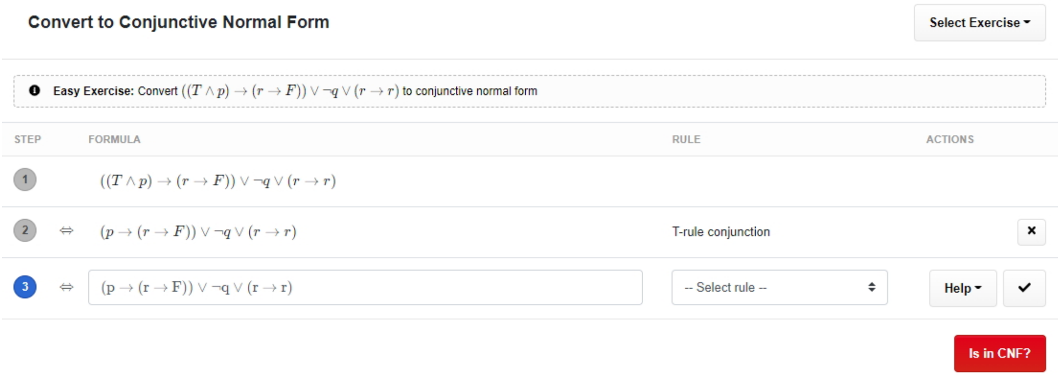

Figure 1.1: LogEx – an ITS to practice proving logic equivalence or rewriting into a conjunctive or disjunctive normal form.

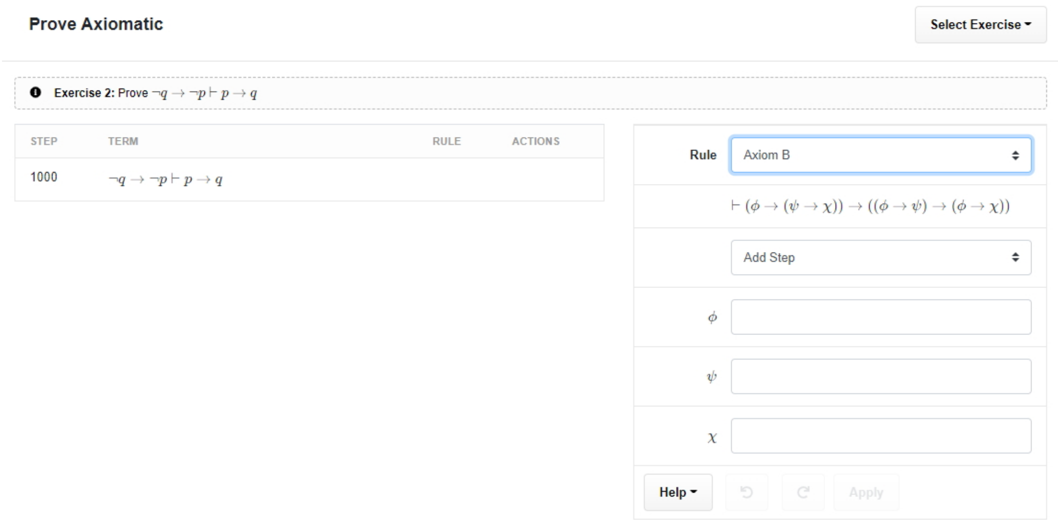

Figure 1.2: LogAx – an ITS to practice Hilbert-style axiomatic proofs.

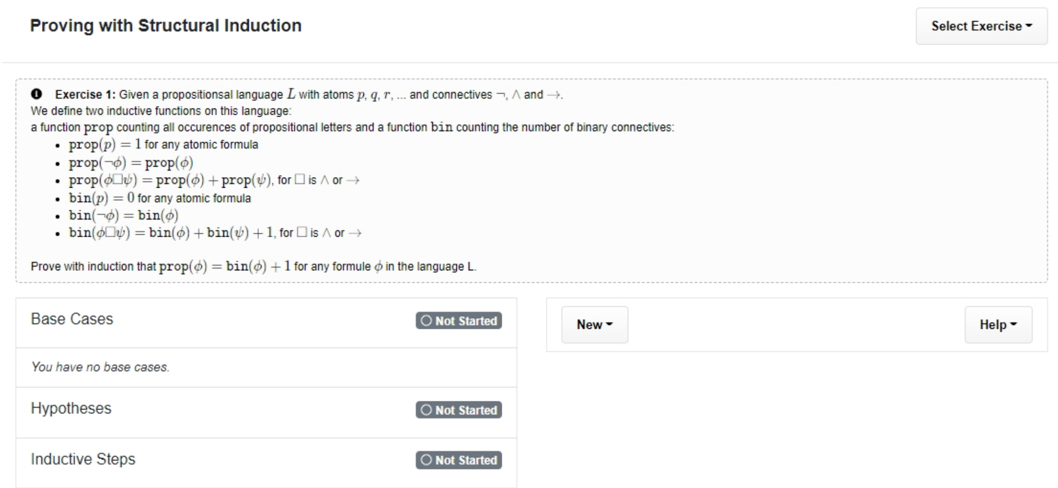

Figure 1.3: LogInd – an ITS that helps students when constructing inductive proofs.

1.1. CONTRIBUTION

Gamification, which involves adding game mechanics to a non-game environment to increase participation, is a strategy that is increasingly being used in education in recent years, and pretends to make difficult subjects more fun, helps to motivate students and get them more involved (e.g. Aldemir et al. [2018], Sonts [2013]). Applying gamification to the IDEAS-tools could therefore also be helpful in giving the tools an even more better place.

This research is conducted to gain new insight into whether and how gamification can also have an impact in logic tools. It also explores the application of gamification in combination with scaffolding (which can be used to build scaffolds to assist a learner's learning): gamified scaffolding, or the application of scaffolding in gamification. This combination, to our knowledge, has not been addressed before.

The main research question was identified from this:
In what way is it possible, by applying gamification, to make logical ITSs more attractive and motivating for university students, resulting in better performance and results?

This research investigates the gamification of tools for teaching logic, which serve for practising tasks. The research is not focussed on how gamification can be applied to the entire course(s) in which these tools are used (as could be done with ClassDojo[6], for example). Besides, the emphasis will be on what can be beneficial for the student, not how it will be perceived from the educator's point of view.

The research focuses on the application of gamification in logic tools in general and, to support the research results, gamification will be applied to one of the IDEAS-tools, namely LogEx.

To get a better understanding of what gamification exactly is, and what it is not, a more in-depth literature-based research has been conducted into this. This resulted in chapter 2, in which the scientific definition of gamification is explained, as well as what forms of gamification there are and on which theories it is based. During this in-depth research, but also during the search for research in the field of gamification, of which many will be discussed in chapter 3, it turns out that much research already has been performed on what gamification could contribute in non-game contexts such as education (e.g. Borys et al. [2013], López Carrillo et al. [2019]). These studies have laid the groundwork for figuring out which gamification elements can be applied in tools for teaching logic.

In chapter 4 the research is described: the (sub-)research questions are outlined in section 4.1, the methods (creating prototypes, performing experiments in which university students participate, and analysing log data and questionnaires) used to answer the research questions are shown in section 4.2 and the results in section 4.3. Finally, several threats to validity are discussed in chapter 5, after which conclusions and recommendations are given in chapter 6.

[6] https://www.classdojo.com : An online application to connect teachers and students through communication features, which includes an online reward system

2

Gamification

In gamification game mechanics and game elements are used to motivate users and enhance their experience. According to Werbach and Hunter [2012] gamification mechanics are for example: challenges, chance, competition, cooperation, feedback, and rewards. Gamification elements refer to elements that will be used in a non-game environment, for example: leaderboards, levels and points.

Why might gamification be an appropriate instrument for making the use of logic ITSs easier and more attractive? According to Sangkyun Kim and Burton [2018], gamification can, due to its fun and playful nature, be a good solution for learning and instruction as it can promote learner engagement. They claim that gamification, besides bringing fun and enjoyment to a learner, primarily can be used to:

- increase student ***engagement*** and ***motivation***,
- enhance learning performance and academic achievement,
- improve recall and retention,
- provide instant feedback on students' progress and activity,
- accelerate ***behavioral*** changes,
- allow students to check their progress, and
- promote collaboration skills.

The following paragraphs successively explain what the definition of gamification, according to scientific research, is, which types of gamification are distinguished, what the difference between games and gamification is and on which theories gamification is based.

2.1. Definition, meaning and types of gamification

This subsection details the definition, meaning and types of gamification.

2.1.1. Definition

A lot of scientific papers have been written about gamification. In these papers, gamification has been given many different definitions, such as:

- gamification is using game-based mechanics, aesthetics, and game thinking to engage people, motivate action, promote learning, and solve problems (Kapp [2012]),
- the process of game-thinking and game mechanics to engage users and solve problems (Zichermann and Cunningham [2011]),
- gamification is a booming technology based on combining the psychological aspects, mechanics, and dynamics of a game in non-ludic (or non-play) environments (López Carrillo et al. [2019]),
- a design technique that uses the motivational elements of games in other contexts (van Roy and Zaman [2017]), and
- the use of game design elements in non-game contexts (Deterding et al. [2011]).

The last definition, which Deterding formulated in the absence of a universal definition, is the most widely used in research papers, but this research best corresponds to the following definition of Sangkyun Kim and Burton [2018], which is most translatable to the subject and main question of this research:

"Gamification in learning and education is a set of activities and processes to solve problems related to learning and education by using or applying game mechanics" (p. 29).

2.1.2. Meaning

Zichermann and Cunningham [2011] stated that gamification can mean different things:

- make games to promote products and services,
- create virtual worlds to change behaviors, or
- provide a way to train people in complex systems.

The latter meaning applies to the underlying research.

A decade after Zichermann and Cunningham's paper gamification is implemented in different application areas. It is used:

- in apps to get motivated, get more done, improve the financial situation, or get better health,
- in products that help to overcome physical and mental disabilities,
- by retail chains where a customer can score points if they are loyal,
- to help people to learn new skills, for example, new languages,
- to improve the online shopping experience or manipulate shoppers or both,
- to get employees to work harder and be more productive, or
- to motivate employees, by, for example, setting up competitions between teams, with the perspective of a reward.

More generally, gamification can be used to motivate interaction and learning, encourage the execution of challenging tasks, achieve goals, create an opportunity for critical reflection and change the behavior in a positive way (Kapp [2012]).

2.1.3. Types

In addition to the various definitions of gamification, some authors also make a distinction between different types of gamification.

Kapp [2012] distinguishes between *Structural Gamification* and *Content Gamification*. Structural gamification is the application of game elements to propel a learner through content with no alteration or changes to the content itself. Only the structure around the content becomes game-like. The primary focus behind this type of gamification is to motivate the learner to go through the content and to engage him in the process of learning through rewards. The most common elements in this type of gamification are points, badges, achievements, and levels. Content gamification is the application of game elements and game thinking to alter content to make it more game-like. For example, adding story elements to a course is a method of content gamification.

Nicholson [2013] makes a distinction between *Reward-based Gamification* and *Meaningful Gamification*. In the case of reward-based gamification, systems rely upon rewards and a thin layer of a game experience to engage people through points, levels, leaderboards, achievements, and badges, which can be appropriate to engage people in short-term activities. When used for long-term change there are concerns about reward-based gamification. The goal of meaningful gamification is to help users find meaningful connections with the underlying non-game activities, and use rewards only when truly necessary.

2.2. Games, Game-based learning, and Gamification

A quick search in Google scholar on the words *games gamification education*, already yields more than 40,000 hits of published papers. Games, GBL, and gamification are closely related and there is often confusion about what exactly the differences between them are. In a nutshell, the differences can be described as follows:

Games are applications that can be played (on the computer) and give pleasure to the users. Games not only keep players engaged but also stimulate the thinking process. A game is like a play, however, according to Caillois [2001], playing involves free-form, non-rule-based, and expressive actions, whereas gaming represents a rule-based and goal-oriented form of playing.

Game-based learning (GBL) refers to a learning environment where games, designed solely for educational purposes, are used to teach users new concepts and skills. It involves the development of applications that help learners better understand taught topics.

Gamification focuses on how game elements can be applied in non-game settings to achieve certain outcomes (such as achieving better study results) and promote desired behavior.

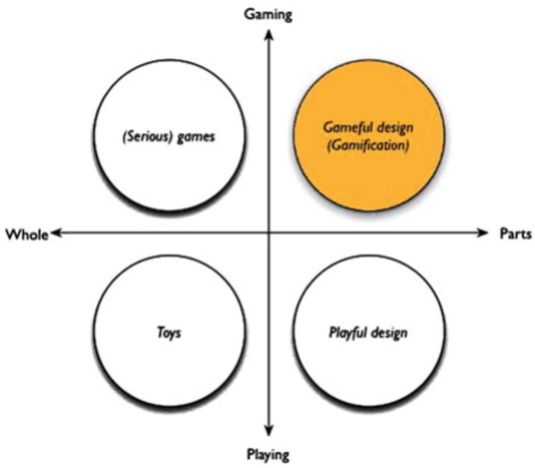

Figure 2.1: *Gamification* between game and play, whole and parts (Deterding et al. [2011]).

Gamification, according to Deterding et al. [2011], is defined as the use of game design elements in non-game contexts. As shown in figure 2.1, whole versus parts refers to which extent gaming elements are used. In gamification gaming elements are only partly used. Analogously, toy design elements (shapes, colours, materials, and behaviors) are used in playful design (toyification). A game is a play but rule-bound and consists of outcome-related elements.

Becker [2021] made an even more detailed attempt to clarify the distinctions between Games, GBL and Gamification. Globally a *game* is interactive, has rules and one or more goals, has a quantifiable measure of progress or success, and has a recognizable ending.
Serious games are games designed specifically for purposes other than pure entertainment. In *Gamification* elements of games are used, for example in education, a game narrative is wrapped around a course or multiple paths to the end, or choices in what work is submitted are created.

The differences and similarities between Games, GBL and Gamification (among some other types) are well summarised by Becker in figure 2.2 shown below:

Distinctions between Types of Teaching & Learning using Games

© K.Becker 2021	Game	Serious Game	Game for Learning (G4L)	Game-Based Learning (GBL)	Game-Based Pedagogy (GBP)	Gamification
Basic Definition	This term includes **BOTH** Serious Games AND Games for Learning	A game ***designed*** for purposes other than or in addition to pure entertainment.	A game ***designed*** specifically with some learning goals in mind.	The process and practice of ***learning*** using games. [From the ***learner's*** point of view]	The process and practice of ***teaching*** using games. [From the ***teacher's*** point of view]	The use of game elements in a non-game context.
Purpose	Can be for any purpose.	Change in behaviour, attitude, health, understanding, knowledge.	Normally connected with some educational goals.	**Not a game** - this is an approach to learning.	**Not a game** - this is an approach to teaching.	Often used to drive motivation, but can also be used to make something more playful and game like.
Primary Driver (why used)	Can be either play or rewards (or both).	To get the message of the game.	To learn something.	To improve learning. To increase learning effectiveness. **Note GBP & GPL are related, but not the same.*	To improve teaching practice & effectiveness. **Note GBP & GPL are related. They are like two sides of a single coin.*	Depending on how it's implemented, it can tap into extrinsic or intrinsic rewards (or both)
Key Question	Is it fun?	Is the message being received?	Is it effective?	Am I learning what I am supposed / need to be learning?	Is it effective?	Business: Does it improve profits? Education: Is it effective?
Focus	Player Experience *(how)*	Content / Message *(what)*	Content / Message *(what)*	Learning Objectives *(what & how)*	Learning Objectives *(what & how)*	User Experience *(how)*
Budgets	Next to nothing to 100's of millions.	Next to nothing to 100's of thousands.	Next to nothing to 100's of thousands.	Usually part of an institutional budget. Largely irrelevant to the user.	Usually part of an institutional budget. Largely irrelevant to the user.	Next to nothing to 10's of thousands.
Business Model	User Pays	Producer Pays	Varies	Institution Pays	Institution Pays	Producer Pays
Concept Catalyst	Core Amusement.	Message.	Performance or Knowledge Gap	Game is the lesson or is used as a part of the lesson.	Game is the lesson or is used as a part of the lesson.	When used in learning it usually impacts HOW things are taught and administered rather than WHAT is taught.
Fidelity	Self-consistent, otherwise irrelevant	Faithfulness to message essential	Faithfulness to message essential	Faithfulness to message essential	Faithfulness to message essential	Not Applicable. If a narrative exists, it need have nothing to do with what's being gamified.

Figure 2.2: Distinction between types of learning using games (Becker [2021]).

2.3. To gamify or not to gamify

In the past, gamification has been mainly applied in healthcare, sustainability, government, and transport, but in the last decade, there have been increasing attempts to use it in education. Lee and Hammer [2011] were among the first to investigate whether gamification could make a positive contribution to education. They concluded that gamification *can* motivate students to engage in the classroom, and give teachers better tools to guide and reward students. Nevertheless, gamification can also absorb teacher resources, or teach students that they only should learn when provided with external rewards. So gamification projects must be carefully designed: focus on the areas where gamification can provide the maximum value and address the potential dangers of gamification.

Although gamification is increasingly successfully applied in the above-mentioned areas, all that glitters is not gold, and not everyone is convinced of its (positive) use: applying gamification goes beyond simply inserting some PBLs (Points, Badges and Leaderboards) into the learning process.

Comparing 44 empirical research papers, Dichev and Dicheva [2017] concluded that the question of whether gamification in education motivates is too broad: a better question would be whether game design elements A are effective for type B learners participating in type C activity.

Much earlier, an experiment by Deci [1971] found that precisely the opposite of the intended goal was achieved by applying (only) motivation enhancement through rewards: performance lagged and people were less willing to continue with the activities for which they were rewarded.

In their paper *The Bright and Dark Sides of Gamification* Andrade et al. [2016] discuss that, besides the benefits of using gamification in learning environments, several issues can hinder learning through the application of gamification. According to them, these barriers can be overcome by using the Framework for Intelligent Gamification (FIG) they propose, a framework for personalised, fading gamification.

Toda et al. [2018] particularly identified the potential negative effects due to the use of gamification in educational contexts, such as indifference, performance loss and undesirable behavior due to decreasing mitigation as a result of misapplied gamification.

Finally, Kapp [2012] endorses the criticism with some examples that gamification is easy to apply and not only consists of the application of badges, points and rewards.

2.4. Implementation of gamification

This subsection illustrates some past and present applications of gamification.

2.4.1. Past

When properly designed and implemented, game concepts motivate and inspire everyone. Games have been around for a long time. Perhaps contrary to expectations, gamification has a long tradition too. In 1896 marketers already sold stamps to retailers who used them to reward loyal customers. This can be considered the beginning of the gamification history. Next figure 2.3 shows a summary of this history, including several other important moments in gamification.

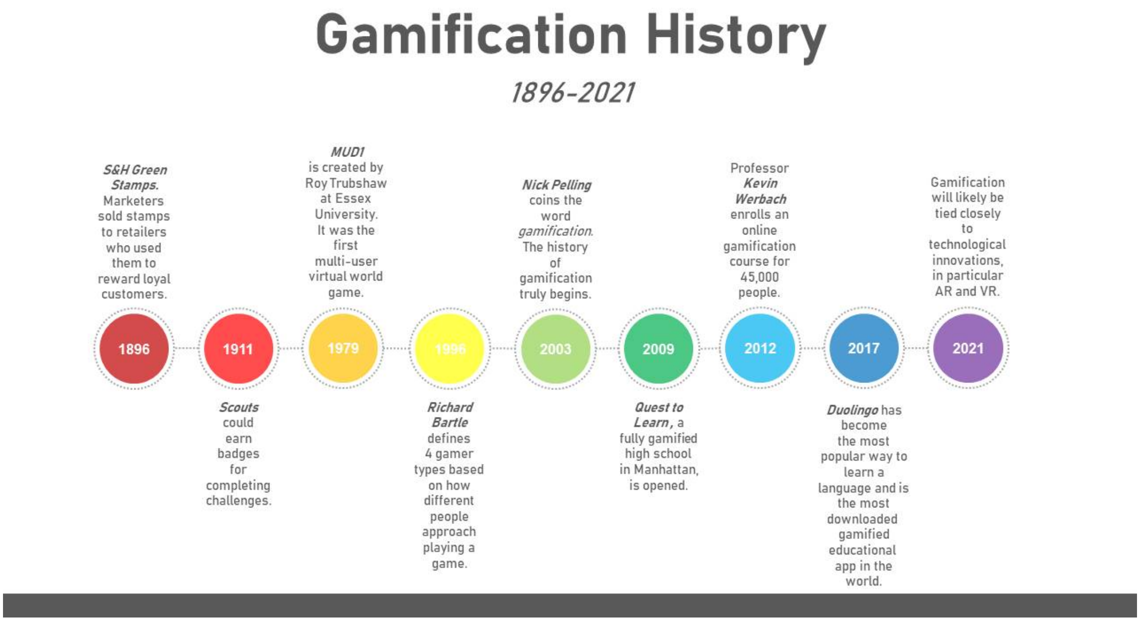

Figure 2.3: Timeline of gamification. Own work.

2.4.2. Present

Many of the games that people play today date back to ancient times, such as the Egyptians' board games and the Persians' dice. So games, just for fun, are of all times. The first, more recent, application of a game in a more serious context was a simulation game, which was developed by Mary Mironovna Birshtein (also known as the *Mother of Simulation Games* (Gagnon [1987]) in 1932. It was used to train managers in how to handle production problems in a typewriter factory.

Another game, especially worth mentioning in the context of this research, which was also developed some time ago, is WFF 'N PROOF (Allen et al. [1966]), a game that teaches the principles of symbolic logic[1].

[1] https://americanhistory.si.edu/collections/search/object/nmah_694594/

Next figures 2.4, 2.5 and 2.6 show a few more recent examples that demonstrate how behavior and motivation can be influenced by the application of gamification:

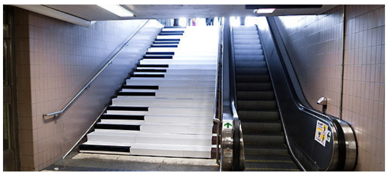

Figure 2.4: Piano stairs

Figure 2.5: Speedcam Lottery

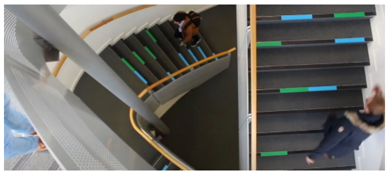

Figure 2.6: Doodle Jump Stairs

figure 2.4 (2009)[2]: This staircase in a subway was transformed into a piano to see if people would use the stairs rather than the escalator next to it,

figure 2.5 (2010)[3]: This speed camera not only penalises but also rewards for keeping to the speed limit by distributing the paid fines as lottery prizes, and

figure 2.6 (2016)[4]: These stairs are adjusted so pairs of students could play the simple game Doodle Jump Stairs, which caused 75% of them to take the stairs instead of the lift.

However, it should be noted that not everybody agrees that the first example is about gamification[5]. Because the game elements like rules, goals and progress, and feedback loops were missing, it only seemed to be a novel change to the environment. When some guidance (like playing a tune) would have been offered and an accuracy score would have been shown (on a monitor) the term gamification should be justified because a permanent behavior change was more likely to be achieved.

An example closer to home is *Holle Bolle Gijs*, the paper globber in the theme park *Efteling*, who always says *thank you* when paper rubbish is put in his mouth. And, of course, everybody remembers the sticker they used to get at primary school when they had something completed successfully.

Kumon, a private after-school tutoring organization, shares ideas, by using toys and children's games, on how to gamify mathematics learning on their website (http://www.kumon.com). For example, the Hopscotch game can be used for learning mathematics by replacing the number in each section with a mathematics question. By solving the question it is allowed to move forward. Another example is to use a jump rope game that can be used to learn to count and add numbers.

[2]Image captured from https://www.youtube.com/watch?v=2lXh2n0aPyw
[3]Image captured from https://www.youtube.com/watch?v=iynzHWwJXaA
[4]Image captured from https://www.youtube.com/watch?v=CWwee62DW3U
[5]https://www.gamified.uk/2019/06/11/the-piano-staircase-isnt-gamification-but-thats-okay/

A famous example of the application of gamification in education is DuoLingo (figure 2.7)[6]. Duolingo is a free, science-based language education platform, and has become the most popular way to learn languages online. Duolingo, which has been developed since 2009 by von Ahn and Hacker, even claims to be *scientifically proven* (Vesselinov and Grego [2012]). For motivating and engaging learners, Duolingo uses multiple game mechanics, such as experience points (XPs), virtual currency, leaderboards, and unlocking. Learners can see daily XPs and accumulated XPs. Learners need to complete missions to increase their XPs. Successful completion of a test is one of the missions. Duolingo uses Lingots and Gems as its virtual currencies, which can be earned by studying lessons for ten days on a streak, finishing a lesson, finishing a new skill, and inviting friends.

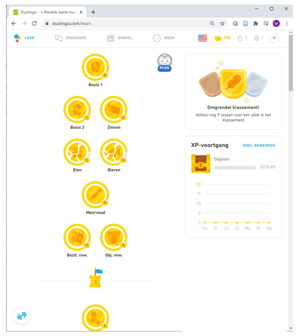

Figure 2.7: Duolingo

And at the time of writing, a Duolingo Math app is even being launched. This app can be used to practise basic maths topics.

2.5. Underlying theories

The principles of several theories of motivation are the foundation for how gamification motivates students. The most mentioned theories in research papers are, to the best of our knowledge, the ones mentioned by Fulton [2019]: Self-Determination Theory, Flow theory and Self-Efficacy Theory. The Scaffolding theory is a theory that this research wants to add to these three, because not applying scaffolding in learning can be very demotivating. All theories have complementary components that support gamification as means to motivate, which will be briefly discussed in the following subsections.

2.5.1. Self-Determination Theory (SDT)

The Self-Determination Theory (SDT) of Ryan and Deci [2000] suggests that people are motivated to grow and change by three universal basic psychological needs. These needs, which are important for psychological well-being and autonomous motivation are, according to SDT:

- *autonomy* – the desire to be in control of one's life,
- *competence* – the desire to experience mastery, and control the outcome, and
- *relatedness* – the desire to interact with, and connect to others.

When these needs are met, then there is well-being, motivation, commitment, and a desire to learn. However, if any one of the three is lacking, then many of the motivation problems, experienced in many learning environments, arise.

[6] http://www.duolingo.com

A distinction can be made between two types of motivation: *intrinsic* and *extrinsic*. Intrinsic motivation comes from within, while extrinsic motivation arises from external factors. Intrinsic motivation leads to engagement in an activity because of joy and personal satisfaction when doing it, for example, studying because of curiosity. When extrinsically motivated, something is done to gain an external reward, for example, studying because of getting a good grade.

Research related to intrinsic and extrinsic motivation has been conducted by Buckley and Doyle [2016]. They investigated the impact of intrinsic and extrinsic motivation on the participation and performance of over 100 undergraduate students in an online gamified learning intervention. Their generally positive results showed that the impact of gamified interventions on student participation varies depending on whether the student is motivated intrinsically or extrinsically.

2.5.2. Flow theory

Csikszentmihalyi [1990] researched subjects on which factors bring happiness while performing a task or activity. He states that being in a flow will make you the happiest. This can be characterized by at least some of the following characteristics:

- Extreme concentration and goal orientation
- One has a clear goal
- The activity is rewarding, for example, it is a lot of fun
- A clear sense of control over the situation or activity or both
- A sense of challenge that is achievable (not too difficult, but also not too easy)
- Success and failure are made immediately clear by giving feedback
- Loss of sense of time, so time flies by

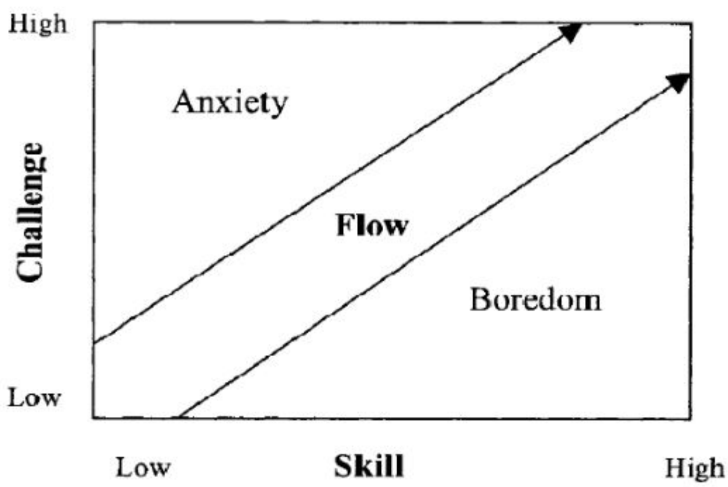

Figure 2.8: Flow Theory (Csikszentmihalyi [1990]).

Every performed activity falls somewhere on the chart in figure 2.8, depending on how challenging it is, and how many of the learners' skills it utilises. The ideal place to be is in the *Flow Channel*: the challenge of the activity is approximately equal to the skills. However, when you are bored, you will need to find a way to increase the challenge and when you are anxious you will need to work on improving your skills to get back in the Flow Channel. The opposite of flow is apathy: not feeling challenged, connected, responsible or interested.

Gamification is a way of giving learners the possibility to work in a state of flow. For example, by providing learning that is difficult enough to undertake, but not so difficult that they simply give up. By allowing the student to choose a level, such as beginner, medium or expert, the learner is given the choice of how to experience the tool and how difficult the tool is for the learner.

2.5.3. Self-Efficacy Theory (SET)

According to Bandura [1977], self-efficacy is *the belief in one's capabilities to organize and execute the courses of action required to manage prospective situations.* Self-efficacy is a person's belief in his or her ability to succeed in a particular situation. Bandura described these beliefs as crucial factors in how people think, behave and feel. Self-efficacy can have an impact on everything from psychological states to behavior to motivation and specifies which goals we set, how we are going to achieve them, and how we reflect on our performance.

The influence of self-efficacy and gamification can work both ways: the motivation or engagement or both, which can be achieved by gamification can influence a student's self-efficacy, but also self-efficacy would influence the motivation or engagement or both, which can be achieved by applying gamification. The first situation was investigated in the research of Banfield and Wilkerson [2014]: they concluded that higher intrinsic motivation and self-efficacy were achieved among the students when gamification was applied. The second situation was investigated in the research of Watford-Spence [2021]: the degree of self-efficacy was not found to be of influence, but the HEXAD-player type (Marczewski [2015]) was.

In Jamshidifarsani et al. [2019] the psychological theories of Self-Determination Theory (SDT) and Self-Efficacy Theory (SET) were used to design three versions of a game. The first version was based on SDT, the second on SET and the third version was based on a combination of these two theories. The objective was to investigate the impact of each game design on user motivation and performance. Surprisingly, the results of the objective evaluation revealed that there is no significant difference among the groups in terms of engagement and performance.

2.5.4. Scaffolding

Lev Vygotsky (1896-1934) was a Soviet psychologist who coined the term *zone of proximal development* (Vygotsky [1978]) and conducted many studies leading to instructional scaffolding. The concept of scaffolding was formulated by Jerome Bruner in the 1960s which he related to Vygotsky's work.

Scaffolding refers to the process of supporting learners in achieving educational goals that they would not be able to achieve on their own. Just as construction workers attach temporary scaffolding to buildings, teachers or tools can use scaffolding to provide temporary assistance while learners improve their skills and knowledge. When the learner is sufficiently trained, the scaffolding can be faded out and be removed. Scaffolding can be used when a learner needs to make progress in his or her *zone of proximal development*, which is the area between what learners can do on their own and what they can achieve when given the right support.

By applying gamification, two types of scaffolds are applied:

- Hints and feedback, which can increase the student's knowledge and, where necessary, the student can ask for help.
- The learner gets support only for the skills needed to solve a task that is just beyond his reach. This means that when the learner reaches certain levels of the skill, it is made more difficult, for example by fading support.

3

Related Work

Gamification has been researched a lot, from different angles. In recent years, research has increasingly moved towards education.
This research can be divided into:

- research that offers an overview or comparison of various other studies,
- empirical investigations that have focused on one aspect of gamification, and
- empirical research in university education.

Each above-mentioned item is discussed in a separate subsection in this section. Each subsection contains references to papers that are a good reflection of the subsection.

3.1. Overviews and comparisons of studies

The following two studies are examples of the large number of *Gamification-overview* studies.

In the research of Dahlstrøm [2017] the relationship is explored between gamification and intrinsic motivation. Dahlstrøm examined whether the use of gamification facilitates or undermines intrinsic motivation by collecting results from empirical research on the relations between gamification, performance, and motivation. She concluded gamification can improve but also undermine intrinsic motivation. However, its effect appears to depend strongly on individual and contextual factors, such as age, personality, and experience with games or whether the use of the gamified system is voluntary or not.

In the overview by Acosta-Medina et al. [2020] also the relationship between gamification and intrinsic motivation was explored. Ninety-nine papers were analysed and the researchers did conclude that the results highlight engagement, motivation, and performance as the benefits of adopting gamified tools in the classroom. Gamification is a motivational didactic tool that, when designed and used correctly, can improve teaching and learning processes. It has the potential to increase motivation, engagement, and participation. However, it is important to keep in mind that gamification must be motivating but not addictive.

3.2. Empirical investigations

This subsection includes several pieces of empirical research that, unlike the studies in the previous subsection, do not provide an overview but focus on one aspect of gamification, for instance:

- what are the effects when gamification is applied in education,
- what are the perceptions of the students when gamification is applied, and
- which problems can arise when gamification is applied and what are possible solutions to mitigate or even solve them.

The research of Borys et al. [2013] is an example of research in which the potential effects of applying gamification in education are investigated. Students of a Software Engineering course were divided into two groups. The non-gamified group was taught using the traditional (theoretical and practical) didactic methods while the gamified group was educated using the gamified course. The applied elements of gamification seemed to have a positive impact on at least some factors, like class attendance or voluntary tasks. However, keeping motivation at a high level during the whole course became a challenge, therefore implementing stronger motivational mechanisms should be considered.

In addition to scientifically explaining the effects of applying gamification, the following studies have looked at the perceptions of students, for they are the ones who can indicate what motivates them.

The research of Aldemir et al. [2018] examined the possible impacts of game elements (namely game dynamics, mechanics, and components) and how they should be designed and implemented from the students' perspectives.

Bicen and Kocakoyun [2018] investigated the perception of 65 students in a computing lesson in Preschool Teaching by using the Kahoot! application[1]. The findings show that the inclusion of a gamification method increased the interest of students in the class, and increased student ambitions for success. Gamification also showed to have a positive impact on student motivation.

[1]Kahoot! is a game-based learning platform. The games (*kahoots*) are multiple-choice quizzes that can be accessed via a web browser or the Kahoot app.

3.3. Empirical research in university education

Only a few papers can be found that describe empirical research in university education. Because this research will be conducted in this context, some short summaries of these papers are included in this section.

Gåsland [2011] made a prototype of an e-learning system using game mechanics, which was used in a class of 44 students at the Norwegian University of Science and Technology. The survey data showed that the system was considered to be *somewhat useful* by most students, *somewhat motivating*, *somewhat fun*, and made the work therein *quite engaging*. The results did not turn out to be very concrete and further verification and case studies were needed. Also because of the small number of students involved, further research is needed to generalise the results.

The aim of the research of Sonts [2013] was to learn how to integrate game elements into the learning process of higher education students. The research conducted a case study that focused on a course on Game Interactions that was designed as a game, which means that it used game elements in the process to engage the students. The game elements that were used in the course included avatars as the characters the students were playing, competition, goals, rewarding points, and challenges. The research concluded that using game elements in a higher education learning process could be very effective and changing the way students are taught has a lot of potentials. The authors offer also some suggestions for designing a gamified course as follows:

- Start with some activities as games. For example quizzes instead of traditional tests.
- Offer a variety of tasks with different challenge levels for different students, so a goal can be reached by various routes.
- The degree of difficulty must be gradually increased to keep students interested.
- Spending time on social interaction increases social engagement and competition level.
- A scoreboard is nice to have but not so important for the students.

Because technical universities are facing the challenge of attracting more diverse groups of students, and keeping the students they attract motivated and engaged in the curriculum, Iosup and Epema [2014] designed a toolbox for course gamification which was used in two courses (BSc Computer Organisation and MSc Cloud Computing Technology). Their toolbox fits within the MDA-framework (which will be explained more in detail in subsection 4.2.2) and identifies seven core tools for gamification. Also is taken into account which of the four player types (defined by Bartle [2004]: the Killer, the Achiever, the Explorer or the Socialiser) fits the student, so students can pass the course by following the path(s) that suit their intrinsic motivation. They used passing ratios, participation counts, and results of evaluation surveys to quantify the effectiveness of using gamification in teaching the mentioned courses. They concluded that gamification is correlated with an increase in the percentage of passing students, and participation in voluntary activities and challenging assignments. Next to the results, they posed some future research questions like which type of instructional goal gains the most from gamification, which type of student gains the most from gamification, and which gamification element is responsible for the largest improvement.

Varannai et al. [2017] investigated the behavior of university students while interacting with Kahoot!. In their research, they made a comparison between IT-students and non-IT-students. The research comprised the statistical analysis of questionnaires, with 20 questions, completed by 86 students. The results of this research indicate that the positive attitude, good experience and ease of availability contributed to improving student performance that strengthened the intention to use the application. Also, the perceived utility was positively influenced by the ease of use. Non-IT students' attitudes tend to be influenced by usefulness and availability, which is in contrast to the IT-students. This can be explained by the fact that IT-students are much closer to the technologies of gamification, so their openness to new technologies meant that no correlations could be established between the availability of the application and their future intention to use Kahoot!

The research of López Carrillo et al. [2019] aims to offer new empirical evidence to support claims about positive impacts on learning outcomes when gamifying educational content. The researchers first set the theoretical basis of gamification and its main components and dynamics, focusing on the context of education. Subsequently, in two consecutive academic years, laboratory practices were gamified. The tools ClassDojo and Kahoot! assisted the process. The gamification methodology has proved to foster the students' motivation but it was not assured that gamification makes the students learn better.

Research is also being conducted in the field of MOOCs (Massive Open Online Courses) to see how the use of gamification can remove or reduce some MOOC shortcomings. Some of these shortcomings concern: high students' drop-out rates, the lack of students' motivation, engagement, and interaction, or the lack of active learning (Ortega-Arranz et al. [2017]). Due to the massiveness, the application of gamification is particularly difficult, because many different types of students are involved which calls for personalised, intelligent and automated gamification.

According to Aleven et al. [2015], a solution might be to embed ITSs to address the limitations of MOOCs: they can track students' skill growth, select problems on an individual basis and they can adaptively respond to student strategies and errors. In the described solution assistance is provided from within the inner loop[2] while the student solves a problem. From the inner loop, the student model is then computed and communicated to the outer loop. The outer loop will then determine the student's selection of problems to be solved. Only a few gamified MOOCs have been developed so far, and research on gamification in MOOCs is in its early stages.

However, Antonaci et al. [2017] have made the first step by identifying 31 game elements as the most used game elements in education. In future steps, they aim to validate the selected game elements and implement them in a MOOC environment.

[2]ITSs can provide inner loop feedback about steps within tasks, and outer loop feedback about performance on multiple tasks (Tacoma [2020])

To conclude this subsection, the study of Loos and Crosby [2017] is slightly different because not the students but the teachers are the basis: they are interviewed and asked about how gamification is applied at their universities. The results of the interviews show that gamification improves learning outcomes, in courses ranging from computer science and technology to languages and multimedia journalism. Game design mechanics such as points, challenges, and collaboration turn out to be among the top three of gamification. The educators noted incremental student coursework completion and discussion participation and that the students had fun learning. The results of the interviews are evidence of how gamification can be applied to achieve better learning outcomes.

Most of the above-mentioned studies do not indicate there is a difference in gamification for higher education and other types of education, but they do show that gamification makes a positive contribution in one way or the other. Notwithstanding the positive results, the studies in which criticisms are being expressed (subsection 2.3), should certainly not be forgotten.

4

RESEARCH

The section *Related Work* shows that a great deal of research has already been done into what gamification could contribute in non-game contexts like education. However, not all research has led to a positive conclusion (Dichev and Dicheva [2017]). A very limited number of these studies focus on university education and an even smaller number on its application in logic education. All of the above are reasons to distil the advantages and disadvantages of gamification from previously performed research and empirical investigations to find out which gamification elements can be applied in the tools for teaching logic.

Subsequently, it seems highly plausible that the power of gamification can be boosted by the application of scaffolding, so at the beginning, a student gets the guidance the student needs by then, but this will be reduced step by step until he can solve the tasks himself without help. For this, however, it will be necessary to keep track of a student's progress. In an ITS this could be done in the student module (figure 4.1). Despite the IDEAS-tools, primarily considered in this thesis, do not yet provide this, (theoretical) attention to this will be paid in this research.

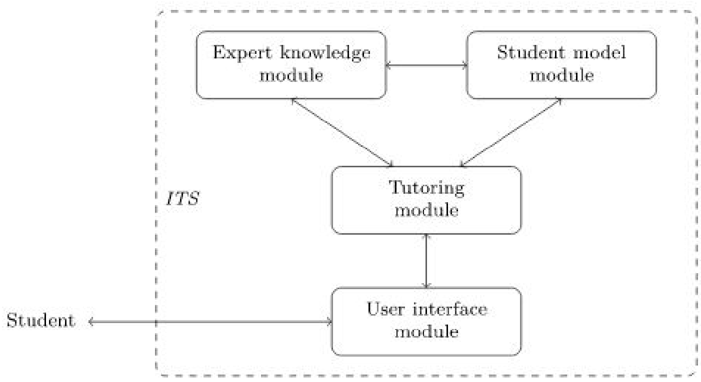

Figure 4.1: Components of an ITS (Heeren and Jeuring [2014]).

4.1. Research questions

Logic is a difficult subject for many university students. Logic ITSs such as LogEx, LogAx, LogInd, ILTIS[1] and The Incredible Proof Machine[2] can support students by making it possible to practice, but if the results, which can be reflected in better understanding, higher grades, or both, are lagging, this can result in less motivation to practise or persist in practising. The application of gamification seems to be a good candidate to improve students' motivation. Therefore this research investigates how the application of gamification can make the use of logic ITSs more attractive so students will be more motivated to use the tool. The improved motivation should then lead to better study results than study results achieved when using a non-gamified ITS.

The main research question is, therefore:
In what way is it possible, by applying gamification, to make logical ITSs more attractive and motivating for university students, resulting in better performance and results?

To answer the main research question the following sub-questions, accompanied by how to get an answer to the question concerned, are formulated:

- **RQ1: Which gamification techniques are promising to be applied in logic ITSs?**
  The techniques identified in the investigated papers are systematically catalogued to determine which of them can be used in a logic ITS and which cannot. The choice of techniques refers to which framework(s) can be used and to which game elements can be applied.

- **RQ2: Which gamification mechanics are already used in existing logic tools, and what problems related to learning and teaching are addressed by these mechanics?**
  Is it useful to use these already used mechanics too, or should they be improved? The answers to RQ1 and RQ2 are used to make a selection of gamification techniques that can be used to conduct the research described above.

- **RQ3: What do university students like or dislike about gamification, and why?**
  Not too many students would participate in this research, but since gamification is about motivating students, it seems logical to ask their opinion. Especially since not much research has been conducted on this subject. Using the answers to this question, the previously assembled list of possibilities is further filtered down to how, according to students, a logic tool can be made more attractive and motivating.

[1] https://iltis.cs.tu-dortmund.de/
[2] https://incredible.pm/

- **RQ4: What differences can be recognised between the use of a gamified and a non-gamified logic tool, and in what way does this affect the performance and results of the students?**
  The way a tool is used can affect the student's performance and their results. To make a statement on whether gamification can lead to better results, the results of tests made before and after using the gamified tool are compared with those made after using the non-gamified tool. Also, the levels of motivation and enhancement are examined.

- **RQ5: Can the results achieved by the application of gamification be further improved when adding scaffolding, and what information should be captured in the student model module of the particular ITS?**
  Gamification should be tailor-made for each student because no two students are alike. Not every student will appreciate gamification, it will not improve the result for every student, and there should also be scaffolding: letting support fade away when it is no longer needed.

4.2. RESEARCH METHODS

4.2.1. OVERVIEW

Figure 4.2 shows in an infographic what the structure of the research looks like.

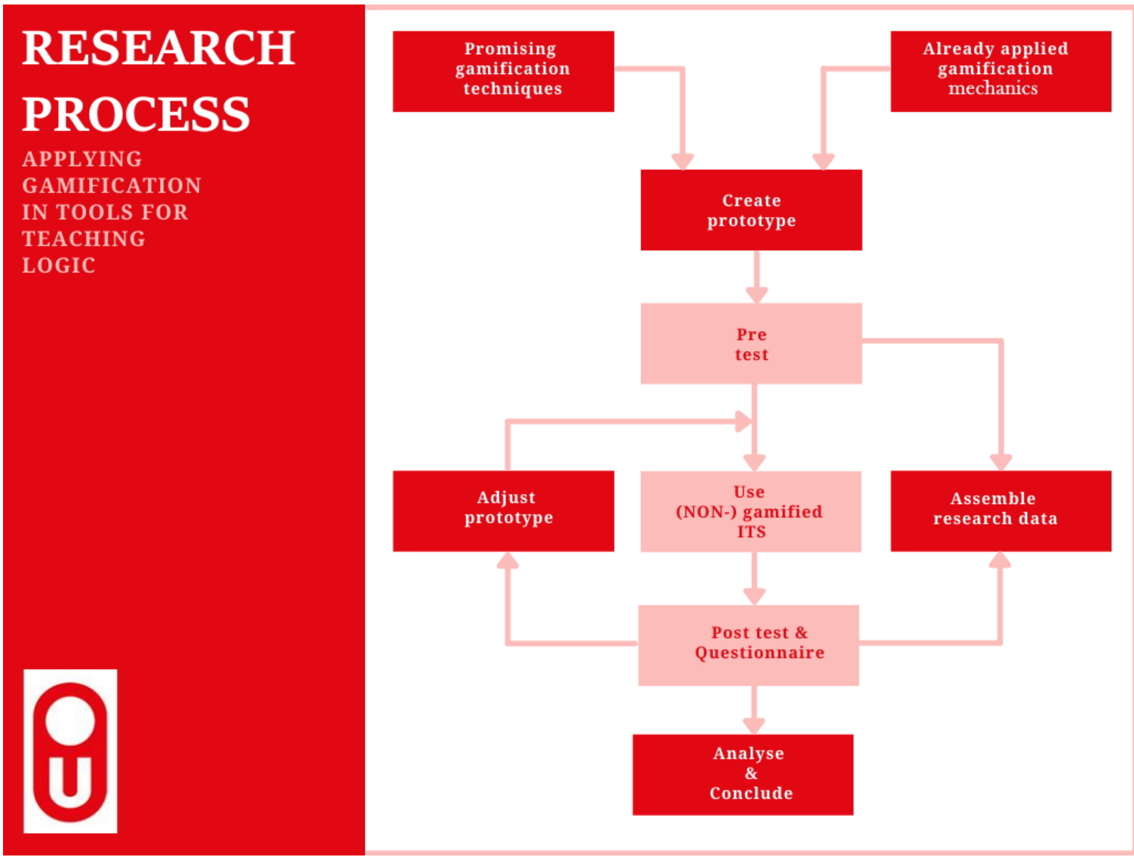

Figure 4.2: Graphical representation of the research process.

The activity ***Promising gamification techniques*** identifies gamification techniques that are promising to be applied in a logic ITS, while answering RQ1. Activity ***Already applied gamification mechanics*** yields gamification mechanics that are already used in existing logic tools (RQ2). The answers to both questions are merged and serve as input for applying gamification to one of the IDEAS-tools (activity ***Create prototype***) and the questions asked in the questionnaire.

To support the learning material in the various logic courses at the Open University, the tools LogEx, LogAx and LogInd were developed. In theory, all three were candidates for applying gamification. Because a course with a larger number of students is more likely to result in a larger number of students wanting to participate in the experiments, of which more details follow below, the choice is made to apply the gamification changes to LogEx, and perform experiments with students of that course. The experiments in this research are therefore an interesting sequel to the experiments performed on LogEx in the past (Lodder et al. [2016]).

The activity ***Create prototype*** involves adapting gamification in the front end of LogEx, which, as of the writing of this thesis, already has been made more user-friendly and adapted to the house style. Adjustments are made in two prototypes of LogEx, but in only one of them, visible gamification was applied. Both prototypes are part of several experiments, comprising a pre-test, the use of the prototype, a post-test and a questionnaire (the pink activities in figure 4.2). In these experiments the students, who are willing to test the adapted tool, are divided into two teams: one team uses the non-visible gamified application and the other team uses the visible gamified application.

To answer RQ3 the participating students are asked, after each experiment using a questionnaire, if they think gamification, after explaining what gamification is, could help them to be (more) motivated and engaged and perform better.

By carrying out the experiments, an answer to RQ4 was obtained by analysing the log files and the questionnaires and by comparing pre-test and post-test results (activities ***Assemble research data*** and ***Analyse & Conclude***). Initially, the intention was to compare the exam results of the two groups. However, because of the AVG/GDPR, this is a difficult operation. Instead, the results of the two groups of students are compared using a pre-test and a post-test, which are taken before and after the use of the tool respectively. An additional advantage of this approach is that the exams include only one question about the teaching material the tool covers and the tests include more than one.

After the first experiment, the results of the questionnaires and the tests are analysed and it was decided whether the prototypes need to be modified.

The answer to RQ5 is not empirical because LogEx, on which the practical applications in this study focus, does not yet include a student model module. This leads to some recommendations, on which further research can be done.

The research described above is most suitable for applying the *Design Based Research* (DBR) strategy (Amiel and Reeves [2008]), as in Pujolà Font et al. [2017] and Cruaud [2018]. This strategy is characterised by successive (iterative) steps: identification of the problems to be solved, the creation of a solution/prototype, its implementation and finally the evaluation of the solution.

The search for the answers to the Research Questions is described in this section with a separate section for each Research Question.

4.2.2. Search for promising gamification techniques (RQ1)

After the extensive literature research that has been carried out already to unravel the concept of gamification, the answer to the research question *Which gamification techniques are promising to be applied in logic ITSs?* requires a more specific search.

There are many ways to discover these promising techniques and make a selection out of them. The most convenient ones are:

- A - using a gamification framework/model that has already been applied in practice in the context of education, or
- B - finding out which gamification elements have been used and evaluated most often in this context and can become a positive contribution, or
- C- a combination/selection of techniques from the above options.

Each of these options is covered by a subsection below. Noteworthy studies that might be of service, are discussed in separate paragraphs, A and B respectively. C will be discussed in the results.

A - Search for an already used gamification framework for learning

To create a general understanding of game elements, they have been classified into various frameworks by different researchers. The Mechanics-Dynamics-Aesthetics (MDA) framework (Hunicke et al. [2004]) and the Dynamics-Mechanics-Components (DMC) framework (Werbach and Hunter [2012]) are most often mentioned in research on gamification, but these frameworks are not targeted at education in particular, so that is why further searching for those types of frameworks is conducted. Before the most notable reviews and studies in the field of education, which the more specific search yielded, are described, MDA en DMC, which have served as the basis for many other frameworks (which are also applicable in education), are explained.

The MDA-framework, the basic framework in game-design. It proposes three levels of game elements:

- *mechanics*: the rules and boundaries established by the designer,
- *dynamics*: user-interactions provided by the previously mentioned mechanics, and
- *aesthetics*: emotions and experiences of the player when he interacts with the game.

The MDA-framework enables us to understand how game mechanics, dynamics, and aesthetics differ from one another and how they work together to create an overall gameful experience for users. This understanding can be of great help in designing one's own gamification.

In the DMC-framework game elements, whose terms are not equivalent to those in the MDA-framework, exist in a hierarchy shown in figure 4.3:

- *dynamics* are the aspects of the gamified system that have to be considered and managed but which are implemented in the game by the hereafter specified mechanics,
- *mechanics* drive the action forward and generate player engagement, like challenges, competition, feedback and rewards, and
- *components* compose previously mentioned mechanics, like points, badges, etc.

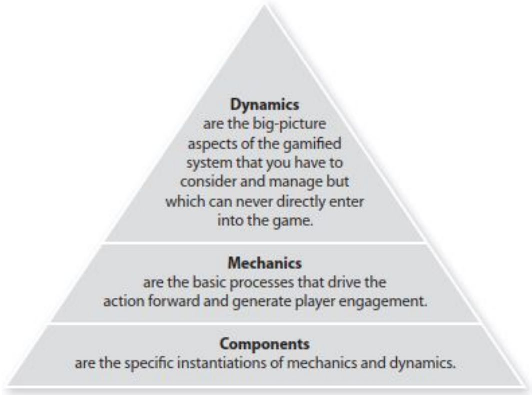

Figure 4.3: The Game Element Hierarchy (Werbach and Hunter [2012]).

This framework is mainly focused on game elements from a design perspective, not on the effects that the elements have on users.

Rauschenberger et al. [2019] analysed ten research papers that all describe different ways of applying gamification in educational environments in higher and lower education as well as digital learning platforms. The gamification elements used in the frameworks were classified according to the levels of the framework of Werbach and Hunter (figure 4.3), to be able to compare and classify the elements over *Dynamics*, *Mechanics* and *Components*. More than half of the components found in the frameworks can be associated with the dynamics *Emotions* and *Progression*, which, according to the researchers, is an indication that the desired motivation improvement can be achieved through emotional engagement and the visualisation of a student's progress. Unfortunately, because more than half of the components are mentioned only once or twice, no advice could be provided on how and which gamification elements could best be applied.

In Mora et al. [2017] also different frameworks are reviewed and six of them have been identified as suitable for learners' engagement in higher education environments. As was the case with the previous survey, also no guidelines could be issued after this research because, according to the researchers, to answer the question of which items are taken into account in the gamification design process, a comparative study should first be conducted. Nevertheless, thoughts of two of the six frameworks, which have been applied in higher education, could be promising to contribute to the answer to the first research question, especially since the frameworks have also been tested in practice.

The first one (of Tomé Klock et al. [2015]) presents a conceptual model that is based on two of the frameworks described at the beginning of this subsection: the MDA-framework and the DMC-framework. The model helps to identify *Who*, *Why*, *What* and *How* elements are involved in the gamification process. It fits in well with the adaptive gamification described further on. However, it is not clear how the characterisation of the student is implemented.

The second framework is an iterative framework for Agile gamification (Mora et al. [2015]). This FRamework for AGile Gamification of Learning Experiences (FRAGGLE) is focused in higher education and based on the use of the Agile methodologies to obtain a fast testable version of a product. The goal is to get feedback during development as soon as possible. This feedback is important to be able to take the most important follow-up steps.

The conceptual model of Tomé Klock et al. [2015], mentioned in the previous paragraph, was extended to the 5W2H-Framework (Klock et al. [2016]), which guides the application of user-centred gamification. It is based on the 5W2H-Method, an efficient problem analysis tool. In the abbreviation 5W2H the 5 W's mean: *Who*, *What*, *When*, *Where*, *Why* and the 2 H's stand for *How* and *How Much*. The framework defines these seven dimensions to design, develop and evaluate gamification by analysing: who are the system users, what are tasks these users must perform, what stimuli are desired to generate and when reinforcement should be applied to create and maintain such stimuli. The framework is not specific to a certain context but an application of each dimension was demonstrated in an educational system.

Garone and Nesteriuk [2019] also examined a selection of frameworks. Most of the investigated frameworks focus on *structural gamification*, and only a few on *content gamification*. In the case of structural gamification, game elements are applied without changing the learning content, while in case of content gamification game elements and game thinking are applied by altering the learning content and making it look more game-like. Examples of game elements in structural gamification are **badges**, **points** and **leaderboards**, and for content gamification, they are **challenges** and **storytelling**.
A framework intended for structural gamification will therefore be the most suitable to apply to a logic tool because the primary focus behind this type of gamification is to motivate the learner to go through the content (Kapp [2012]).

The conceptual model of Tomé Klock et al. [2015], mentioned above, is a good example of structural gamification. Structural gamification is also applied in the Framework for Intelligent Gamification of Andrade et al. [2016], which is applied to an ITS.

In the research of Kusuma et al. [2018] 33 papers about gamification have been analysed using the MDA-framework. MDA is used as an analysis framework because gamification elements are based on the framework. The researchers believe that the best way forward is to combine several mechanics in such a way that a dynamic is created that results in all kinds of aesthetics. In light of this, several gamification strategies are recommended. For example, giving game points and rewards in form of badges or trophies, could give students a sense of achievement and greatly increase their motivation to use the tool and at the same time learn the subject.

In the opinion of Toda et al. [2019], many frameworks have no common understanding of the set of game elements that can be used by gamified systems, and the knowledge of how to apply them. This hinders the adoption of gamification by teachers and instructors because of differences and similarities in deciding which game elements to use, as well as which game elements are more appropriate in an educational context. That is why the researchers propose a classification using five dimensions to group 21 gamification elements, which is shown in figure 4.4:

- *performance/measurement* – elements related to the environmental response, which can be used to provide feedback to the learner,
- *ecological* – elements related to the environment that the gamification is being implemented,
- *social* – elements related to the interactions between the learners,
- *personal* – elements related to the learner, and
- *fictional* – elements related to the user and the environment.

The difficult applicability of frameworks is intensified by the fact many frameworks have only been applied in theory, so Toda et al. [2020] describe how their taxonomy (figure 4.4) is used in practice, by using a Design Sprint method.

Figure 4.4: Gamification Taxonomy (Toda et al. [2019]).

Recent studies show that learners react differently to different game elements, and that learner motivation, engagement, and performance can vary greatly depending on individual characteristics such as personality, game preferences, and motivation for the learning activity. Results indicate that in some cases game elements that are not adapted to learners can at best fail to motivate them, and at worst demotivate them.

Hence, in a most recent study, Hallifax et al. [2021] propose an adaptation framework that uses initial static adaptation based on learner profiles, and dynamic adaptation that uses learning analytics to refine the static adaptation recommendations. The system observes various learning analytics to estimate learner engagement, compares it to the engagement of other learners, and signals to teachers the learners that require a change in their gamified environment. Also, a protocol is proposed to test the approach in real conditions in the future.

Another adaptive framework is proposed by Hassan et al. [2021]. It identifies the learning styles of students based on their interactions with the system and provides an adaptive gamification experience according to their identified learning dimensions. The results of the experiments show that the motivation of learners was increased by 25%, and the drop-out ratio was reduced by 26%. The profiles of the learners were determined by the application of Felder-Silverman Index of Learning Style instead of using a user typology. The index is an instrument used to assess preferences on four dimensions (active/reflective, sensing/intuitive, visual/verbal, and sequential/global) of a learning style model formulated by Richard M. Felder and Linda K. Silverman.

In the case of Game-based Learning (GBL) (including Serious Games), the learning objectives and learning outcomes to be achieved must be defined, so the game can be designed accordingly. Bloom's taxonomy[3] can be used as a tool for defining the learning objectives and learning outcomes. Learning mechanisms can be used to achieve these learning objectives and learning outcomes. Lim et al. [2015] and Arnab et al. [2015] defined learning mechanisms as the aspects (e.g., tasks, activities, goals, relationships, etc.) that researchers have derived from different pedagogical approaches. When using the *Learning Mechanics-Game Mechanics* (LM-GM) model, a framework that can be helpful in designing serious games, they can then be linked to different game mechanisms, depending on the specific nature of a serious game.

Although gamification and GBL are very similar, gamification is not about defining learning outcomes and learning goals, but about adding game mechanics to non-game contexts to enhance a specific behavior, such as motivation. Because this research is about the application of gamification to an existing tool and not about the development of a serious game, this framework, therefore, seems less applicable.

[3] https://learning-tribes.com/en/how-to-create-corporate-learning-objectives-using-blooms-taxonomy/

B - Which gamification elements are used / evaluated most frequently?

In this section, various noteworthy reviews and empirical studies are described that have investigated the effects of applying various gamification elements or that have reviewed a variety of studies to that end.

In Antonaci et al. [2019] a systematic literature review is conducted to close a gap by clarifying the effects of gamification on users' behavior in online learning. In this review, the game elements most used in the literature are identified and mapped with the effects they produced on learners. These empirical effects of gamification are clustered into six areas: *performance*, *motivation*, *engagement*, *attitude towards gamification*, *collaboration*, and *social awareness*. By analysing 61 studies, implemented in e-learning and online learning scenarios, 24 game elements were found.

The ten most frequently mentioned are, *sorted from most to least used*:

- **Badges**: external rewards delivered to users once a goal is accomplished.
- **Leaderboards**: a game element to understand how the learner is performing (showing the score or the position or both) in relation to others and the leader.
- **Points** (or Score or Ranking): a numerical representation of player success.
- **Feedback**: information delivered to users related to their progress, achievements, issues, or other aspects of their activities.
- **Challenges**: appear in the form of quizzes or problems to be solved.
- **Likes**: supporting what another user communicates via a thumbs up.
- **Communication Channels**: the medium and the methods to send messages to other players.
- **Narratives**: using stories to pass information and intrigue users.
- **Levels**: related to goals and have different degrees of difficulty. To move up a level, it is generally necessary to reach all the goals of the current level.
- **Progress bars**: gives the user information about his/her improvement.

By correlating the game elements most used and the effects they generate on learners, the following observations were noticed:

- Effects of **badges/rewards** are observed on motivation, attitude toward gamification use, and performance in terms of time management, engagement, emotional states, and enjoyment. The effects of badges may vary according to gender and personality, and they may negatively affect motivation and engagement.
- Effects of **leaderboards** have been found on attitudes toward gamification use, learning performance, performance in general, engagement, enjoyment, and goal commitment. Effects generated by leaderboards vary according to personality.
- Effects of **point/score/ranking** have been reported related to motivation, attitude toward gamification use, learning performance, performance in general, engagement, enjoyment and emotional states. Effects of point/score/ranking may vary according to personality and gender.

An analysis of 19 studies was conducted by Lister [2015] to determine to what extent gamification supports student achievement and motivation among students at the post-secondary level. The sub-themes that emerged from the analysis were common elements of gamification, motivation effectiveness, and the impact on performance. The findings from the analysis revealed that **points**, **badges and achievements**, and **leaderboards and levels** are the most commonly implemented forms of gamification. Incorporating gamification elements into post-secondary environments can motivate students and support student achievement.

In previous studies, gamification is offered as a generic construct. Because these studies neglected the fact that many different game design elements can result in very diverse applications, Sailer et al. [2017] performed a randomized controlled study that used an online simulation environment, based on a SDT-framework. Different configurations of game design elements were deliberately varied and analysed regarding to their effect on the fulfilment of basic psychological needs.
The game elements they used and discussed are:

- **Points**: rewards for the successful accomplishment of specified activities.
- **Badges**: visual representations of achievements that can be earned and collected.
- **Leaderboards**: ranks players according to their relative success, measuring them against a certain success criterion.
- **Performance graphs**: provide information about the players' performance compared to their preceding performance.
- **Meaningful stories**: the narrative context in which a gamified application can be embedded.
- **Avatars**: visual representations of players.
- **Teammates**: players who can induce conflict, competition or cooperation.

The researchers based their selection of elements on their direct visibility to the players, how easily one can activate or deactivate them in an experimental setting, and how strongly they can be expected to address motivational mechanisms within the theoretical framework (Sailer et al. [2014]). The conclusions of the research show that **badges**, **leaderboards**, and **performance graphs** positively affect competence need satisfaction.

Chapman and Rich [2018] investigated, employing design-based research (DBR), how participating in a gamified (organisational behavior) course motivated students overall and examined the individual effect of 15 game elements that were included in a gamification platform. A Likert-scale-survey, to measure the perceived impact on the motivation of both the gamified course overall and each of the game elements, was deployed and the outcomes were analysed. The results of this study demonstrate that:

- a large portion of participants reported that the educational gamification environment used increased their perceived motivation,
- game elements related to tracking one's progress and the progress of others, and those providing feedback about performance, were found to be most motivating, and
- the benefits of gamification were not limited to participants with specific demographic characteristics.

Chapman and Rich also explained why the use of gamification is justified when traditional education already supports many game-like elements, like points for assignments, grades and diplomas as badges, rewards and punishments, and levelling from class to class. According to them, the reason for this is, there is a huge contrast between the engagement achieved in traditional education compared to what can be achieved by games. While millions of people are entertained by recreational games, schools, on the other hand, experience disengagement, cheating, learned helplessness, and drop-outs. So although traditional education seems to have a lot of characteristics of a game, it does not seem to be a very good game from a motivational point of view.

In Hallifax [2020], the author states that one of the core problems with earlier gamification approaches is the fact that all users are presented with the same game elements, thus ignoring individual user preferences and expectations. The *second wave* of research identified by Nacke and Deterding [2017], aims at understanding *how* gamification works, and *when* it should be applied (and when it should *not* be applied). This approach focuses on understanding individual differences in users, and how these individual differences translate to preferences for game elements. The second wave is in contrast with the *first wave* of gamification research that was held together by fundamental questions of *what* and *why*.

Because learners react differently to different game elements, results of research like Monterrat et al. [2014], Monterrat et al. [2015] and dos Santos et al. [2018], indicate that in some cases, game elements that are not adapted to learners, can at best fail to motivate them, and at worst demotivate them. Therefore, adapting game elements to individual learner preferences is important. Generally, this is done by identifying different categories of learners and proposing different game elements for each of these categories. Two types of adaptation can be distinguished: *static*, and *dynamic* systems. In a static system, the adaptation occurs once, usually before the learners start using the learning environment. In a dynamic system, the adaptation happens multiple times during the learning activity.

In one of the studies described in Hallifax [2020] six game elements (**points**, **badges**, **ranking**, **timer**, **progress**, and **avatar**) were implemented in a mathematics learning environment. In that study, the static adaptation consists of determining the player type and (initial) motivation, for which participants were asked to fill out questionnaires. The HEXAD Gamification User Types-Questionnaire (Marczewski [2015]) turned out to be the most appropriate user typology. To measure the variation of motivation the Academic Motivational Scale-questionnaire (AMS, Vallerand et al. [1992]) was answered at the beginning and the end of the performed experiments. The research revealed that the impact of game elements on learners' motivation varies greatly depending on their initial motivation (for mathematics) and their HEXAD-player profile. So the adaption of gamification should not only be based on a learners' player profile, but also on their initial motivation. Both factors determine how a game element will affect learners' motivation, behavior and engagement.

4.2.3. Already in logic tools used gamification mechanics (RQ2)

The use of feedback is considered one of the most powerful strategies to improve student performance (Hattie and Timperley [2007]), which is one of the challenges related to learning and teaching. One of the possible elements of gamification, according to (Kapp [2012]) is feedback, so it is one of the learning mechanics or elements that can be gamified. A distinction can be made between feedback created from the inner loop (immediate feedback) and feedback created from the outer loop (by progress indicators).

Feedback (and feedforward) provided in the inner loop are, according to van Lehn (VanLehn [2006]), who described *The Behavior of Tutoring Systems*, services that an ITS offers to learners:

- minimal feedback on a step. In most cases, this means indicating only whether the step is correct or incorrect,
- error-specific feedback on an incorrect step. This information is intended to help the student understand why a particular error is wrong and how to avoid making it again,
- hints on each step,
- assessment of the knowledge, and
- review of the solution.

The outer loop, which main responsibility is to decide which task the student should do next, can be implemented, according to VanLehn [2006] in one of these four ways:

- the outer loop displays a menu and lets the student select the next task,
- the outer loop assigns tasks in a fixed sequence,
- the outer loop implements a pedagogy called *mastery learning*, in which the tutoring system keeps assigning tasks from that unit until the student has mastered the unit's knowledge, and
- the outer loop implements a pedagogy called *macro adaptation*, the tutor chooses a task based on the overlap between the tasks' knowledge components and the student's mastered knowledge components.

To answer this sub-question, the search for already applied elements is therefore targeting both types of feedback, with tools and apps being discussed in separate paragraphs, A and B respectively.

A - Tools

In previous research, comparisons have been made between the IDEAS-tool LogEx and other logic tools. In the research of Lodder et al. [2016] into a domain reasoner for propositional logic and the research at heuristic steps in logic tutoring systems (Steins [2020]), LogEx was, among others, compared with *DeepThought* (Mostafavi and Barnes [2017]), *Organon* (Dostálová and Lang [2007]), *FMA* (Prank [2014] and *SetSails!* (Zimmermann and Herding [2010]). Several properties have been compared such as (inner loop) *feedback* and *feedforward* (or hints).

During the development of the web interface of LogAx (Berkhof and De Wit [2016]), several tools, which allow the practice of proofs with natural deduction or axiomatic derivations, have been compared, especially focusing on *feedback* and *feedforward*.

Both comparisons have concluded that all compared applications are nowhere near the feedback- and feedforward-capabilities that LogEx and LogAx offer: in addition to feedback, a hint or next step can be requested during the execution of a task, the proof can be completed by the tool, and the full derivation can be requested.

An attempt is made to apply some of the tools found in the above-mentioned studies as a starting point for the inventory, to determine whether gamification has been implemented, and if so, what kind of gamification. Unfortunately, most of them are no longer alive, not working anymore or are so outdated that gamification is most probably not applied.

But several recent tools can still be seen in action:

LogicPalet[4]: A desktop app designed to help students master the basic concepts of symbolic logic. This tool is used for practice and homework at the Katholieke Universiteit Leuven, and contains for example a proof assistant.

ILTIS[5]: An interactive, web-based system for teaching propositional, first order and logic (Geck et al. [2019]). The tool contains interactive tutorials, web exercises, self-tests and supplementary, with even a Monthy Python-YouTube film as an example of how not to reason.

Sequent Calculus Trainer[6] (Ehle et al. [2018]): An app to construct formal proofs in sequent calculus with automated feedback on the provability status. Feedback is given when a mistake is made and an explanation is given of how to apply the rules.

Larch[7]: A prototype of an ITS that supports learning different proof methods (such as analytic tableaux or sequent calculi). The main ideas behind the interface are: step-by-step guidance through the proof, an effective hint system and engaging gamification features. It is a promising tool but is still in the start-up phase. Now the only implementation of the interface ideas is a hint which shows the number of steps that must be completed for each task.

The Incredible Proof Machine[8] (Breitner [2016]): This web tool provides game-like graph-based exercises in propositional and predicate logic using natural deduction. This tool shows various tasks in one overview and indicates which of them have already been solved or are still to be solved. In addition, the tool provides feedback on errors made and hints by only showing the possible graphical elements to be used. It is also possible to add your own exercises.

[4] `https://logicpaletwebapp.azurewebsites.net/`
[5] `https://iltis.cs.tu-dortmund.de/`
[6] `https://www.uni-kassel.de/eecs/fmv/software/sequent-calculus-trainer`
[7] `tiny.one/larch`
[8] `https://incredible.pm/`

Most tools provide (inner loop) feedback, but do not (yet) provide feedforward. Except for the Incredible Proof Machine, they cannot touch the way it is provided in the IDEAS-tools. However, in contrast to LogEx, in the Incredible Proof Machine blocks represent the various proof steps. When connected properly, and if the conclusion turns green, then a proof is complete.

Finally and although not in a logic tool, to illustrate, two examples of how gamification is used to show progress in MathTutor[9], a free website where middle school students learn math (Aleven and Sewall [2016]), which is one of the tutors of The Cognitive Tutor Authoring Tools (CTAT)[10], a suite of authoring tools for tutors developed at the Carnegie Mellon University.

Figure 4.5 shows the progress of the student using progress bars in the different problem sets.

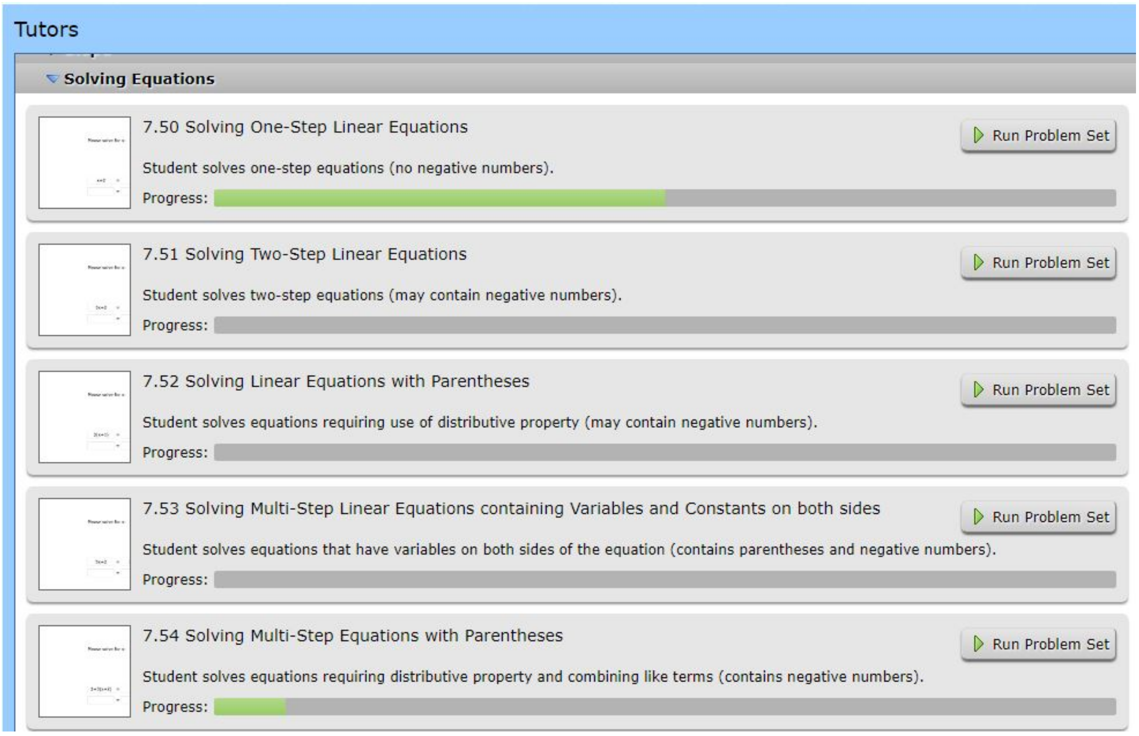

Figure 4.5: MathTutor: Overview of the Problem Sets in the category *Solving Equations*.

Figure 4.6 shows the situation when performing an exercise. Next to the feedback and feedforward, applied just like in LogEx, the number of tasks already performed and to be completed is shown at the top. When the exercise is successfully performed the next exercise is automatically loaded. The exercises must be performed in a fixed order and no exercise can be skipped.

[9] https://mathtutor.web.cmu.edu/
[10] http://ctat.pact.cs.cmu.edu/

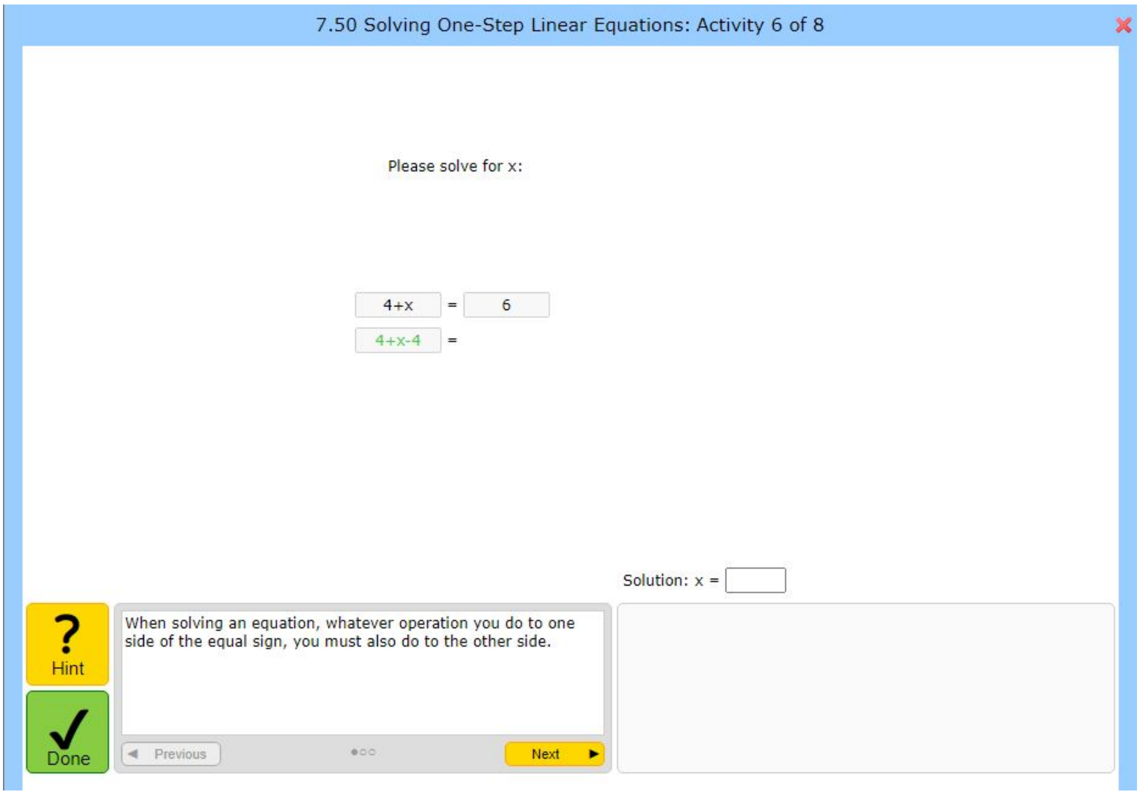

Figure 4.6: MathTutor: An exercise in the Problem Set *7.50 Solving One-Step Linear Equations*.

B - Apps

A tool that is worth mentioning is the educational game ***TrueBiters*** (figure 4.7)[11] developed for a Logic course in Bachelor by De Troyer et al. [2019].

The tool has been created to practice the use of truth tables in propositional logic, the branch of logic that is also the playing field of LogEx, LoxAx, and LogInd. TrueBiters is a game for one or two people. On the top line, six binary values are randomly generated. By applying basic logical operators of propositional logic (represented by the monsters at the bottom of the screen) on two values each time, the player(s) should end up with the rightmost binary value. After each development version, the game was evaluated by students and the evaluations were presented. After the last development, the authors concluded that the game is well suited for its target audience and has the same learning effect as the classical exercise session under the supervision of a teacher. Although this multiplatform game provides an engaging game for students to practice the truth tables, the only gamification mechanics that can be recognised are competition and challenge, but it does not contain elements such as points, badges and progress bars.

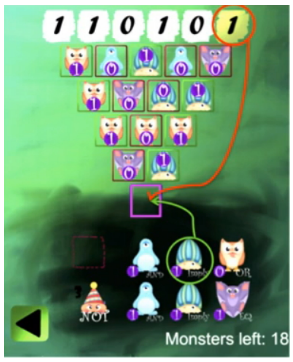

Figure 4.7: TrueBiters

[11] https://wise.vub.ac.be/project/truebiters

A researcher, a PhD student, and a graphic designer joined forces in a research in which they developed the mobile application ***AXolotl*** (Cerna et al. [2020], figure 4.8). This application was introduced into an introductory logic course as part of an optional laboratory assignment and contains several libraries for different types of logic, including a library for classical logic problems in three categories of problems, namely Hilbert style (which can also be practised in LogAx), sequent style and natural deduction. Even though the researchers did not mention the application of gamification at all in their paper, Axolotl provides hints and an extensive tutorial, but no feedback is given.

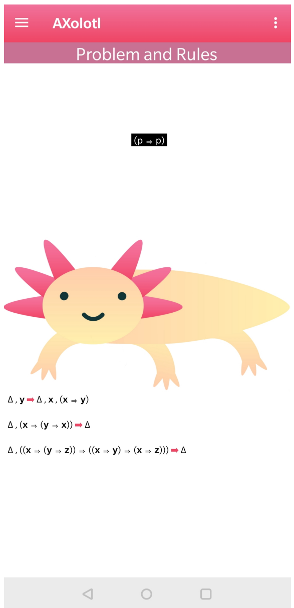

Figure 4.8: AXolotl

Because it is hard to find more scientific papers about applications like TrueBiters and AXolotl, also a search on Google Play is carried out which resulted in several apps. Screenshots of some of these apps are shown in figures 4.9, 4.10, 4.11 and 4.12, as well as a short description for each app. Although they do not seem very promising, they certainly show how things can be done better.

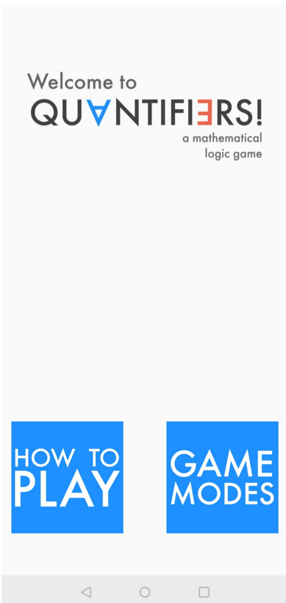

Figure 4.9: QUANTIFIERS!

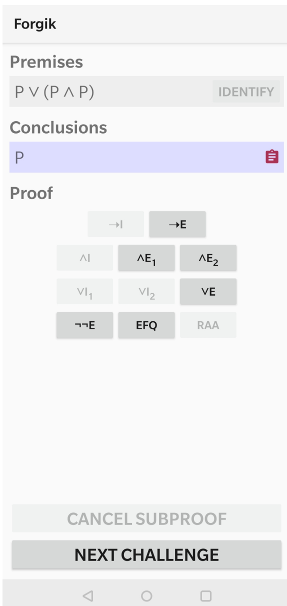

Figure 4.10: Forgik

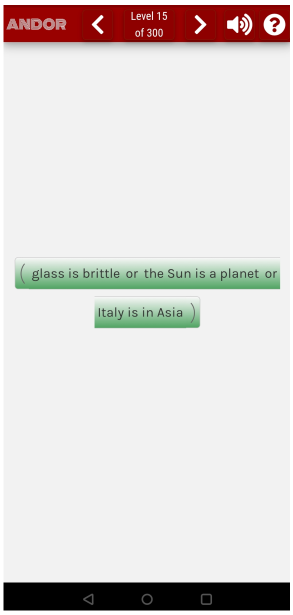

Figure 4.11: Andor

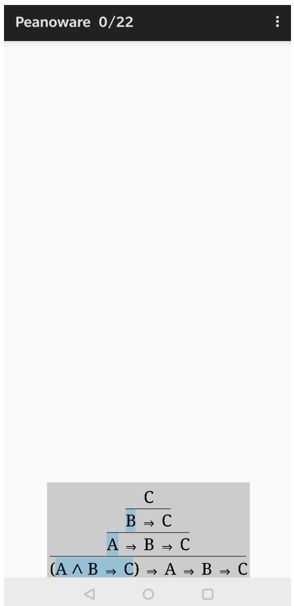

Figure 4.12: Peanoware

The app ***QUANTIFIERS!*** (figure 4.9), which at the time of writing ceased to exist, is developed by undergraduate students at the University of Toronto to ease the math learning curve. This game introduces users to foundation logic using a mathematical notation which is essential in proof writing. This app provides little to no feedback, but there is a very small explanation of how to play the game. The only gamification present (apart from being a game) is the progress bar that fills up (too!) quickly as time passes.

The propositional logic prover ***Forgik*** (figure 4.10) is an educational app to learn and practice natural deduction. By using inference rules, the goal is to prove a conclusion by assuming multiple premises. Even though a short video is shown as manual the app does not seem intuitive for novice learners. Forgik provides an instructional video (of 21 seconds) but does not provide feedback.

Andor (figure 4.11) is an educational game to learn the rules of logic. The goal is to drag and drop parts of a statement to create a true statement. 300 increasingly challenging levels are included to *turn the learner into a Master of Logic*. Andor also offers a short video as a manual and provides Help per question.

Peanoware (figure 4.12) is a proof construction system for natural deduction. The app has a minimalistic interface and includes 22 problems. The main goal of the app is to construct a proof for the given formula. In an explanatory video a tutorial is included, but Peanoware does not provide feedback.

4.2.4. WHAT STUDENTS LIKE AND DO NOT LIKE ABOUT GAMIFICATION (RQ3)

Gamifying the outer loop consists of two parts: choosing a particular type of outer loop and making the progress visible to the student. For the type of outer loop, it was chosen to offer the tasks in a fixed order, also to allow comparison between the two groups in the experiments, and for visibility, the progress bar was chosen, which will only be shown to one of the groups in the experiments.

The following activities are carried out to answer this sub-question:

- A - The identified gamification elements are applied in two LogEx-prototypes.
- B - On the website of the Open University an appeal is placed for students to participate in the first or the second experiment.
- In these experiments:
  - C - Half of the participating students use a prototype in which gamification is visibly recognisable and the other half a prototype in which the gamification is not visible.
  - D - The students complete an IMI-questionnaire indicating their motivation when using the prototypes.

A - APPLICATION OF ELEMENTS IN PROTOTYPE

LogEx[12] is a web application which consists of a server and a client. Using a framework with a domain-reasoner, the server provides feedback services that can be called from the client by means of HTTP requests from the JavaScript code. The domain-reasoner provides hints, elaborations and analyses of steps a student takes while completing an exercise. By configuration settings, options in the tool can be turned on or off. In a default configuration, a number of pre-selected tasks, a task with a certain difficulty level or a own task can be chosen. In addition, a hint, a next step and the example elaboration can be requested.

By modifying the configuration and (in the case of the prototypes) the JavaScript code, four different LogEx versions were created: a pre-test[13], a prototype without visible gamification[14], a prototype with visible gamification[15], and a post-test[16]. The pre-test and the post-test each contain one *Easy*, one *Normal* and one *Difficult* exercise where no hint or next step can be asked for. The prototypes both do not have predefined exercises, but contain the same lists of five tasks of each difficulty level (which tasks is defined in the configuration - thus easily adjustable), which, for each difficulty level, must be performed in a fixed order. In the prototypes, however, you can ask for a hint or a next step. The fixed order is guaranteed because when an exercise in a prototype, at the chosen difficulty level, is completed, the corresponding exercise is marked as completed (in the local storage of the browser) for that student (identifiable by the userid the student logs in with).

[12] https://ideas.science.uu.nl/logex/
[13] https://ideastest.science.uu.nl/logic-game1/
[14] https://ideastest.science.uu.nl/logic-game2/
[15] https://ideastest.science.uu.nl/logic-game3/
[16] https://ideastest.science.uu.nl/logic-game4/

If the student chooses a difficulty level for which all exercises already are completed, this is reported and the student is advised to choose another difficulty level or another exercise type. When all exercises of all types, and all difficulty levels are completed, the student receives a congratulatory message: "All exercises of all types have been completed. Congratulations!".

Figure 4.13 shows the application of progress bars in the LogEx-prototype in which the gamification is visible. When an exercise, at a chosen difficulty level, was completed, this is also updated in the corresponding progress bar, so the progress bars visualised the number of already performed and the number still to be performed exercises.

Figure 4.13 shows the part of the tool, in which a student can practise the conversion to the *Conjunctive Normal Form*. The green bar shows that two, out of a total of five, easy tasks have been completed. The blue bar indicates that one, out of a total of five, normal tasks has been completed and the yellow bar indicates that one of the difficult tasks, out of a total of five, has been completed. The pages for converting to the *Disjunctive Normal Form* and proving *Logical Equivalences* each have their own set of progress bars.

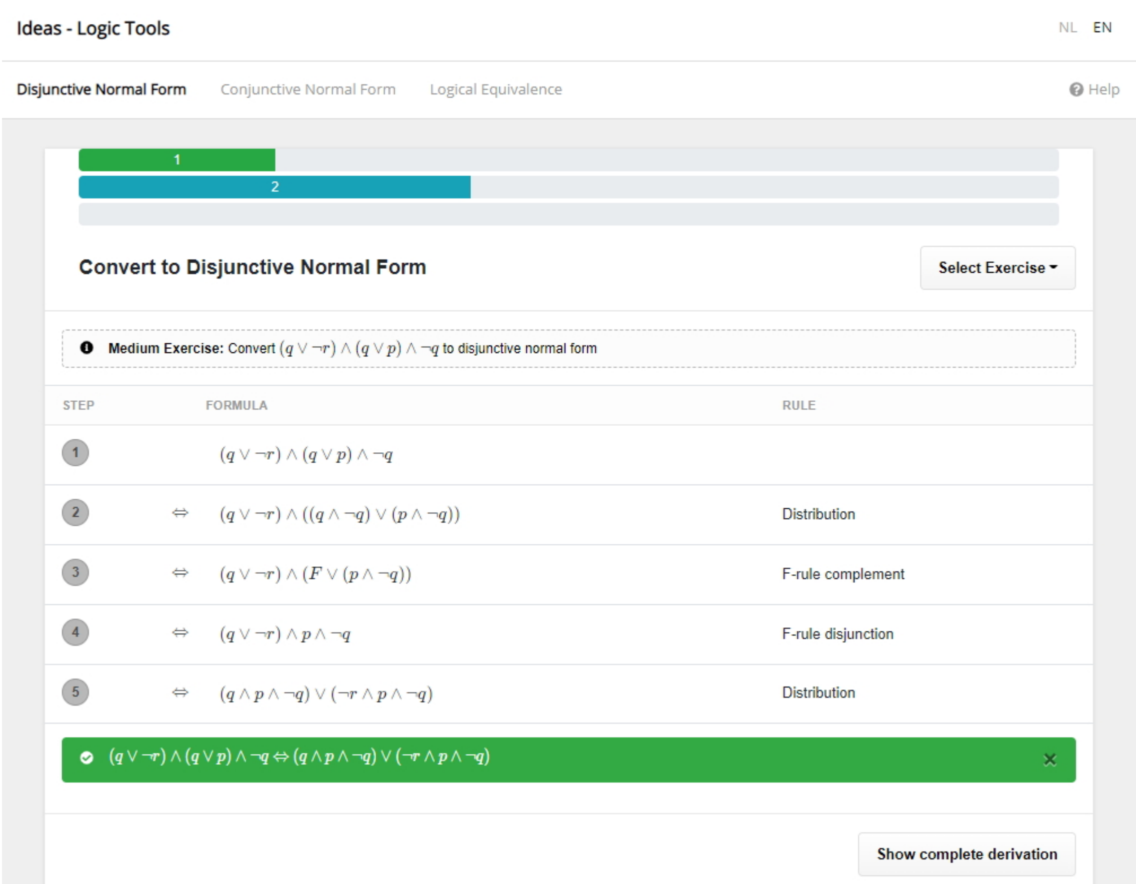

Figure 4.13: Prototype of LogEx with progress bars

B - Appeal to participate in the experiments

The tool LogEx is used in the course *Logica, Verzamelingen, Relaties* and is a part of the Premaster Software engineering, Bsc Informatica and Bsc Informatiekunde.
About a month before the course examination (in week 16-2022 and week 27-2022), students were asked, by placing a call on the study web of the Open University, if they wanted to practice for two weeks, with exercises of different types[17] and also support this research. Before the second experiment started, the students of the course also received a request from the teacher of the course by email and the information about the experiment was made more clear. Every student who responded positively, received an invitation with further information about the steps to take in the experiment and a link to fill in the IMI-questionnaire. The (completely online and anonymous) experiments consists of the following parts:

- A pre-test (with one task for each type[17]), duration of approximately 15 minutes.
- Using one of the LogEx-prototypes - this should take as much time as the student wants to spend on it.
- A post-test (with one task for each type[17]), duration of approximately 15 minutes.
- Filling in the IMI-questionnaire, which takes about 10 minutes.

The number of students in the course, during the two periods, was about 65 and 30. The number of students who indicated they wanted to participate was 20 and 4, and of these, 5 and 1 eventually completed the entire experiment.

C - Usage of LogEx tools - Prototypes and pre- and post-test

During the experiments, students practised with a LogEx-prototype. How to use the prototypes was explained in a *How to use Logex* instruction[18]. One group worked with a prototype with visible gamification (figure 4.13), and the other with a prototype without visible gamification (figure 4.14). The students were distributed among the prototypes in turn, in order of the date on which their commitment to participation was received. Both groups were given the same tasks to be completed in a specific order (recorded in a configuration file). They were also asked to do a pre-test and a post-test and to fill in an IMI-questionnaire. The results of these four parts can be linked to each other because the students were asked to choose a unique identifier, which, to keep it as anonymous as possible, could not be traced back to the student. The activities pre- and post-test were included to measure the performance of both groups in relation to errors made and the number of completed exercises, and because they provide a more accurate view than viewing exam results would, if it were allowed at all. The pre-test was used to establish a baseline against which the post-test was compared, but also to check whether the initial level of the students was comparable. It was assumed that both tests had an equivalent degree of difficulty.

[17] LogEx exercise types: Disjunctive Normal Form, Conjunctive Normal Form and Logical Equivalence.
[18] `https://gamification-in-logic-tools2.webnode.nl/use-of-logex/`

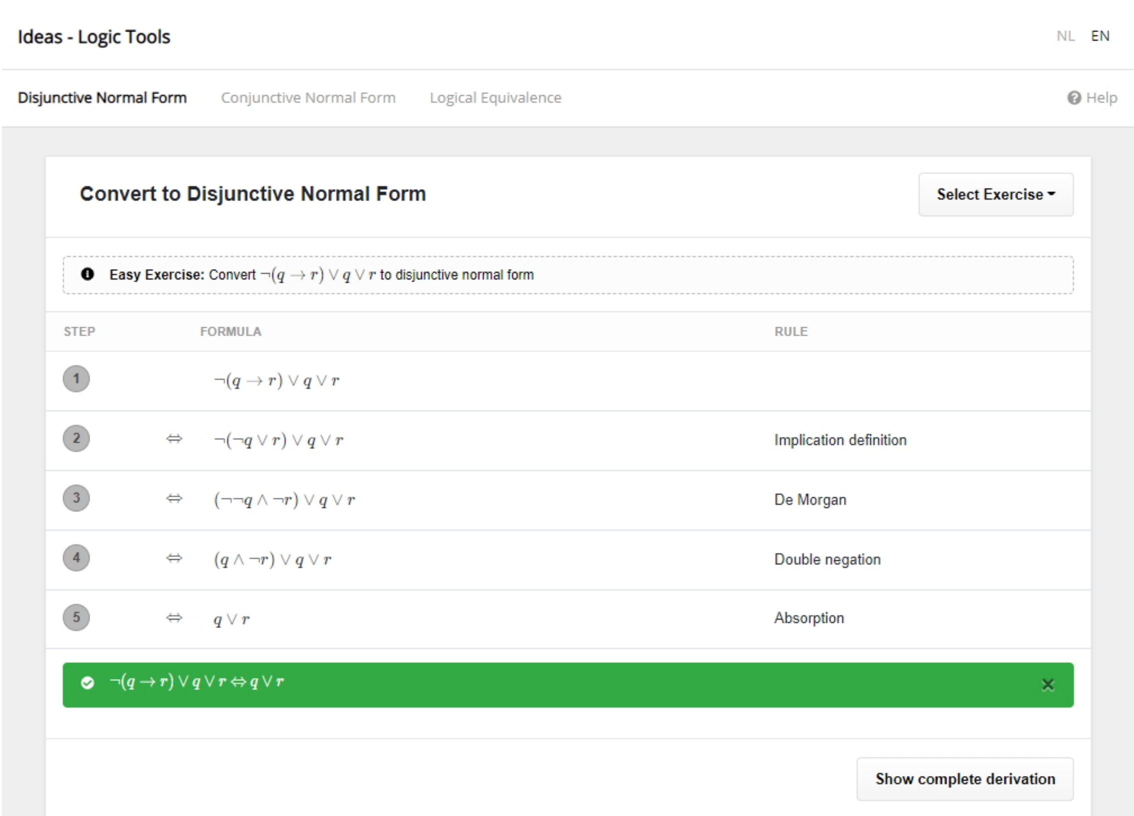

Figure 4.14: Prototype of LogEx without progress bars

D - Motivation questionnaire

There are several valid and reliable approaches measuring motivation. The *Academic Motivation Scale* (AMS, Vallerand et al. [1992]) focuses on how students experience learning as a whole. It examines to what extent a certain behavior is caused by intrinsic or extrinsic motivation, or by demotivation. In this study, however, the *Intrinsic Motivation Inventory* (IMI, Ryan and Deci [2000]) is used. This questionnaire is a multidimensional measurement scale that is intended to assess a person's subjective experience of an activity. Students' intrinsic motivation is measured with a selection of five items from the IMI. The IMI is commonly used to determine intrinsic motivation and self-regulation and consists of several subscales: interest/enjoyment, perceived competence, effort, value/usefulness, felt pressure and tension, perceived choice and relatedness.
The *interest/enjoyment* subscale is the measure of intrinsic motivation. It indicates whether the activity held the user's attention and whether the activity was found fun or boring. The concepts of *perceived choice* (how many choices are felt while completing the activity) and *perceived competence* (how competent the user thinks he or she was in the activity, and how satisfied was the user with his or her performance) are assumed to be positive predictors of measures of intrinsic motivation, and pressure and stress is assumed to be a negative predictor of intrinsic motivation.

Effort indicates how hard the user tried to complete the task, and how important the user thought the task was. This is a separate predictor that is relevant to some motivation issues, for example, if a user perceives a task as too difficult and requiring too much effort, they will not be motivated to complete the task. The subscale *value/usefulness* indicates how useful the user found the activity, both for himself and for others. Finally, the *relatedness* subscale was recently added but its validity has yet to be established. This subscale is used in studies dealing with interpersonal interactions.

Not all subscales need to be used to measure intrinsic motivation for a given activity: the questionnaire in this study used five of the seven IMI-subscales (the values in parentheses indicate the number of statements to be evaluated in each subscale): interest/enjoyment (7), perceived competence (6), pressure and tension (5), effort (5), and value/usefulness (4). The subscales perceived choice and relatedness were not included because participation in the experiment is voluntary and interpersonal interactions were not examined.
Students were asked to indicate how true each statement was for them using a Likert scale (1 = Strongly disagree, 7 = Strongly agree). In addition, some open-ended questions, which are discussed in more detail in the results, are also added.

The analysis of the results of the activities carried out in response to this sub-question (the determined gamification types, the questionnaires and the data that, when using the tools, is created in log files) would help to find out how LogEx, and logic tools in general, should be made more attractive and motivating in the opinion of students and the results after using the tool.

To guarantee the anonymity of the participating students, LimeSurvey[19] is used to conduct the IMI-questionnaire. The students participating in the experiment are invited by e-mail, and although their e-mail address is known, the answers in the questionnaires are processed anonymously. To be able to link the use of LogEx of student A to the questionnaire of student A, the students are asked to make up an identifier for themselves. This identifier had to be chosen in such a way that it could not be traced back to the student and that the risk of the same identifier being used by two different students was minimised.

[19] https://limesurvey.ou.nl/

4.2.5. Comparison of the usage of prototypes (RQ4)

The search for the answer to this sub-question is divided into four parts:

- A - Collecting the log data, which is generated automatically by making the pre-test, practising with one of the prototypes and making the post-test,
- B - Collecting the answers given to the questions in the IMI-questionnaire,
- C - Analysing the log data in combination with the IMI-data, and
- D - Comparing the data of the two groups of students.

The choice has been made to only process the data of the students who have carried out all of the parts of the experiment: made the pre-test and the post-test, have practised with one of the prototypes and have completed the IMI-questionnaire. Otherwise, no proper comparison could be made. Unfortunately, this resulted in only a small number of students: four of them were part of the group that worked with the prototype without visible gamification (NVGM), and the other two were part of the other group (VGM). Three students in the NVGM-group and three students in the VGM-group would have been a better distribution, but this unplanned imbalance, besides the small number of participants, was caused by the fact that students indicated that they were willing to participate, but did not take part in the end or did not complete the whole experiment. Figure 4.15 shows which parts the students have (partially) executed. Students who did not (partially) complete any part are not included in the table.

Student	Pretest	NVGM	VGM	Posttest	Questionnaire
Experiment 1					
1	x		x	x	x
2	x	x			
3	x		x	x	x
4					x
5	x	x			
6	x	x		x	x
7	x		x		
8	x				
9	x	x			
10	x	x		x	x
11	x				
12	x	x		x	x
Experiment 2					
1	x		x		
2	x	x		x	x
3			x		

Figure 4.15: Overview of parts of experiments that students performed

During the first experiment, a problem emerged in the part of the prototypes that could be used to practice Logical Equivalence. As a result, until halfway through the first experiment, only the Disjunctive and the Conjunctive Normal Forms could be practised. Surprisingly, after the problem was solved, there was no catching up to be seen. The second experiment also showed that there was little or no practice with this type of exercise. To keep the totals and averages pure, it was therefore decided to exclude the logs of these exercises from this research.

A - Collecting log data

The log data created when the students used the prototypes during the two experiments, is examined to contribute to the comparison of the motivation of the two groups. The observations are shown graphically in the following bar charts:

- figure 4.16 shows the number of exercises each student practised per type of exercise,
- figure 4.17 illustrates the time each student spent using the prototype (measured by subtracting the times between asking for the exercise and the end of it, and totalling them across all exercises conducted), and
- figure 4.18 presents the average time a student spent on the tests and the prototype in each group.

As expected, figure 4.16 and figure 4.17 show that the lengths of the bars are comparable for each student: practising more tasks requires more time. Only student VGM1 seems to deviate from this: his average time per exercise (6:22 minutes) is considerably faster than the average time of the other students, with averages of 10 to 16 minutes. As this concerns a student who is part of the VGM-group, this is mentioned further in the results, as well as the analyse of figure 4.18.

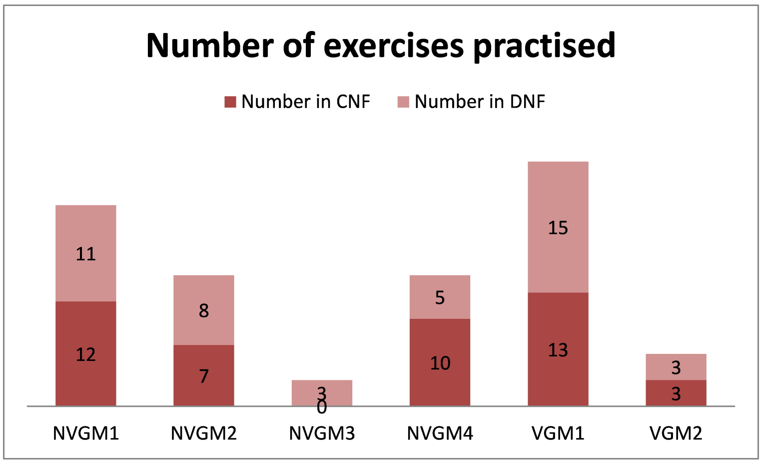

Figure 4.16: The number of exercises practised in the prototypes per student

NVGMx = student working with the prototype without visible gamification
VGMx = student working with the prototype with visible gamification

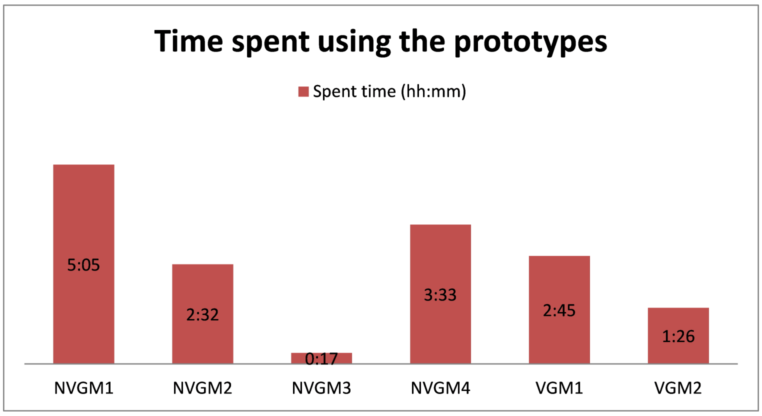

Figure 4.17: Time spent using the prototypes per student

NVGMx = student working with the prototype without visible gamification
VGMx = student working with the prototype with visible gamification

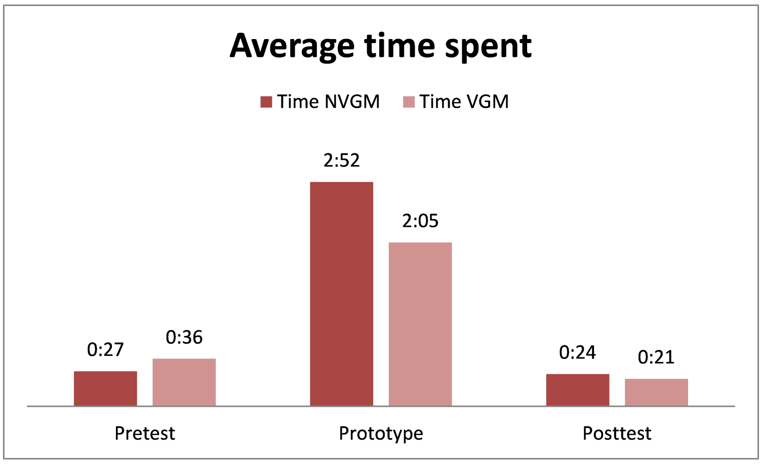

Figure 4.18: Average time spent in the tests and the prototypes

B - Collecting data from the IMI-questionnaire

The students are asked to fill in this questionnaire to determine their motivation during the use of the prototypes.

The values derived from the answers to the questions in this questionnaire can be considered valid and reliable, because before the questionnaire was approved and improved by Ryan and Deci [2000], it was proved by McAuley et al. [1989] that the reliability of the overall scale was 0.85, which proves that the instrument can be used in research about intrinsic motivation.

The values shown in figures 4.19 and 4.20 were calculated by first calculating the inverse of some questions, e.g. *I thought this was a boring activity*, which means the value was subtracted from 8. Then the subscale scores were calculated by averaging the item scores for the items on each subscale. In figure 4.19, in contrast to figure 4.20, no distinction was made as to which group a student was assigned to.

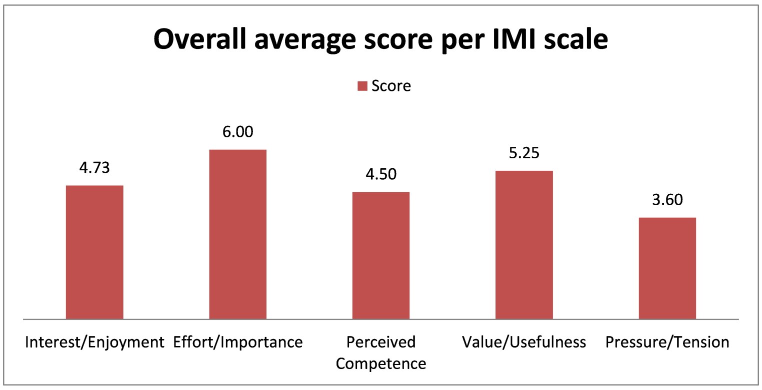

Figure 4.19: Average score over both groups per IMI-scale

Figure 4.19 shows the following regarding the different scales:

- The scale **interest/enjoyment** that consists of seven questions has an average of 4.73, with 3.71 as the lowest and 4.86 as the highest value. This result shows that most students felt that using the tool was medium interesting and not too boring, and the students found it moderately enjoyable.
- The scale **effort/importance** consists of five questions. The average of the answers is 6, with 4.4 as the minimum and 6.2 as the maximum. This means most of the students believed that practising with this tool is important to them and they also put effort into this tool to get good results.
- The scale **perceived competence** involves six questions, which resulted in an average of 4.5, with a min of 2.8 (an outlier) and a max of 5.7. This shows that most of the students felt confident when they did the activity well and believed they are good enough compared to other students.
- The scale **value/usefullness** that consists of for questions has an average of 5.25, with the lowest value of 4.75 and the highest value of 6.5. This result shows the students felt that using the tool was good for them and important. They would even be willing to do it again because it seemed valuable to them.

- The scale **pressure/tension** involves five questions that resulted in an average of 3.6, with a minimum of 2.2 and a maximum of 4.8, the lowest average of all scales. This result shows that students participated without feeling uncomfortable, which has a little negative impact on their motivation.

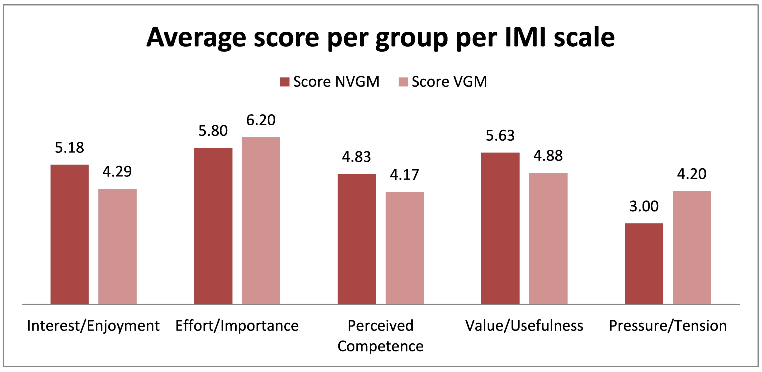

Figure 4.20: Average score per group per IMI-scale

NVGM = students working with the prototype without visible gamification
VGM = students working with the prototype with visible gamification

Figure 4.20 shows the averages of the different scales split into the groups NVGM and VGM, to make a comparison between the two. Except for the Pression/Tension scale, the averages of the various scales do not really differ between the groups. It can also be observed that not one group consistently scores higher or lower than the other group for all scales. But the group sizes are too small to draw conclusions from this.

C - Analysing the data of the logs and the IMI-questionnaire

When the logs and the results of the questionnaire, especially figures 4.18 and 4.20, are combined, this can be summarised as follows:

- the NVGM-group has spent 2:52 hours on the prototype and the VGM-group 2:05 hours,
- the IMI-score (calculated by taking the average of all scales) of the NVGM-group is 4.88, and the score of the VGM-group is 4.78, and
- as an answer to an additional added IMI-question, 50% of the NVGM-group would have liked to have a progress bar, and 50% of the VGM-group thought having a progress bar was necessary.

4.2.6. Improvement by scaffolding (RQ5)

To answer this sub-question, 2 sub-part questions had to be answered:

- A - Can the results of the application of gamification be further improved by adding scaffolding?
- B - What information should be recorded in the student model module of the specific ITS?

To answer the first question, the results of RQ3 and RQ4 are studied, and previous research in this field is reviewed. To answer the second question, further research is done on student models and the information they may hold.

A - Adding Scaffolding

In general, sufficient research, like the studies of Vygotsky [1978], Andrade et al. [2016], Hassan et al. [2021] and Hallifax et al. [2020] shows personalised support in combination with a fading mechanism produces the best results. Because not all students are identical and a student grows during his learning process and goes through different phases: the zone of proximal development (Vygotsky [1978]) is moving.

Hassan et al. [2021] identified the learner type of each student based on interactions with the investigated system. According to the learner type, certain gamification elements are presented to the students. Using a questionnaire, it was verified that the manual determination of the learner type by using the Felder Silverman Learning Style Model corresponded to the type identified by the system. Because this method of adapting gamification, according to the researchers, contributed to an increase in student motivation of 25% and a reduction in the number of dropouts of 26%, this kind of adaption seems an excellent option to serve as a starting point for further exploration.

Another way to determine which gamification elements are best suited for a particular student, is the approach that was used in the research of Hallifax et al. [2020]. This research shows that the impact of gamification elements on students' motivation varies greatly depending on their initial motivation (for mathematics) and their HEXAD-player profile. Thus, the adaptation of gamification should not only be based on a learner's player profile, but also on their initial motivation. Both factors determine how a game element will influence learners' motivation, behavior and engagement.

B - Student models

The ability of an ITS to adapt to each individual student, based on his/her characteristics and by making observations on the student's activities while they interact with the system, is known as *student modelling* (Sani et al. [2015]).

The advantages of student modelling are:

- Because every student is unique, he/she deserves to be individually treated.
- The strength and weaknesses of each student can be identified.
- The motivation and performance of students will be improved by providing effective feedback.

Sani et al. [2015] present a summary of several student model approaches. These classifications of student models do not exclude each other. Some of the types mentioned in the summary:

- **Overlay**: Considers student's knowledge as a subset of the whole domain knowledge.
- **Perturbation**: Views student's knowledge of the student as a distinction between *Correct* and *Incorrect*.
- **Differential**: Divides the domain knowledge to be learned by students into categories of *Mandatory* and *Optional*.
- **Stereotype**: Classifies students based on their common characteristics.
- **Machine Learning**: Is based on observing students' interactions with the system and is used to learn which characteristics are needed to model the students.

Student modelling involves building a profile of a student based on his/her knowledge level and characteristics to make conclusions about the type of learning style or the most preferred teaching methods or strategy that may be suitable for each individual student. Figure 4.1 illustrates the position of a student model within an ITS.

The use of the, previously mentioned, Overlay-model is described in the research of Tacoma [2020], in which the technical design of the domain reasoner which is evaluated, also is based on the IDEAS-framework (Heeren and Jeuring [2014]). This model consists of two parts: the *domain model* and the *overlay*. The domain model is a list of knowledge components that are important in the domain. The overlay itself contains scores of these knowledge components, obtained by each student, which indicates to what extent the student masters the relevant knowledge component. The scores in the student model are determined by the student's performance on the various exercises. The scores provide an automatic guide to, for example, what the next task to be performed by the student will be. By making the model inspectable, a part of the responsibility can be transferred to the student. On the bases of each score, the student can see whether the material of the relevant component has been mastered well enough or which components still require some attention.

In addition to domain-specific information, which indicates the level of knowledge, which is characteristic of the Overlay model, the student model should, in line with the scope of this research, also contain information like measures of motivation and preferences regarding the presentation of the ITS. The latter information can be adapted in the student model in two ways: *statically* and *dynamically*. Static adaptation mainly relies on learners' profiles (mainly their preferences and motivations), and dynamic adaptation is based on how learners perform with regard to the learning content, or how the learners interact with the system in general. Systems then use this information to select which gamification elements would be the most appropriate for learners (Hallifax [2020]). A potential adjustment for a student can then be made automatically or it can be a proposal to the teacher, who then decides whether or not to follow this proposal.

4.3. Results

This chapter discusses the results of the sub-research questions investigated. The results of RQ3 and RQ4 are combined into one sub-section.

4.3.1. Promising gamification techniques

Already used frameworks for learning

Three issues emerge after reviewing the various frameworks: 1) recommendations on which elements should be used, 2) the design process to use and 3) the adaptation of the gamification to a user. Most of the discussed frameworks, have only been applied in theory and are therefore not directly applicable to this research. In addition, the research of Rauschenberger et al. [2019] and Mora et al. [2017] have not resulted in any recommendations on which elements can be applied and when, but some of the gamification strategies Kusuma et al. [2018] recomments, can be an option. The studies of Mora et al. [2015] and Toda et al. [2020] focus mainly on the design approach, not on determining which elements could be applied. They each apply a different but similar approach (Agile and Design Sprint). Hallifax et al. [2021] and Hassan et al. [2021] have focused their research on adaptation and personalisation. The reason gamification sometimes does not seem to work is most likely caused by gamification not being applied adaptively, so adaptive gamification (whether or not based on the use of a framework) seems, for the time being, to be a good choice for this research. Especially when it is used in combination with the 5W2H-Framework, which clearly defines Who, What, When, Where, Why, How and How Much. Because the framework of Andrade et al. [2016] is applied to an ITS and its most important features are personalisation and fading mechanism, this framework is also kept in mind.

Most frequently used game elements

From the mentioned papers can be concluded that the most commonly used and evaluated game elements that could be applicable are **points**, **leaderboards**, **levels** and **badges**. From the observed results of Antonaci et al. [2019], the best results can be achieved by applying gamification elements that provide the students with feedback. Lister [2015] also came to a similar conclusion after research in university education. By applying various configurations of (visible, easy to turn on and off) elements, Sailer et al. [2017] also included that badges, leaderboards and performance graphs have a positive effect. However, in order not to fall into the trap that many gamification applicators fell into during the first gamification wave, many problems can be prevented by looking at the differences between users, which results in preferences for other gamification elements (Hallifax et al. [2020]). In a follow-up study, Hallifax et al. [2021] even concluded that not only the player type, but also the (initial) motivation determines the impact of gamification on motivation, behavior and engagement.

A combination of techniques and elements

After searching promising techniques in frameworks and most applied and evaluated elements, a combination of using a framework and make a choice out of frequently used game elements, is a good choice for this research. Because the Framework for Intelligent Gamification (Andrade et al. [2016]) deals with structural gamification in an ITS, with a focus on personalisation and scaffolding, it could have been very well applied in this research. Unfortunately, because it has not been applied in practice before, the framework is not covered by the used selection criteria. Applying the principles of adaptive gamification seems to be unavoidable, to avoid many mistakes made in many past gamification attempts. If the 5W2H-Framework, which describes seven dimensions to design, develop and evaluate gamification, is used then as well (in addition or simultaneously), a good foundation can be established for the expected outcome of the application of gamification. Especially since the application of each dimension of the 5W2H-Framework was demonstrated in an educational system.
These are the seven dimensions the framework consists of:

- *who* are the users? This dimension points to the characteristics of the user,
- *what* is the behavior that the users should exhibit while using the gamified system?,
- *why* is gamification being applied? This dimension is related to the stimuli that will be generated in the users through the interaction with the gamified system,
- *when* should gamification be applied? In what situations should the users be stimulated to the desired behavior?,
- *how* will gamification be implemented? What game elements will be chosen?,
- *where* will the modifications be made? In which system or prototype?, and
- *how much* gamification will produce the desired behavior?

To increase the motivational aspects using the Self-Determination Theory, the 5W2H-Framework was extended to 5W2H+M (Conejo et al. [2019a], Conejo et al. [2019b]). To deepen the motivational aspects of the 5W2H-Framework towards a more motivational outcome four of the original dimensions of the framework were modified: “Who?”, “Why?”, “How?” and “How Much?”. Each one of these four dimensions was altered without changing the end goal and use of the framework.

The Design Sprint method (to be considered the "successor" of Agile) can, like in the research of Toda et al. [2020], serve as an instrument in designing, prototyping and testing the adaptations. The six phases of *understand*, *define*, *diverge*, *decide*, *prototype* and *validate* closely resemble the six iterative phases of the earlier mentioned, most suitable DBR: *focus*, *understand*, *define*, *conceive*, *build* and *test*.

4.3.2. Already, in logic tools used, gamification mechanics

Once this sub-question has been answered, the applicable combination of a framework, development methods and gamification elements are explained further. To answer this sub-question, it has been examined which elements already had been applied in logic tools and whether they could be, possibly improved, used. All the discussed apps discussed, arguably, seem not to be motivating due to the lack of feedback and feedforward. Truebiters and Axolotl slightly exceed this because both applications really look nice and therefore have more appeal, but they are still demotivating because no feedback is given at all. So, unfortunately, comparing these apps offers little or no guidance in answering this sub-question.

Looking at the good immediate feedback provided by the IDEAS-tools and the fact that gamification should be applied to one of those tools, improving it through gamification does not seem to be an improvement for the IDEAS-tools themselves. For tools in general, bringing them up to the level of the IDEAS-tools by contrast, would certainly improve.

In the logic tools considered, only the first (as in the case of the IDEAS-tools) or second method of implementation of the outer loop (sub-section 4.2.3) is used in practice. For the outer loop to work properly across multiple tasks and sessions, the information about the student must be stored on a server or the student's computer disk. This persistent information is often called a student model, and what it contains depends on the type of outer loop. Because the outer loop is mainly responsible for the next task the student has to perform, and the best results can be achieved by providing the students with feedback (Antonaci et al. [2019], Lister [2015]), it seems that the improvement of the tool LogEx, which already excels in inner loop feedback, can be found in making the outer loop, the steps already taken by the student and the steps still to be taken, visible to the student, in other words: to show the students' progress.

Why improvement can be achieved by making the outer loop visible, can be explained by the fact that showing the student their progress, is one of the dynamics described in the DMC-framework of Werbach and Hunter [2012]. These dynamics stimulate competence, one of the three basic psychological needs defined in the Self-Determination Theory (subsection 2.5.1), which appears to be necessary to promote intrinsic and extrinsic motivation.

As a consequence, LogEx is modified so students perform several tasks in a fixed order, and is adapted to show the progress using one or more gamification elements. By having participating students fill in an Intrinsic Motivation Inventory (IMI) questionnaire, the question motivation of the students has improved as a result of this adaptation, is evaluated.

The four dimensions of the 5W2H-Framework have been used to assist and wrapped up in a motivational cloak as follows:

- *Who* - students from the earlier-mentioned courses, who, in response to a call, have stated that they wish to take part in one of the experiments.
- *Why* - according to the SDT, intrinsic motivation sticks better than extrinsic motivation. To achieve this, all three basic psychological needs of autonomy, competence and relatedness have to be stimulated. The focus of this research will be on competence.
- *How* - identify the outer loop game elements: progress bar, showing the number of tasks and showing exercises in a fixed order. These elements are parts of the mechanics Challenges and dynamics Progression and stimulate Competence.
- *How much* - to evaluate how much the gamification was able to stimulate the desired behavior the IMI is used.

By having the students fill out the HEXAD Gamification User Types-Questionnaire[20] too, it would have been possible to investigate whether the expected improvement in motivation applies to all user types. If this is not the case, adaptive gamification would be necessary in the future. However, in order not to overload the students, it was decided not to ask them to participate in the HEXAD-questionnaire.

4.3.3. Differences in use prototypes and student preferences

This study is conducted to investigate whether the application of gamification could improve student motivation, and whether this could subsequently produce better study results. The improvement in motivation could be found in spending more time on, in this case, practising exercises in the two prototypes and the results of the IMI-questionnaire. A progression of study results could be distilled from a noticeable progression between the pre- and post-test.

Based on the results of the IMI data, as shown in figure 4.19, it can be concluded that an average score of 4.81 (out of a maximum of 7) over the five scales shows, the overall intrinsic motivation of the students who participated, certainly seems adequate. The scale effort/importance, which is the scale with the highest average, contributes to this to a large extent indicating how important the students thought it was to complete the task. Although the overall IMI-score is sufficient, the score of the NVGM-group is higher than the score of the VGM-group: 4.88 and 4.78 (averages taken from the values contained in figure 4.20).

[20] `https://gamification-in-logic-tools2.webnode.nl/hexad/`

To check whether, by adding progress bars, the visual gamification had or would have made sense in the opinion of the students, a question was added to the IMI-questionnaire:
You are part of the group for whom the progress bar is not shown in the exercise tool. Would you have preferred to have a progress bar displayed? (for the NVGM-group) and
You are part of the group for whom the progress bar is shown in the exercise tool. Do you think showing a progress bar has been advantageous to you? (for the VGM-group).
The answer to this question could not contribute shifting the balance in favour of gamification either, as only 50% of the NVGM-group would have liked a progress bar, and 50% of the VGM-group thought that a progress bar was not really necessary.

For both groups, the average percentage of tasks completed by the students and the average number of steps needed to complete them were examined. The NVGM-group managed to complete 50% of the tasks in the pre-test where the number of steps compared to standard completion was 2.74 times higher on average. The result of the VGM-group was also 50% and 2. For the post-test, the values were 62% and 3.87 and 100% and 2.5, respectively. In both groups, the number of tasks increased, but so did the number of steps taken.

Although the analyses, unfortunately, show that the application of visible gamification did not seem to bring any benefits so far, no firm conclusions can be drawn from this, because the small number of pupils who participated in the two experiments most likely contributed to that. Subsequent studies involving larger numbers of students will most certainly yield more reliable results. Particularly when it is also investigated to incorporate the ideas that the students came up with during this experiment in response to another additional IMI-question *Do you have any suggestions on what other adjustments could be made or what other gamification elements could be applied to improve your motivation or results?*

- Perhaps a challenge mode would also be great: complete this exercise within x steps.
- Show the number of steps of derivation in the *Show complete derivation.*
- Put progress bars of all three types of exercises on one sheet so that you can see that there is still a lot more.

The reason why student VGM1 deviates in the speed of doing the exercises cannot be found in the speed of making the tests or in the results. Nor can a reason be deduced from the questionnaire filled in by this student. Although this was not immediately apparent from the student's pre-test, which was carried out immediately before to the use of the prototype (with visible gamification), the reason must be that he/she probably mastered the relevant material better than the other students.

4.3.4. SCAFFOLDING ADVICE

From the findings of Vygotsky [1978], the research of Hassan et al. [2021] and Hallifax et al. [2020], and this research, it can be (cautiously) concluded that the best results can be achieved by personal guidance, for which the data on which it is based, is continuously modelled in a model. By allowing this to serve as a personal guide, motivation can be improved and performance optimised. By applying student modelling the outer loop can implement the mastery learning pedagogy (VanLehn [2006]), in which the tool keeps assigning tasks until the student has mastered the desired knowledge. The answer to the first sub-part question can therefore be answered positively when based on the conducted research. Whether this could also be the case with the application of gamification in logic tools has not yet been conclusively proven and will therefore require further research.

The various studies mentioned in sub-section 4.2.6 describe different ideas about which data should be stored (as a basis) in the student model, but as the Overlay-model has been used before in a similar situation, this could serve as a good starting point. However, what needs more investigation is what other ways can be considered, besides the two already mentioned, to determine student types and which ones could then be used in that investigation.

5

Discussion

This research tries to answer the question of what way ITSs for logic could be made more attractive and motivating for university students, leading to better performance and results. The two experiments conducted, in which two groups of students completed a questionnaire and each worked with a different prototype of the logic tool LogEx, did not unequivocally show that the prototype in which gamification was visibly applied, was found more attractive and improved the results: the motivation measured by the questionnaire did not diverge much between the two groups and the time spent in the unadapted prototype was even longer. Also, the (expected) attractiveness of the adaptation was judged differently within each group: the group without visual gamification was not unanimous about whether gamification could have made a positive contribution, and the group with visual gamification was not unanimous about whether gamification had made a positive contribution.

The results suggest that the application of visible gamification in the prototype did not increase motivation and performance. However, based on the results of similar studies with non-logic tools, an explanation might be the (too) small number of students that participated in the experiments, the unbalanced distribution of students over the prototypes, the selected type of gamification or the fact that the gamification was not offered in a personalised way. These threats of validity are discussed below.

Number of students
If a larger group of students had been involved, the results would show a more diversified and more representative representation and then this research could be generalised. Twenty students registered for the first experiment, but in the end, only four remained and participated in all parts of the experiment, and only two participated in the second experiment. The teacher's attempt to send an email to all students who were going to take the exam, and an even clearer explanation of the content of the experiment did not help either. Also, the temporary bug in the prototypes during the first experiment most likely did not contribute to the willingness to participate in all parts of the experiment.

Distribution over prototypes
Because many students completed only part of the experiments, and only the results of the students who had performed all parts of the experiments were analysed, the distribution of students over the two prototypes, which was based on the students who applied, was unbalanced.

Persisted to the end
The decision is made to include only those students who completed all parts of the experiment in the analyses, but this may have introduced bias.

Type of gamification
The choice has been made to offer assignments in a fixed order and to show progress bars in one group and not in the other. In both groups, no consensus could be reached as to whether the progress bars made or could have made a positive contribution. This shortcoming could be solved by involving the students in the choice of which gamification to apply, or by letting the students make a personal choice for one or more types of gamification. Also, a different kind of design of the progress bars, or in a different location on the screen or with different information, could lead to different effects.

Adaptation and personalisation
If the gamification would have been offered in a personalised way, it would have been possible to cope with the diversity in the groups themselves. The use of a student model is currently being researched within the Open University. The learner model tracks a learner's level of knowledge based on their interactions with the LogEx tool. Using this model initial learner profiles can be further refined to generate exercises based on the learner's knowledge level and enhance motivation.

IMI-questionnaire twice
Having the questionnaire filled in twice (before and after practising with the prototypes) could have given a more accurate picture, but in this research students were only asked to do that afterwards.

5.1. FUTURE RESEARCH

The limitation of this study is the small amount of data that the experiments eventually resulted in, which is making the results of the analyses on those data ambiguous and not generalisable. Future research should therefore *conduct this study again* but with more students, perhaps over a longer period, keeping the balance between the two groups in the experiments in mind.

A second option for future research is to *increase the number of gamified elements*, which would allow a comparison between the application of different elements.

A subsequent study could investigate *which student model* offers the best application and whether adaptive gamification in logic tools indeed produces better results.

Finally, if the optimal situation regarding gamification for LogEx is found (including the part that was excluded from the experiments), this could be extended to tools like LogAx and LogInd, to investigate what differences and similarities can be seen.

6 CONCLUSION

The main research question

In what way is it possible, by applying gamification, to make logical ITSs more attractive and motivating for university students, resulting in better performance and results?

was subdivided into five sub-questions. Detailed answers per sub-question are described in section 4.3, and a summary of the answer to each question is listed here:

RQ1: Which gamification techniques are promising to be applied in logic ITSs?
After searching promising techniques in frameworks and most applied and evaluated elements, applying a framework and using one of the considered elements seems to be a good choice for this research. According to the various studies studied, the application of the principles of adaptive and personalised gamification seems to be a must for gamification to work, and the 5W2H- Framework seems to be a good basis to use for this research.

RQ2: Which gamification mechanics are already used in existing logic tools, and what problems related to learning and teaching are addressed by these mechanics?
While searching for tools and apps, it is found that the majority of tools and apps do not excel in providing feedback, the form of gamification that is the focus of this study. So, to answer the question: only a few gamification mechanics are already being used. This is despite the evidence that the use of feedback is considered one of the most powerful strategies to improve student performance. IDEAS-tools, however, do excel at providing feedback in the inner loop. Improvement can still be sought in gamifying the outer loop, by making the outer loop visible (by showing the progress to the student).

RQ3: What do university students like or dislike about gamification, and why?
After the identified gamification elements were applied in two LogEx prototypes, students worked with these prototypes in two experiments. Half of the participating students used a prototype in which gamification was visible and the other half used a prototype in which gamification was not visible. In addition, they were asked to fill in a questionnaire indicating their motivation, preferences and ideas when using the tools. However, from the results, it is not possible to unequivocally conclude what students think about gamification and why.

RQ4: What differences can be recognised between the use of a gamified and a non-gamified logic tool, and in what way does this affect the performance and results of the students?
By analysing the log data, it can be seen that the time spent on the tests and th prototypes does not differ very much. After studying the results of the IMI-data, it can be concluded that the average score of 4.81 over the five scales shows the overall intrinsic motivation of the students who participated, which certainly seems adequate. The score of the group working with the prototype without visible gamification is a little bit higher than the score of the group working with the prototype with visible gamification: 4.88 and 4.78. When asked if adding a progress bar has been or could have been beneficial, the answer in each group was fifty-fifty, so in both groups, there was no clear preference for showing the progress bar.

RQ5: Can the results achieved by the application of gamification be further improved when adding scaffolding, and what information should be captured in the student model module of the particular ITS?
From previous research, it can be (cautiously) concluded that the best results can be achieved by personal guidance, for which the data on which it is based, is continuously modelled in a student model. By allowing this to serve as a personal guide, motivation can be improved and performance optimised. As the Overlay-model has been used before in a similar situation, this could serve as a good starting point.

By following the steps to find the answers to the sub-questions, the literature studied suggests that by applying gamification, it is possible to make logical ITSs attractive and motivating for university students. For LogEx in this research, the IMI-questionnaire score cautiously supports this. However, the motivation of the two groups does not differ much, so whether gamification makes the tool more attractive and motivating cannot yet be concluded (partly because of the small number of students that participated). Therefore the research question cannot be answered concretely, so it will remain a presumption and more research is needed before general conclusions can be drawn.

ACKNOWLEDGEMENT

Five years ago, after 18 years of study, I received my Bachelor's degree in Computer Science from the Open University. Together with another graduate colleague, I developed a web interface with which axiomatic proofs can be practised. This tool was given the name LogAx. LogAx is one of the Intelligent Tutoring Systems that can be used at the Open University to support the teaching of logic.

After graduating, I got tired of studying, but after a while, it began to itch again and I started my Master in Software Engineering. Things did not go entirely smoothly, for example, I had to take a break during one of the modules and the (first) graduation subject turned out not to be a very good choice either. So I had to look for another one, which I found in this research and to my pleasure, Josje Lodder became my (first) supervisor.

I owe her a big thank you, and Bastiaan Heeren and Ebrahim Rahimi have also been of great help. And last but not least: mega thanks to "my Henk".

I never thought I would be able to do this. Thank you all very, very much!
Marianne Berkhof
Apeldoorn, October 2022

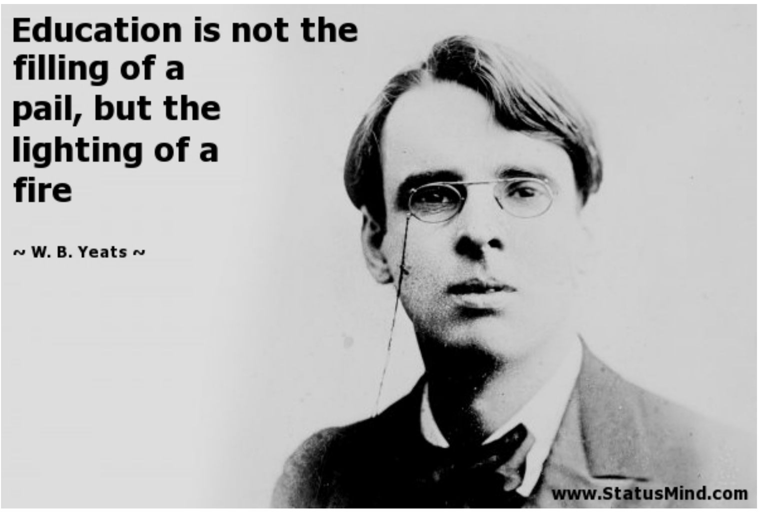

Figure 6.1: W.B.Yeats (1865-1939)

Improvement of motivation and commitment is closely related to the quote of W.B. Yeats (1865-1939), whose portrait is shown in figure 6.1:

Education is not the filling of a pail but the lighting of a fire.

Education should inspire people to learn more about things. It should not just be something people learn because they have to. That is why teachers should not just teach the students facts and data alone, but get them interested and then they figure it out themselves and love it.

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Appendices

A. Appeal for participation in the experiments

This appeal (in Dutch) for the 2nd experiment is placed on the website of the course. The appeal for the 1th experiment is pretty much the same.

Geachte studenten,

Als je op 5 juli 2022 (her)tentamen gaat doen, kan de Open Universiteit je de mooie tool LogEx bieden om te oefenen met de Disjunctieve en de Conjunctieve Normaalvorm en de Logische equivalentie.

In het kader van mijn Master Software Engineering ben ik, Marianne Berkhof, momenteel bezig met mijn afstudeeropdracht "Applying gamification in tools for teaching logic". Ter ondersteuning van mijn onderzoek heb ik in de tool LogEx een aantal gamification elementen aangebracht en is de tool uitgerold naar een testomgeving met twee prototypes. Het gebruik van het zichtbaar-gegamificeerde prototype zal worden vergeleken met het gebruik van een niet-zichtbaar-gegamificeerd prototype, om een uitspraak te kunnen doen over eventuele verbetering van (intrinsieke) motivatie en resultaten bij het gebruik van een zichtbaar-gegamificeerde tool. Het gebruik van de prototypes zal plaatsvinden in de vorm van een experiment, waarin tevens een pre-test, een post-test en een vragenlijst zullen worden afgenomen.

Ben je geïnteresseerd in het oefenen met opgaven van de types Disjunctieve en de Conjunctieve Normaalvorm en de Logische Equivalentie en wil je me daarnaast ondersteunen in mijn onderzoek? Mail me dan op m.berkhof@studie.ou.nl en ik stuur je, voor 11 juni 2022, een uitnodiging met nadere informatie over de in het experiment te nemen stappen en een link voor het invullen van de vragenlijst. Nadere informatie over mijn onderzoek is ook te vinden op https://gamification-in-logic-tools2.webnode.nl/[1].

Het experiment is volledig anoniem en zal uit de volgende onderdelen bestaan:

- Een pre-test (met één opgave voor ieder type), tijdsduur ongeveer 15 minuten,
- Het gebruiken van de aangepaste LogEx-tool – dit zal net zo veel tijd vragen als je er zelf aan wilt besteden, maar ik hoop natuurlijk dat alle participerende studenten er genoeg tijd aan besteden zodat ik daar valide conclusies uit kan trekken,
- Een post-test (met één opgave voor ieder type), tijdsduur ongeveer 15 minuten,
- Het invullen van de vragenlijst, dit zal ongeveer 10 minuten kosten.

Het is de bedoeling dat ALLE onderdelen van dit experiment worden uitgevoerd, de twee laatste onderdelen kunnen ook ná het tentamen worden uitgevoerd.

Mocht je denken dat meedoen met het experiment veel tijd lijkt te gaan kosten, bedenk dan dat meedoen een hele goede basis legt voor je tentamen! En natuurlijk zal mijn eeuwige dankbaarheid je deel zijn.

Vriendelijke groet,
Marianne Berkhof

[1] `https://gamification-in-logic-tools2.webnode.nl/`

B. INVITATION SENT TO THE PARTICIPANTS

This inviation for the second experiment is send to the students who wanted to participate in the experiment. Below the invitation some explanations of the words in italics.

Dear Student,

hereby you are invited to participate in the second experiment of the research "Applying gamification in tools for teaching logic". This experiment will take place from 13/06/2022 till 05/07/2022.

Thank you very much for participating! You are assigned to the group that will practice with the *gamified* LogEx-tool. The experiment will be completely anonymous and contains four stages which must be conducted in the order listed below.
Before you start your participation in the experiment, you are advised to read the additional information about the different versions of LogEx that will be used in the supplementary manual, which can be found *here*. It explains, among other things, why it is very important to use the same userid at all stages.
The four stages to be conducted:

- A *pre-test* (with one task for each type). This will take approximately 15 minutes. Complete this test before starting the second stage.
- Practice with the prototype. Practise for as long as you like. Do not forget: the longer you practise, the more it will contribute to my research, but certainly also to the preparation for your exam.
- A *post-test* (with one task for each type). This will take approximately 15 minutes. Start the test after finishing the second stage.
- Filling in the questionnaire (http://limesurvey.ou.nl/index.php/*number*?token=*token*&lang=en). This will take about 10 minutes. Fill in the form to conclude your participation in the experiment.

ALL parts of this experiment are meant to be conducted, the last two parts can also be conducted after the exam. If, on second thought, you do not want to participate in this experiment/survey or you do not want to take part in the WHOLE experiment, please click the following link:
http://limesurvey.ou.nl/index.php/optout/tokens/*number*?langcode=en&token=*token*.

Sincerely,
Marianne Berkhof (m.berkhof@studie.ou.nl)

Italic word	**Explanation**
here	link to https://gamification-in-logic-tools2.webnode.nl/use-of-logex/
gamified	*non-visibly-gamified* or *visibly-gamified*
pre-test	link to the pre-test
prototype	link to the non-visibly-gamified or visibly-gamified prototype
post-test	link to the post-test
number	number of the questionnaire generated by LimeSurvey
token	personal token generated by LimeSurvey

C. Intrinsic Motivation Inventory

This Intrinsic Motivation Inventory is filled by the students. The questions here are completed with the IMI-scale it belongs to (but this was not shown to the students), i.e. I = Interest/Enjoyment; E = Effort/Importance; PC = Perceived Competence; V = Value/Usefulness; and PT = Pressure/Tension. The questions were answered with a value between 1 and 7, where 1 = Strongly disagree and 7 = Strongly agree. The bold questions had to be reversed first before they could be included in the results. The other questions were open-ended or had to be answered with Yes or No.

Enter your self-chosen identifier here
I enjoyed doing this activity very much (I)
I tried very hard on this activity (E)
This was an activity that I could not do very well (PC)
I think I am pretty good at this activity (PC)
This activity was fun to do (I)
I did not try very hard to do well at this activity (E)
I believe doing this activity could be beneficial to me (V)
I thought this was a boring activity (I)
I would be willing to do this again because it has some value to me (V)
This activity did not hold my attention at all (I)
After working at this activity for a while, I felt pretty competent (PC)
I felt pressured while doing this (PT)
I think this is an important activity (V)
I would describe this activity as very interesting (I)
I was very relaxed in doing this (PT)
I thought this activity was quite enjoyable (I)
I did not feel nervous at all while doing this (PT)
I did not put much energy into this (E)
I am satisfied with my performance at this task (PC)
I believe this activity could be of some value to me (V)
I felt very tense while doing this activity (PT)
I was pretty skilled at this activity (PC)
I was anxious while working on this task (PT)
It was important to me to do well at this task (E)
While I was doing this activity, I was thinking about how much I enjoyed it (I)
I think I did pretty well at this activity, compared to other students (PC)
I put a lot of effort into this (E)
Approximately how many hours do you think you spent practising with LogEx?
How many (of the in total 45) exercises you were you able to complete?
You are part of the group for whom the progress bar is not shown in the exercise tool. Would you have preferred to have a progress bar displayed?
or
You are part of the group for whom the progress bar is shown in the exercise tool. Do you think showing a progress bar has been advantageous to you?
Do you have any suggestions which other adjustments could be made or which other gamification elements could be applied to improve your motivation or results?