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Do Serious Games Facilitate Learning Mathematics with Positive Emotions for Adult Learners?

Faculty of Behavioural, Management, and Social Sciences (BMS)
Educational Science & Technology Program

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Abstract

Context and Aim	In the STEM field, students encounter emotional problems (lack/low motivation and high anxiety) in mathematics courses. These problems affect not only their achievements in the mathematics courses but also their future career/educational path. Therefore, there is an urgent need to change the current educational methods. Serious Games can be one promising educational method to facilitate desired changes in the teaching methods and the students' emotions. In this study, we investigated whether introducing a simulation and a Serious Game to teach advanced mathematical topics could increase the students' motivation and decrease their anxiety while learning complex numbers and the definition of derivatives.
Methods and Results	One simulation and one Serious Game were designed and implemented in two lectures for the experiment group while the control group was taught via traditional teaching methods. The "Questionnaire on Current Motivation and Anxiety" from the existing literature was used. Fifty-eight students of Electrical Engineering participated in this project. They responded to the questionnaire before and after the lectures. Only the descriptive statistics of the Probability of success subscale showed an increase in the experimental group. The descriptive statistics of the Challenge, Interest, and Anxiety subscales did not reveal any increase or decrease in either of the groups.
Discussion and Implications	Although the results confirmed that the simulation and the Serious Game of this study could strengthen students' confidence in learning mathematics, no supporting evidence for the hypotheses was found. This obstruction might be justified by the effects of the students' mathematical ability and the teachers' efficacy on the results. Furthermore, this teaching method was employed in a brief period and the topics were not included in the final exam. Therefore, replication of this study in different settings, and for each individual participant over a longer period may lead to more corroborated findings.

1 Introduction

In this study, one simulation and one Serious Game (SG) were designed for the Electrical Engineering Department at Amsterdam University of Applied Sciences (AUAS). The results of this study, aside from its contribution to the current literature on Serious Games in mathematics education, will contribute to the Game-Based Learning in Mathematics (GAMMA)[1] project at AUAS. In this chapter, the problem statement, design approach, and the goal of this study are elaborated.

1.1 Problem Statement

Mathematics can be perceived by students as an abstract body of knowledge, isolated from the real world; whereas it should be regarded as a systematic and structured science that not only has inter-related topics but also is strongly connected with other sciences (Siregar & Daut Siagian, 2019). Not being able to connect to and relate to the mathematical topics may discourage students from learning mathematics. That is why the learning materials play a significant role in mathematics learning process (Novianti et al., 2020). Additionally, traditional teaching methods are criticised for not being able to stimulate the students' interest, and for not providing the students with autonomy (Boaler, 2002), which leads to lack of or weak ability in the students to connect with mathematical subjects (Siregar & Daut Siagian, 2019).

Among engineering students failure in mathematics courses is generally high. Bigotte et al. (2012) found out that the rate of success among engineering students in mathematics courses, particularly in the Differential and Integral Calculus course is low, which leads to lack of motivation. Harris et al. (2015) emphasized that high rate of failure is even more overwhelming and frustrating for first-year engineering students. Similarly, almost fifty percent of the first-year students enrolled in the Network Theory course of the Electrical Engineering Department fail the final exams at the first opportunity at AUAS (Hogeschool van Amsterdam, n.d.). This course is taught via traditional teaching methods and the course materials are textbooks. Although textbooks attempt to make connections between the content and the daily practices of the engineering students, homework assignments are usually superficial, and not designed for engaging practices (Coller & Shernoff, 2009). Thus, traditional teaching methods and the course materials are identified as two possible reasons behind this high rate of failure.

In the current practice of teaching at AUAS, teachers are usually regarded as sources of knowledge, leading the students to become passive learners. Thus, the students do not

[1] http://www.project-gamma.eu

have extensive autonomy over their learning process. Some scholars like Coller and Shernoff (2009) acknowledged the lack of efficiency of traditional approaches and nominated games as an alternative way of teaching. Games can build an intrinsically motivating learning structure where learners are at the centre (Turner et al., 2018) and are able to gain stronger mathematical connection abilities (Siregar & Daut Siagian, 2019). In this regards, introduction of the Serious Games into the mathematics curricula can be considered as a promising method. Over the last four decades, several studies have pointed to the use of games as a way of enhancing learning while simultaneously decreasing the amount of time spent teaching (Divjak & Tomić, 2011). However, before making any concrete decision regarding changing the teaching methods or the course materials, various and intensive investigations should be conducted to draw concrete conclusions on the reasons behind the students' failure in the Network Theory course.

This study evaluates the impacts of a simulation, and a Serious Game on the students' feelings toward learning mathematics in comparison with traditional teaching methods. Traditional teaching method in this study refers to a method that is teacher-centred, course materials are printed (a textbook), and the students are passive listeners while the teacher is working on some examples on a board (Spector, 2014). It should be underlined that the focus of this study is on the Serious Game and its effects on the students' motivation and anxiety level rather than the simulation. The simulation is added to familiarize the students with a different method than traditional methods and to prepare them for playing the game.

1.2 Design Approach of the Study

The design model of (McKenney & Reeves, 2014; Figure 1) is followed to design an effective project investigating impacts of a simulation and a Serious Game on learning mathematics.

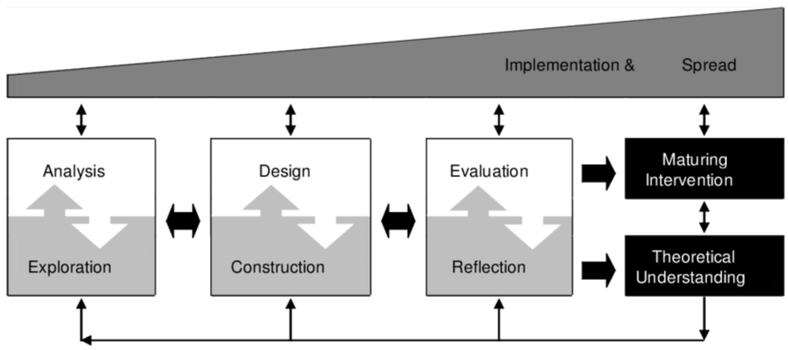


Fig.1 *McKenny and Reeves model for conducting educational design research*

McKenney and Reeves (2014) mention that educational design research can serve two purposes. Firstly, they facilitate seeking solutions for the challenges that teachers, educationalists, or educational practitioners face. Secondly, they can open doors for new knowledge discovery and hence, set an example for resolving similar difficulties. This educational design research focuses on generating usable knowledge or solutions for problems appearing in practice. Therefore, this model and its phases have shaped the outlines and structure of this study.

Analysis and Exploration

This phase (Chapter Two) provides more information about the instructional and the institutional problems, the learning environment, and the characteristics of the learners. These aspects require further analysis due to their importance for designing Serious Games. The main analyses of this study are about content, context, and correspondents (learners). Analysis regarding the content is necessary for setting the learning goals of the game whereas contextual analysis is about where and how the learners will activate or use their prior knowledge and skills to acquire the new ones. This analysis is crucial because the students are completely new to Serious Games and the mechanics thereof. The last analysis is about the target group of this study and their motivation and anxiety levels with respect to learning mathematics by a conveyance from traditional teaching methods to playing a simulation and a Serious Game.

Design and Construction

In this phase (Chapter Three), the simulation and the Serious Game are designed based on the common characteristics of Serious Games and the data collected from the analysis and the exploration phases. The simulation of this study is designed based on the definition formulated by Tarnopolsky (2012). Tarnopolsky (2012) characterizes a simulation as a learning activity that focuses on achieving a goal or solving a problem through discussion and role-playing regarding how to achieve this goal or solve this problem by two students.

Evaluation and Reflection

Evaluation is an ongoing process after each stage. The first evaluation regarding the motivation and anxiety of the students will be done via a pre-test survey among all the participants. Afterward, a post-test will be conducted to monitor the impact of the simulation and Serious Game versus traditional teaching methods on the students’ motivation and anxiety levels while learning mathematics (Chapter Four). Collected data will be analysed to affirm the assumption of the hypotheses of this study (Chapter Five).

Theoretical Understanding

This study aims at further contribution to the current literature on and the utilisation of simulations and Serious Games for adults in mathematics education. This study theorizes that playing a simulation and a Serious Game in comparison with traditional teaching methods will lead to an increase in the students' level of motivation and a decrease in their degree of anxiety. Therefore, students' level of motivation and degree of anxiety are the dependent variables of this research. Both variables are measured before and after the course is taught by using research instruments from the literature (See Appendix A). The dependent variables are manipulated by changing the teaching method from a traditional method to playing a simulation and a Serious Game in the classroom to introduce the following mathematical topics: complex numbers and testing differentiability of a function.

1.3 Guideline of this Study

Chapter one focuses on introducing the problem statement, educational design approach, and the importance of this study for the field. Chapter two elaborates on the definition and characteristics of the Serious Game of this study, and the associations between the Serious Games and the motivation or anxiety levels of students while learning mathematics in the literature before formulating the main question of this study. Chapter three explains the learning goals of the course and its materials. Besides, this chapter describes the learning goal of the Serious Game of this study, and its design process in this study. Chapter four is about the simulation and its importance and connection to the Serious Game. It also expounds the transition from the simulation toward the game. Afterwards, it will go in-depth about evaluating the game in the classroom. The fifth chapter is about data analysis and its interpretation. It finalises this study with the justification of drawn conclusions, relevant discussions, and recommendations for further investigations.

2 Analysis and Exploration Phase

This phase elucidates the definition of Serious Games, the reasoning behind the use of Serious Games in mathematics education in general, and the correlation between the degree of motivation-anxiety and Serious Games. This phase contributes to the preparatory phase of the simulation and the game for this study. To narrow down the design scope, the definition provided by Foshay (2014) is chosen for this study. More details regarding the Serious Game of this study is provided in chapter three.

2.1 (Educational) Serious Games

Entertainment Education, Game-Based Learning (GBL), E-learning, Serious Games (SGs), Digital Game-Based Learning, and Classical Edutainment Games have some common characteristics. Nevertheless, they should not be used interchangeably. Thus, as Breuer and Bente (2010) classified them in Figure 2, this study focuses specifically on Serious Games and not on other concepts coupled with them.

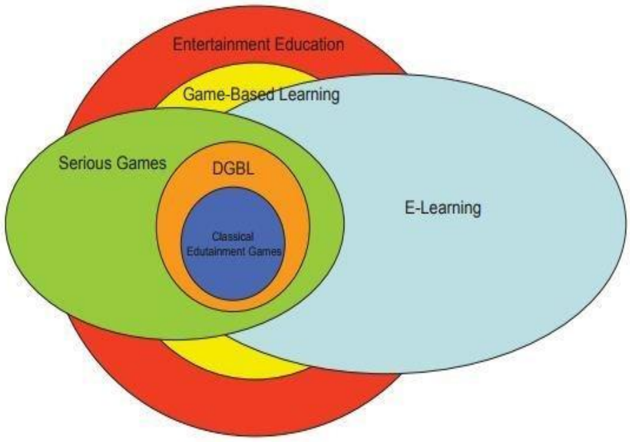


Fig. 2 *The relation between Serious Games and similar educational concepts. (Breuer & Bente, 2010)*

2.1.1 Definition

Regardless of the extensive literature on Serious Games, there is no exact consensus on their definition yet. Literature goes through the characteristics that Serious Games encapsulate rather than formulating an abstract definition for the concept itself. In this study, the definition formulated by Foshay (2014) is used. Foshay, (2014) defines Serious Games as a storyline that promotes the acquisition of a particular knowledge or skill which can be achieved according to the game's rules, challenges, (sub)goals, feedback, and interaction. The characteristics of the Serious Game of this study are explained in detail in the chapter three.

2.1.2 Characteristics

In contrary to the different definitions attributed to Serious Games, remarkably similar characteristics are assigned to them in the literature. Leemkuil (2006) catalogues the components of a Serious Game as a challenging goal, rules and the main model, competitiveness, interaction (feedback), ambiguity, and a fictitious scenario or story. Romero et al. (2014) describe Serious Games by their objectives, competitiveness, (complex) collaborative aspects, category of choices offered to the players, rules, fantasy, and challenges that players need to embrace. Some other dimensions of Serious Games' design according to the first GAMMA training and further elaborated by Schell (2008) can be listed as:

1) **Game Mechanics**: Hunicke et al. (2004) define game mechanics as particular control mechanisms that allow the player to act accordingly in the game environment.

2) **Game Dynamics**: Leemkuil (2006) defines game dynamics as an exploration or discovery in a predefined situation or scenario; players' actions can lead to a new situation or scenario. Hunicke et al. (2004) describe the dynamics in four distinct categories:

a) *Challenge*: created by components like time pressure.

b) *Fellowship*: the actions that take place collaboratively or cooperatively to achieve a goal.

c) *Expression*: if the player is having a direct interaction within the game such as creating a character or adding a building.

d) *Dramatic tension*: if a dynamical component leads to tension, for instance losing or gaining money.

3) **Game Aesthetics:** Hunicke et al. (2004) discuss that the players find some games more appealing or repulsive than others due to aesthetic elements of the games.

2.2 Motivation and Learning Mathematics

Different psychological factors such as feelings, talents, and habits affect the students' success in mathematics courses (Simanihuruk, 2021). Yet, relentlessly most mathematics curricula focus on the arithmetical, reasoning, and logical abilities of the students and tend to neglect their emotions (Piu & Fregola, 2011). In the STEM field, most college students, due to lack of or low intrinsic/extrinsic motivation, struggle with passing the introductory mathematics courses. Thus, it is vital to find methods that not only motivate the students to learn but also help them maintain and regulate their motivation level consistently. It can be achieved by shifting the teaching methods toward a more affectionate and encouraging approach, introducing more challenging and relevant tasks to the students' daily lives, and implementing these tasks in the classrooms effectively (Nguyen & Goodin, 2016).

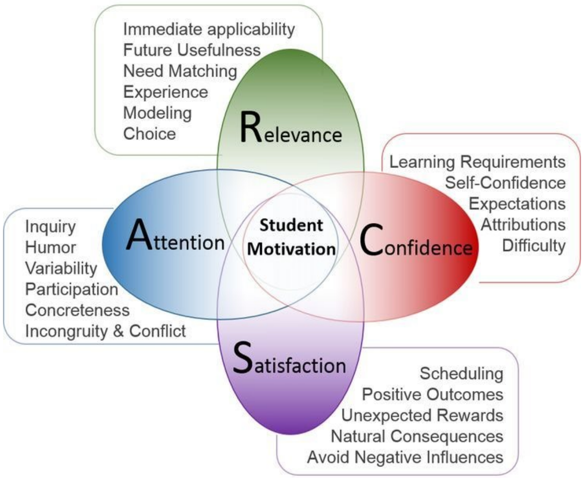


Fig. 3 ARCS Model of Instructional Design (143)

This model was developed in a search for effective and well-structured methods through which motivation to learn can be initiated and subsequently enhanced. The four main categories are:

1. *Attention*: directing attention to the desired stimuli
2. *Relevance*: the directedness of relevance between the content and what is taught
3. *Confidence*: high expectancy in success and achievement and low fear of failure
4. *Satisfaction*: being content with autonomous achievements

Despite some limitations in implementing this model, Keller (1987) concluded that if these four elements are addressed, then the learners will have a higher tendency to become and remain motivated. Nguyen (2011) also argues that there is a direct correlation between the implementation of ARCS in course materials and students' motivation for learning mathematics. Kishore (2018) argued that design of systems based on ARCS model can lead to a positive hope for success and satisfaction rate amongst engineering students. Thanks to the characteristics of the Serious Games, these four elements can be embedded in a game.

2.2.1 Serious Games: Motivating Learning Mathematics

Recently, Serious Games have become popular in the education field for specific domains including mathematics. In contrast to traditional teaching methods, Serious Games are believed to engage and motivate students to acquire deeper knowledge and to develop new skills (Girard et al., 2013). Even though there is no concrete evidence available regarding the effectiveness of Serious Games for learning per se, it is claimed that they match affective and cognitive engagement with motivation which might lead to learning effectively (Annetta et al., 2009).

Professional engineers are assumed and expected to think mathematically and see the relation between what they engineer and the real world. Bigotte et al. (2012) concluded that engineering students (mostly first-year students) experience difficulties, particularly in mathematics courses. More specifically, the rate of failure is extremely high in infinitesimal calculus which leads to not only the demotivation of the students but also the teachers. Additionally, Bigotte et al. (2012) concluded that students lack the basic knowledge, skills, or competencies in mathematics.

Another challenging topic for the students is the correlation between the quantities, functions, and how they behave in different systems (Thompson & Carlson, 2017). To address this issue and promote covariational reasoning for the students, mostly graphing is utilised in mathematics courses. Moore et al. (2013) found that if the students can fully understand a graph, whether in a Cartesian or Polar coordinate system, then they can have a better understanding of the relationships between the quantities, functions, or their behaviours. According to the current curriculum of the Electrical Engineering program, viable comprehension of quantities such as complex numbers or functions are crucial for succeeding in the Network Theory course.

Garris et al. (2002) believe Serious Games provide students with an interactive environment in which they focus on solving problems rather than memorising the information. Garris et al. (2002) emphasise the role of some unique characteristics of instructional computer games (fantasy, rules/goals, sensory stimuli, challenge, mystery, and control) in increasing the degree of motivation for learning. Kors et al. (2015) argue that games are unique media that can result in attitude and behaviour alternation, such as increase in motivation.

To conclude, games can shed light on the possible prospects of learning and add new practices and efficient elements that are missing in traditional mathematics education. The first GAMMA project training articulated that Serious Games could enhance the students' motivation to learn through:

1. *Ownership:* This element of Serious Games provides the learners with autonomy.
2. *Accomplishment:* Serious Games allow the students to monitor what they can accomplish under different circumstances.
3. *Developing a personalised Meaning*: accomplishing the pre-set goals gain importance.
4. *Empowerment:* Serious Games can offer opportunities for self-recovery.
5. *Positive Social Pressure*: while being under social pressure (in)visibly in a classroom to compete, to cooperate, or to collaborate might result in feeling "*less"* than their peers, Serious Games can stimulate the self-confidence by being more engaged differently or remotely.
6. *Avoidance*: while failing in a classroom setting can be mortifying for some learners, Serious Games can facilitate avoiding embarrassment and challenge them to continue.
7. *Unpredictability*: Serious Games can surprise the players which can trigger the players' commitment to the game and learning.
8. *Scarcity*: competing against a deadline or being eager to win a scarce reward.

2.3 Anxiety and Learning Mathematics

The Cambridge Dictionary of Psychology defines anxiety as "a fearful mood that has a vague or no specific focus and is accompanied by bodily arousal" (Matsumoto, 2009, p. 46). Anxiety is very widespread globally and its decapacitation effects on individuals are higher than most psychiatric disorders (Stein & Hollander, 2002). Scholars in the field of education have identified a type of anxiety specific to mathematics decades ago. Richardson and Suinn defined Mathematics Anxiety as "a feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations" (1972, p. 551).

Breuer and Bente (2010) found three reasons why anxiety becomes an impediment to learning and success. The first one is excessive worry; in this case, the student may be engaging in self-criticism excessively, causing them to doubt their own mental capacities. The second one is refraining from producing intellectual work due to the fear of low-quality output. The third one is the utilisation of inefficient and tiring learning methods. Because anxiety can seriously undermine the teaching process, it is crucial for teachers to counterbalance the effects of anxiety. Mathematics Anxiety (MA) in learners might stem from variety of reasons:

parents' approach (Vanbinst et al., 2020; Casad et al., 2015), teachers' attitudes or gender (Stoehr & Olson, 2021; Wood, 1988), cultural and societal labelling and stereotypes (Spangenberg & Putten, 2020; Brown et al., 2020), mathematics exams (Bellinger et al., 2015; Hong & Karstensson, 2002) and/or (lack of) self-efficacy (Samuel & Warner, 2021; Hiller et al., 2021). Thus, addressing Mathematics Anxiety may be considered as an overly complicated task.

Early researchers approached Mathematics Anxiety as a personal characteristic among others and attempted to measure it via different tools in the form of surveys. They demonstrated that mathematical competencies decreased due to this type of anxiety since it prevents the individual's working memory from functioning properly. For instance, Norton et al. (2019) concluded that Mathematics Anxiety forces the working memory to go beyond its limited capacity and work harder than what a mathematical task requires, and as a result, even gifted students with high Mathematics Anxiety perform less competently. Accordingly, it was suggested that students with a high Mathematics Anxiety should be given sufficient time to work on mathematical tasks. Elimination of time pressure and negative feelings would reduce the pressure on their working memory and therefore enhance the opportunity for learning (Figure 4). However, in the Serious Game's, time rather than overwhelming the players brings about a challenge to achieve a more reachable goal in a designated period (Coller & Shernoff, 2009). Additionally, timing a task can help the students to gain experience in time management (Dicheva et al., 2015). Hence, time in games does not create the feeling of pressure as it does in the traditional classroom settings.

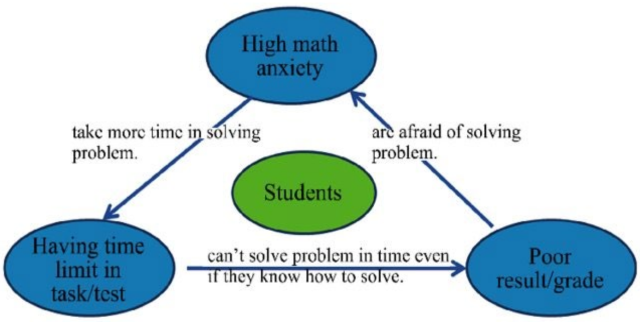


Fig. 4 The vicious cycle of Mathematics Anxiety

Mathematics Anxiety's negative consequences on the students outreach their performance in the classrooms. For instance, Mathematics Anxiety might directly affect the students' future educational or professional choice which is called "avoidance tendency". The students with a high Mathematics Anxiety might prefer a major that does not require any mathematics courses (Ashcraft, 2002). Huang et al. (2019) asserted that female students can have higher Mathematics Anxiety than their male counterparts. This high Mathematics Anxiety has negative impacts on their self-efficacy and consequently, on their future career path. Considering the seriousness of the Mathematics Anxiety problem, a shift from traditional methods to more student-centred approaches, such as Serious Games, seems very promising (Rincon-Flores et al., 2018).

2.3.1 Serious Games: Anxiety in Learning Mathematics

Motivating the students before addressing their apathetic emotions towards mathematics may not be realistic. Negative emotions such as fear, anxiety, or stress affect learning destructively. Hence, the teaching should take place in a way that counterbalances these undesirable feelings and allows the students to develop interest and positive mindsets.

Zettle and Raines (2000) believe that implementation of innovative teaching methods which are process-oriented and focus on comprehension rather than drill-practice methods can reduce anxiety. Moreover, (digital) games can offer deep learning through reflection and active engagement and interaction (Young et al., 2012). Rincon-Flores et al. (2018) suggested that assessing students' mathematical skills and competences via gamification can offer students enjoyable and achievable challenges. In this light, it may be hypothesised that the simulation and the Serious Game of this study can diminish the students' Mathematics Anxiety.

2.4 Focus of the Study

This chapter provided the definition that shapes the Serious Game of this study and explicated its characteristics. It explored the literature to analyse the effects of the Serious Games on the students' degree of motivation and anxiety level while learning mathematics.

After completing the analysis and exploration phase, one main question is formulated to investigate and to find supportive evidences to confirm the accuracy of the hypotheses of this study.

The main question is:

Will playing a simulation and a Serious Game in comparison with traditional teaching methods increase the level of motivation and decrease the degree of anxiety of the first-year Electrical Engineering students at AUAS while learning advanced mathematical subjects?

Addressing the following sub-questions will contribute to answering the central research question:

I. Will playing the simulation and the Serious Game increase the motivation degree of the students for learning complex numbers, and derivatives? (Interest, Probability of success, and Challenge subscales)

II. Will playing the simulation and the Serious Game decrease the anxiety level of the students for learning complex numbers, and derivatives? (Anxiety subscale)

III. Is there a difference in the motivation degree and anxiety level of the students between playing a simulation and Serious Game versus traditional teaching methods?

This phase and these questions outline the design and construction of the game in the next phase.

3 Design and Construction Phase

This chapter focuses on the designing process of the simulation and the Serious Game. For this purpose, the four base-system (Mechanics, Story, Aesthetics, Technology) of Schell (2008) is described and linked to the game structure.

3.1 Current Materials and Learning Goals

Learning goals are imperative for varied reasons. Not only they assist the students to set goals accordingly and to know what to achieve but also the teachers to design their lessons, assignments, activities, and assessment more successfully (Wang et al., 2012). Wang et al. (2012) conclude that formulating clear, measurable, and understandable learning goals is an indispensable step for the students to have a more successful and broader learning process. However, in higher education, sometimes the learning goals are formulated vaguely. Consequently, the students can feel lost and find navigating and regulating their learning journey challenging (Fessl et al., 2021); as it applies to the students of the Network Theory course. The current learning goals for the mathematics part of the course are:

- *The students know complex numbers and can use them in the electrical engineering field*
- *The students know the standard rules of integrals and can apply the rules in calculations required for capacitors and coil*
- *The students know how to do integration by parts and by substitution*[2]

In this study, the learning goals of the games do not completely deviate from the original ones because of the setting of the final assessment. Bloom taxonomy is one of the most widespread taxonomies that teachers benefit from while formulating their learning goals. According to this taxonomy, the learning goals should be broad enough to cover the ultimate goals of the course but more importantly should be measurable. Thus, “know” does not fit these criteria and needs to be replaced with “defines and describes complex numbers,” for instance. The Taxonomy of Significant Learning (Figure 6) was the second taxonomy to formulate the learning goals of the game because it has a strong overlap with the Serious Games’ ideology. According to Fink (2013), students should be challenged and activated to learn significantly.

Figure 5 explains the current relationship between the mathematics courses and how they are taught in the Electrical Engineering program. The Mathematics-1 course is mandatory

[2] **Translated from Dutch**: leer je de nodige wiskundige gereedschappen gebruiken, zoals complexe getallen en integreren, om elektrische netwerken te doorgronden en deze te kunnen doorrekenen.

for all the students enrolled in Engineering Programs of the Faculty. However, the Network Theory Course is offered only to the Electrical Engineering Students.

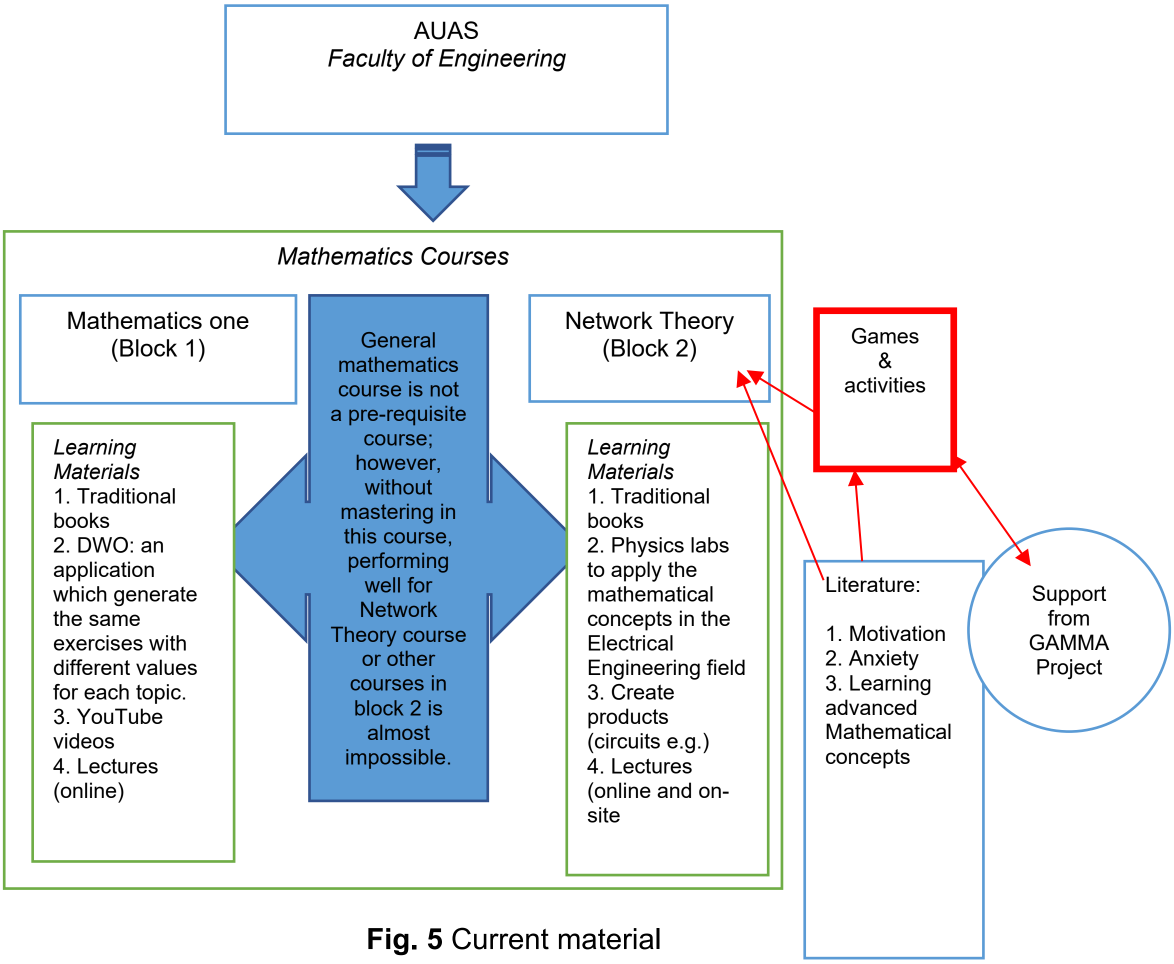


Fig. 5 Current material

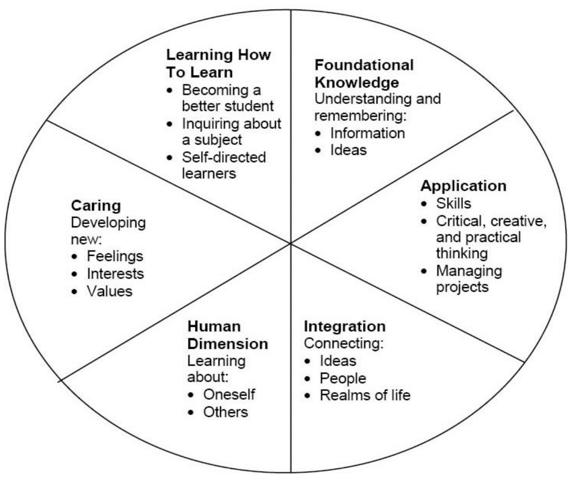


Fig. 6 A Taxonomy of Significant Learning. From: Fink (2013). Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses. (P. 35-37).

3.2 Learning Goals in the Serious Games

Learning goals are like the destination of a journey. By having a clear goal, teachers, students, and designers can make more accurate, effective, and appropriate decisions (Wiggins & McTighe, 1998).

3.2.1 Learning Objectives of the Game

Goals are the fundamental essences of the player(s)' devotion to the game. Two key factors should be considered while formulating the goals: first, the type of educational (or persuasive) objectives and the way they are addressed in the game; second, the purposes that they serve. Leemkuil (2006) categorises the purposes of (learning) goals as:

a) to solve a particular problem or a set of problems
b) to accomplish a task
c) to compete against others and win.

Table 1

Formulation of learning goals in Serious Games in general versus in this study

General situation	In this study
The learning goals of the game can vary per player in some games	*It will be fixed for all the players*
Set at the beginning or open to be set by the players	*Set at the beginning*
Clear, specific, meaningful, and challenging	*In alignment with the current learning goals of the course and Bloom Taxonomy*
The difficulty level should be challenging and complex enough to keep the players motivated and committed to the game	*The complexity of the goals is in accordance with the difficulty level of the actual learning goals of the course*

The didactic learning goals of the game in this study are:

1. Students can analyse the behaviour of the functions and its effect on its "derivative"
2. Students can apply their knowledge of functions
3. Students can construct and design their own functions and work with their derivatives
4. Students can apply their knowledge of derivatives in real-life situations

Students can analyse the importance of maximum, minimum, and turning points in a function (if they exist)

3.2.2 Prior Knowledge

For this game, students must have a substantial knowledge of

1. Functions and their properties
2. Behaviours of functions
3. Domain and range of the functions

3.3 Four Design Foundations and Their Elements in the GAME

Each game has its own unique characteristics because they are built upon different models. These models help the game designers or teachers to have a guideline and monitor the development of the Serious Games that they want to design. The Serious Game of this project is constructed according to the Schell's model (2008; Figure 7). In the following section, each main foundation in addition to the elements of this project's Serious Game are explained categorically.

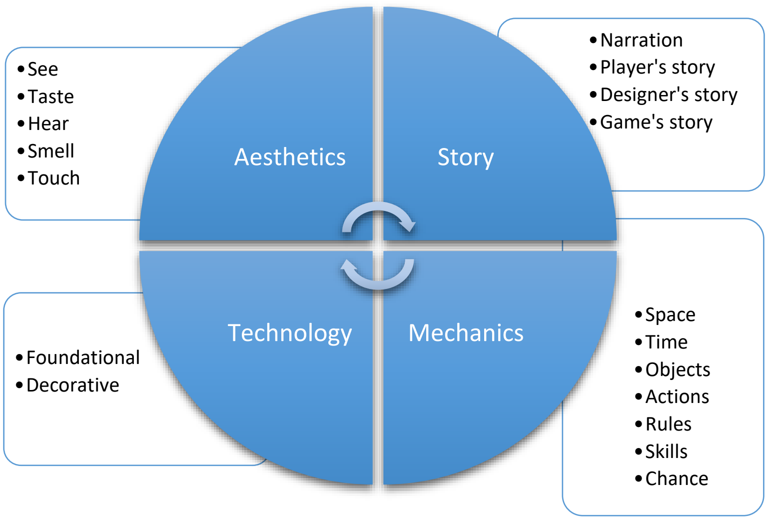


Fig. 7 Four main elements of a game

3.3.1 Mechanics

Mechanics are the outline of the game, regulate the rules of the games, and make the players follow specific procedures (Schell, 2008). They should be clear and not open to interpretation. Mechanics have seven subcategories: space, time, objects, actions, rules, skills, and chance.

1. *Space:* the place where a game happens. Features of the space in the Serious Game of this study are presented in the Table 2.

Table 2

Space subcategory in Serious Games in general versus in this study

Subcategories of "Space"	**General definition/examples**	***Space of the SG in this study***
Discrete or continuous	in the monopoly nested spaces (regions) are discrete while in a pool table, the ball can move freely in the boundaries of the space.	Continuous
Singular or multi-dimensional	the space is 2D or 3D.	2D
Disconnected or connected	nested spaces can be (dis)connected and the objects or events needed for these spaces can remain the same or differ.	no nested space

2. *Time*: it can appear in three separate ways (See Table 3).

Table 3

Time subcategory in Serious Games in general versus in this study

Subcategories of "Time"	**General definition/examples**	***Time in the SG in this study***
Discrete or continuous	Each player must wait for their turn, or a variety of events can happen at the same time. It does not mean that a real clock is embedded in the game space.	Continuous
Clocks and races	a tool that tracks time such as a sand-timer to show a deadline. Player may compete against time or must act faster than their opponents to win; for example, in a soccer game.	Maximum 40 min to complete the task
Controlling time	players can manipulate time. They can have a time-out or if a character dies, it can come back to the game.	They have control over time (section 4.4.2)

3. *Objects*: refer to characters, props, or tokens. Each object has attributes and attributes have states. Objects of Serious Game used in this study are elaborated in the Table 4.

Table 4

Objects subcategory in Serious Games in general versus in this study

Subcategories of "Objects"	**General definition/example**	***Objects of the SG in this study***
Attributes	define and categorise objects, thus are not subject to any changes.	Materials are listed in section 4.4.1.
States	the state of the car or its speed at any moment can vary constantly.	The players cannot change the functions (See Appendix D: attribute), but they are free to choose how to connect them (state).
Secrecy	is another attribute/state of an object in some games.	There is no secrecy about the attributes nor the states of the objects.

4. *Action*: what the players can do, how objects can move, or how the players/objects interact with each other (See Table 5).

Table 5

Actions subcategory in Serious Games in general versus in this study

Subcategories of "Actions"	**General definition/example**	***Actions of the SG in this study***
Basic actions	The players' moves	The players can move. (See section 4.4.2)
Strategic actions	The manipulation of basic actions to achieve the main goal	The students are allowed to manipulate the basic actions. (See section 4.4.2)

5. *Rules*: have five subcategories: rules of the game, modes, enforcers, cheating-possibilities, rewarding (See Table 6).

Table 6

Rules subcategory in Serious Games in general versus in this study

Subcategories of "Rules"	**General definition/example**	***Rules of the SG in this study***

David Parlett's eight different rules (Rojas Millán, 2012)	*Operational*: these rules define the operations of the game; what can be done. *Foundational*: are the mathematical states of the game (subject to change). *Behavioural*: is about the courtesy and respect that players show towards each other. *Written*: is the written on the instruction handout indicating how to execute the game for the players. *Laws*: or "tournament rules" if a special clarification regarding laws is required *Official*: if the written rules and laws are combined based on a special need. *Advisory*: or "rules of strategy" they are the ones that appear as the game proceeds. *House*: or "feedback" are the rules that might emerge if they are missing but are necessary for instance, to make the game more fun.	*Operational*: Applicable *Foundational*: Applicable *Behavioural*: Applicable *Written*: instructions (appendix D) *Laws*: Not Applicable *Official*: Not Applicable *Advisory*: Applicable *House*: Applicable
Modes	Some games can have a main mode and some sub-modes.	One main mode (the board)
Enforcer	Who or what controls the enforcement of the rules and prevents the players from cheating? it can be the space/objects/actions of or an avatar acting as a judge.	Teacher- peers (other groups)
Cheating-ability	The game should be played fairly.	Not Applicable
Rewarding	The most important rule: *how to reach the goal of the game*. Thus, the goal(s) should be clear, reachable, and rewarding.	A bag of m&m chocolate

6. *Skill*: the focus now is on the players rather than the game itself. Players might be expected to have three distinct types of skills (See Table 7).

Table 7

Skills subcategory in Serious Games in general versus in this study

Subcategories of "Skills"	**General definition/example**	***Skills of the SG in this study***
Basic Skills	*Physical*: depending on the games, sometimes the players must be physically strong or be able to do some specific functions.	Not Applicable

	Mental: are particularly important if the players need to make decisions or observe a particular situation to make the next move efficient.	Applicable
	Social: are necessary for cooperating and collaborating with the teammates and competing against the other players.	Applicable
Real versus Virtual	Mostly important for video or digital games.	Not Applicable

7. *Chance:* is the most unique element of the games because it connects math (probability mostly), human psychology and the other 'mechanics' elements (space, time, objects, actions, rules, and skills). Chance beautifies the game by bringing uncertainty and complexity which leads to surprise and fun in a game. Its subcategories are listed in the Table 8.

Table 8

Chance subcategory in Serious Games in general versus in this study

<table>
<tr><th><u>Subcategories of "Chance"</u></th><th>General definition/example</th><th><u>Chances of the SG in this study</u></th></tr>
<tr><td>Probability</td><td>a pure mathematical calculation of an outcome after taking an action.</td><td>The possibility of connecting one of these roads is 1/24.
<table>
<tr><td>1-->2-->3-->4</td><td>2-->1-->3-->4</td><td>3-->2-->1-->4</td><td>4-->2-->3-->1</td></tr>
<tr><td>1-->2-->4-->3</td><td>2-->1-->4-->3</td><td>3-->2-->4-->1</td><td>4-->2-->1-->3</td></tr>
<tr><td>1-->3-->2-->4</td><td>2-->3-->1-->4</td><td>3-->1-->2-->4</td><td>4-->3-->2-->1</td></tr>
<tr><td>1-->3-->4-->2</td><td>2-->3-->4-->1</td><td>3-->1-->4-->2</td><td>4-->3-->1-->2</td></tr>
<tr><td>1-->4-->2-->3</td><td>2-->4-->1-->3</td><td>3-->4-->2-->3</td><td>4-->1-->2-->3</td></tr>
<tr><td>1-->4-->3-->2</td><td>2-->4-->3-->1</td><td>3-->4-->3-->2</td><td>4-->1-->3-->2</td></tr>
</table></td></tr>
<tr><td>Expected value</td><td>It is the quantification of outcomes values. Ex: does an action have a hidden reward or punishment? How would this value affect the game and the players' commitment to the game? (Gaining or losing tokens or money). All these expected values support the balance in the game.</td><td>Not Applicable</td></tr>
<tr><td>The human element</td><td>Despite the rules, pre-estimated probabilities of something (not) happening or other mechanisms that anticipate the actions and their outcomes, it is almost</td><td>Applicable</td></tr>
</table>

	impossible to predict how a player will interact with or feel about the game.	
The entangled skills and chances	Emphasising that sometimes distinction between skills and chances can get intertwined. Calculating the odds about what should/would happen next or interpreting these calculations in favour of the players requires specific skills. Risk-evaluation needs the players to be skilled in making decisions successfully. Observing the opponents' moves, predicting how they would play their hands, and being able to deceive them are hidden but especially important skills. Avoiding seeking patterns in actions and accepting that the players cannot control everything, and some actions or outcomes rely on pure chance.	Students with a better understanding of functions and their behaviour are expected to play more successfully. Students with a better understanding of speed and related topics are expected to make better decisions. Students with higher social and communication skills are expected to collaborate more effectively. students with a better understanding of "self" are expected to choose a more suitable role for themselves and hence, play more enthusiastically. Students with better observational skills are expected to make more efficient use of the game objects and come to better conclusions.

3.3.2 Story

Story (Schell, 2008) is the second step in the game design procedure. It contextualises the game. However, producing a story that triggers the players' interest and invites them to the game world is another challenge for game designers. A story can be developed either during the development process of the game or by the players, thanks to the fantasy aspect of the stories. Fantasy fulfils the desire for a different world, or a non-existent power (fantasy of game). To exemplify, the players can fly, can be invisible, or can create characters of their own choice (actions of games). They can have access to not only extraordinary powers but also imaginary economic systems and currencies (economy of games). In short, the players can fantasise about the storyline, characters, or the story's world even if the designers already predetermine it. Additionally, the stories keep the relevance and complexity level of obstacles or challenges in alignment with the goal of the game.

Yet, all the stories have an important characteristic in common: a hidden cliché (a familiarity). Without this cliché, the players cannot connect to these worlds and might feel lost and therefore lose their interest in the game. The story worlds can be divided into five subcategories (Table 9).

Table 9

Story subcategories in Serious Games in general versus in this study

Subcategories of "Story"	**General definition/example**	***Story of the SG in this study***
Medieval	The time that civilisations were completely different from what we have today.	Not Applicable
Futuristic	A time when the earth is destroyed, and human beings must find a new planet, or it can create a world in which robots have taken over the world and human beings need to combat them.	Not Applicable
War	A place where almost no rules apply.	Not Applicable
Modern	A place like the current world offers the players possibilities that are beyond real life.	Applicable (See Appendix E).
Abstract	Special game worlds where the players have magical powers, for instance.	Not Applicable

3.3.3 Aesthetics

Aesthetics (Schell, 2008) are important because they connect the game to human senses: what they see, hear, touch, smell, or even taste. Aesthetics can offer more than activating the visual and audio channels of the players. It makes the games more enjoyable if they have proper and suitable renderings. For instance, adding music that enthrals the players as they fly to create the feeling of soaring in the sky, not only allows the players to enjoy the game but also feel the game. It will help the players to have a stronger connection with the game story as well. And as a final remark, aesthetics bridges the artistic aspect of the game (visuality, audio, and so forth) with technology. They give life to the robotic dimension of the games and make technology more relatable for the human mind by creating an atmosphere. Aesthetical aspects of the Serious Game designed for this study are explained in the Table 10.

Table 10

Aesthetics of the Serious Game in this study

Object of the game	**Aesthetical Aspect for the SG in this study**
The board of the game	It is appealing to the eye, looks fun to work on; it has buildings, trees, or other nature-related elements to beautify the board but also makes the process challenging.

	It helps the participants visualise how it may look like in real life. It does not overwhelm the players with too many details (not being too colourful).
Cars	The cars are arranged to be different for each team.
Traffic signs	To add a fun element, make the game more relatable to daily life, and more challenging. The parking lot is added to create the “economy system” of the game and to make it more playful.
Audio	Not Applicable

3.3.4 Technology

Technology (Schell, 2008) is the last element in the game tetrad. Technology does not necessarily mean digitalisation. It is merely the medium of a game like the board of a monopoly game. Technology is the element that brings novelty, dazzle, dynamic, and surprise to the game because it is unpredictable for the designers and the players. Technology can be divided into two categories (Table 11).

Table 11

Technology subcategories of the Serious Games in general versus in this study

Subcategories of “Technology”	**General definition/example**	***Technology of the SG in this study***
Foundational	The basis of a new experience	Applicable
Decorative	make the base (experience) more entertaining, fun, colourful or interesting	Applicable

4 Preparation and Implementation Phase

This phase focuses on the steps before and after implementing the simulation and playing the Serious Game, respectively. It also explains the connection between the simulation and the game.

4.1 Connection Between the Simulation and the Game

The purpose of this phase is to prepare the students for playing a Serious Game in the upcoming week. Due to the unfamiliarity of the students with innovative teaching methods, and to eliminate its unexpected impacts on the results of this project, this phase was crucial. The simulation was about the relation between complex numbers and Euler's formula ($e^{ix} = \cos x + i \sin x$)). The students had an introductory lecture about complex numbers, their real and imaginary components, and how to apply the four basic algebraic operations to them in the previous lecture. In the lecture before playing the Serious Game, the simulation helped the students find out about the connection between trigonometric functions, complex numbers and Euler's formula.

This lecture was expected to offer a safe and open classroom climate and to encourage the students to engage. It was designed in such a way that would require the students to think about how to achieve the goal together in addition to how to contribute to the success of each other's learning process. Being able to cooperate and reason together was the essence of coming to a valid conclusion before sharing it with the entire class in this simulation. Unlike in traditional classroom settings where the students listen passively to their teachers, in this lecture, they were expected to take responsibility. They were expected to share their individual opinion, and to express themselves more freely in their own groups (two students in each group). They were expected to gain more experience in teamwork because this activity played a vital role in preparing the students mentally, emotionally, and skilfully for playing the Serious Game.

4.1.1 Simulation: Complex Numbers

One of the earliest known users of complex numbers is Cardan around 1545 while studying the roots of polynomials. Later scholars including Euler were able to solve some problems with the help of the notation *i* and -*i* for the two different square roots of -1 ($i^2 = -1$). This was an extraordinary contribution because the roots of a squared number cannot be negative. Afterward, Wessel and Gauss used "the geometric interpretation of complex numbers as points in a plane." Complex numbers can be written in two different planes:

Cartesian ($z = a + ib$) and Polar ($z = r(cos\theta + i\ sin\theta)$. The component without "*i*" is the real part and the one with "*i*" is the imaginary part. Finally, Hamilton extended the definition and function of complex numbers to the theory of quaternions. That constituted the concept of complex numbers in the modern sense. This notion was abstract and theoretical; however, in the current age of electronics, complex numbers proved to be extremely useful in understanding things that come in waves such as radio and Wi-Fi signals (*A Brief History to Imaginary Numbers*, n.d.). Therefore, the students of Electrical Engineering departments must be able to operate with complex numbers.

With real numbers $k = (\pm n)^2, n \in \mathbb{R}$, "k" will always be positive. Thus, diverting the students' understanding of a number being powered by an even number to have a negative sign ($i^2 = -1$) is a strenuous task for the teachers.

4.1.2 Overview Materials for the Simulation

The materials needed for this simulation (Figure 8) were:

1. *one board,*
2. *one pencil or marker,*
3. *one compass,*
4. *one protractor,*
5. *one triangle ruler,*
6. *one straight ruler,*
7. *3 paper squares,*
8. *1 pin.*

They were intentionally chosen from a mathematical equipment category because:

A. The students were already familiar with the functions of the tools. They were simply considered as a necessity to execute the simulations' steps.

B. For the sake of this project's results, it was important for the author that the students could easily singularise the two methods (simulation versus game). Thus, the tools were expected to demonstrate the purpose of the simulation distinguishably: to let the students know that they will be introduced to a new mathematical topic. Whereas in the game, the mathematical topic is hidden, and the students should discover it by playing the game. Hence, to prevent the creation of a game atmosphere while implementing the simulation in the classroom, these tools were found more suitable.

C. The tools should not bring fun nor an aesthetical element to the simulation; because enjoyment is one of the simulation's outcomes, not one of its main characteristics as it is for the game. Consequently, the tools were selected from a mathematical category.

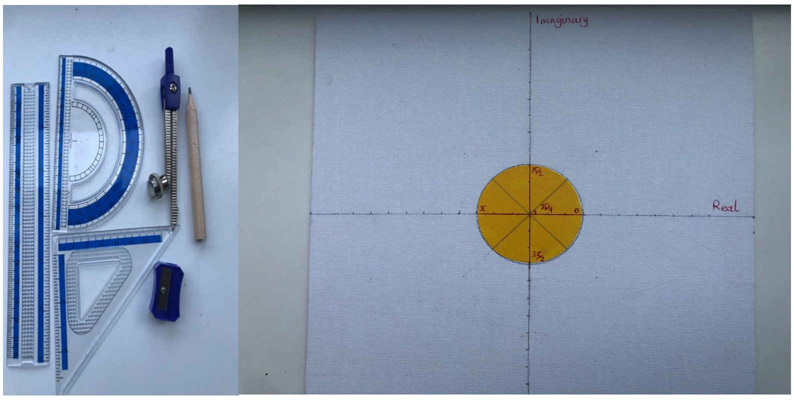


Fig. 8 Materials for the simulation

4.2 Implementing the Simulation in the Classroom

In the classroom, the learning objectives were explained. The materials were delivered to the students. Due to Corona-measurements, they formed groups of two with the peers that were sitting at the same table. At the time, moving around and changing the sitting arrangements for the students could threaten their health. Students were handed the instructions (See Appendix C) and were allowed to begin.

1. The goal of the simulation was hidden in its story (See Appendix C)
2. To start the simulation steps, they needed to find a point on the line that is on the bisect line of the first quartile (45' from x-line and y-line).
    a. Then by rotating this point by 90 degrees find the second one and repeat this process until they have 4 points without doing any calculations.
    b. Write down the coordinates of the points in a complex number form. Not doing any calculations at this stage was important because mathematically, multiplying a complex number by "j" (originally "i") means rotating a complex number by 90'. They were taught about this operation in their previous lecture; yet, they had difficulty imagining why and how.
3. This time, they multiplied each point (A, B, C, D) by "j (i)" as they had been taught in the previous lecture. Afterward, they should try to locate these new points (ex. "$A_1 = A.i$") on their board. Depending on which point they have started with, they could see that the new point is a 90' rotation of the previous point. For instance, if they have

started with A and multiplied it with “j”, the point that they located would be B. The below picture belonged to one group of students.

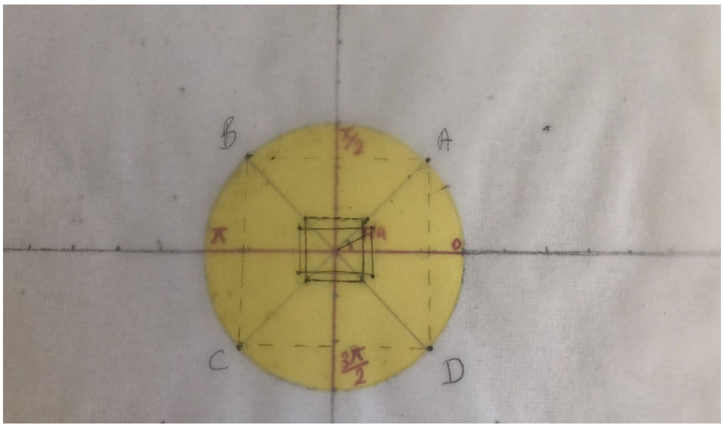


Fig. 9 Work of a group of students on the board: finding the points and the shapes

4. Then they were expected to choose some angles that are smaller and bigger than 45’ such as 30’ and 60’ and repeat the same steps. At the end of this step, they had two different rectangles which helped them understand why angles are related to complex numbers and how they affect them. In the above picture, by choosing the 30’ angle, they found a horizontally laid rectangle, whereas by choosing an angle like 60’ they ended up with a vertical rectangle. This step helped them to understand more deeply about the role of trigonometry in complex numbers.

5. However, since the goal was to find a circle, they needed to find a way to reach this shape. To help the students to succeed, they were given three small square-shaped papers in assorted sizes as shown in Figure 10.

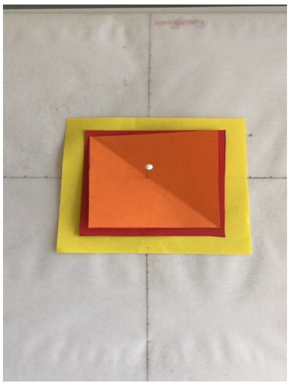


Fig. 10 A group of students’ work on the board: creating the loops

The students were asked to rotate these squares one by one gradually, from the biggest to the smallest and then to increase the number of rotations respectively and mark the rotation points each time. Since the smallest square had the most points, it looked closer to a circle, and it was the first hint for the students regarding what to expect in the next step.

They were expected to produce five loops (circular routes for the airplanes). Rotating these squares and increasing the frequency gradually, already, gave them the hint that they need to reduce the angle of rotation. They could observe that the more frequently they do the rotation, the closer they get to the shape of a circle. On the other hand, they realised that regardless of the frequency, it is almost impossible to create a perfect circle. It raised three important questions for them:

a. If the angle of rotation is 0' to have the smallest angle (change), then there is no rotation at all. How can they solve this paradox? (Mathematically: $\Delta x \to 0$)

b. If it is so small that it is neglectable ($\Delta x \ or \ \varepsilon$), then there is still an angle of rotation which means they are causing a change. How can they address this dilemma? (Mathematically: $\Delta x \to \ 0^{+} \ or \ 0^{-}$)

c. What makes finding the optimum rotation angle so complicated?

Questions a and b led them to discussing the meaning and role of *change* (Δx). For the students' understanding mathematically how change ($\Delta x \ or \ \varepsilon$) can have such a small quantity that is neglectable yet effective was a rewarding moment. This stage prepared them for rules of differentiability, the subject of this project's game.

The students with a stronger foundation in mathematics guessed that the third question might be answered by "π" (π=3.14…): *Since the circumference of a circle is equal to 2.π. r ($C = 2.\pi.r$), and if there is no end for π, then we cannot have a perfect circle, but we can get extremely close to it.* Comprehending the importance of π was a very enlightening moment for all the students and it triggered their interest and curiosity to move forward.

At the end, this simulation helped the students to address some of their misconceptions. They struggle with visualising when a quantity changes, what happens to its covariation. Therefore, graphs could help them to understand the behaviour of a function or to locate the critical points more conveniently as supported by the findings of Palha et al. (2020). Additionally, the students had the opportunity to observe the effects of changes in an angle (quantity) on the components of a complex number (its covariation) (Thompson, 2011). At the end of the simulation, most of the students agreed that they could see the connection between trigonometry, geometry, and complex numbers via this simulation.

4.3 Transition from the Simulation to the Game

Not being able to draw a circle conveniently was significant for bridging this simulation to the game. It directed them to the introduction of notion of "limits" as stated in the definition of the derivative, without going into any details yet. To particularise, they could apply this notation (rate of change) by decreasing the rotating angle gradually from 90' to 1' as shown in the instructions (See Appendix D). Mathematically, it means minimising the delta x (Δx) very close to zero ($\Delta x \ approaches \ 0$) and therefore, its effect on the original function.

4.3.1 Definition of Derivatives

The definition of derivatives (Sengupta, 2021) is

$$as \ a \ function \ of \ x: f'(x) = \lim_{\Delta x \to 0} \frac{f(x + \Delta x) - f(x)}{\Delta x} \ or \ at \ point \ c: f'(c) = \lim_{x \to c} \frac{f(x) - f(c)}{x - c}$$

If this limit exists, then the function can be differentiable at a point, or only from right/left ($\Delta x \to 0^{+} \ or \ 0^{-}$). Derivatives demonstrate the change of one input in respect to another ($\frac{dy}{dx} \ or \ \frac{dx}{dt}$) at a specific position and moment (transition from $\frac{\Delta y}{\Delta x}$ to $\frac{dy}{dx}$). For instance, by calculating the derivative of a function at a specific point (slope of a tangent line), if the function is differentiable at that point, we can decide on how it behaves in a close-by interval. More specifically, we can decide whether the function is increasing or decreasing or how drastically/slowly it is changing.

4.4 Implementing the Serious Game in the classroom

After designing the game and deciding on the elements of the game by the author of this project, it was presented to two other mathematics teachers of the team. The instructions were modified accordingly. Before playing the Serious Game, the students were notified one more time about the purpose of this experiment and were assured that they were not obliged to participate. Additionally, they were assured that participating in the experiment would not affect their final grades since this topic will not be included in the exam.

4.4.1 Overview of Materials for the Game

The materials chosen for this game (Figure 11) are

1. *a board*
2. *2 cars for each group*
3. *traffic signs*:
    a. *1 stop sign*
    b. *1 two-way road sign*

c. *2 traffic cones*

4. *4 roads*
5. *traffic light*
6. *parking slot sign*
7. *instructions*

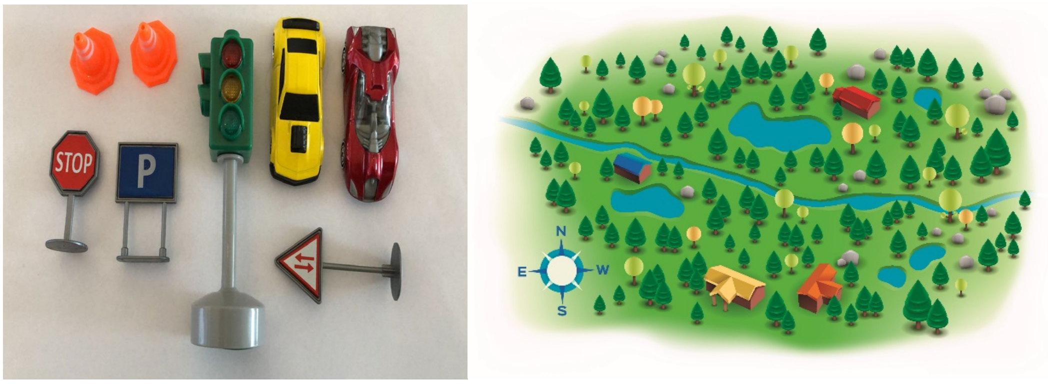


Fig. 11 Materials for the game (Small Landscape Trees and Homes Map stock illustration [Cartoon]. by filo, 2015, iStock.)

4.4.2 Testing the Game in the Classroom

In the classroom, the students formed their own groups. Then, the materials were distributed. Thanks to their previous experience, they could easily appoint the responsibilities and tasks. Additionally, they could organise their steps with more confidence. This time, they could start in approximately five minutes.

1. The first step was to decide which function should be at the beginning. This decision was important because of the functions "$\log_2 x$" and "$\sin x$" (See Appendix D) had parts that are in the fourth quartile (points with negative coordinates). As shown in the placement graph (Figure 12) the position of an object at a particular moment as well as whether the motion is uniform or nonuniform, all must have positive quantities. As a result, the students needed to make sure that time (t), location (x), or velocity/speed (v) did not have a negative value. To do so, they had to consider "absolute value" or to choose a segment of the function that is in the first quartile. For instance, to guarantee positive outcomes for x, t, and v while doing the calculations for the speed limit by applying the derivative roles. This step helped the students to connect their content knowledge in mathematics with the respective topics in physics. s.

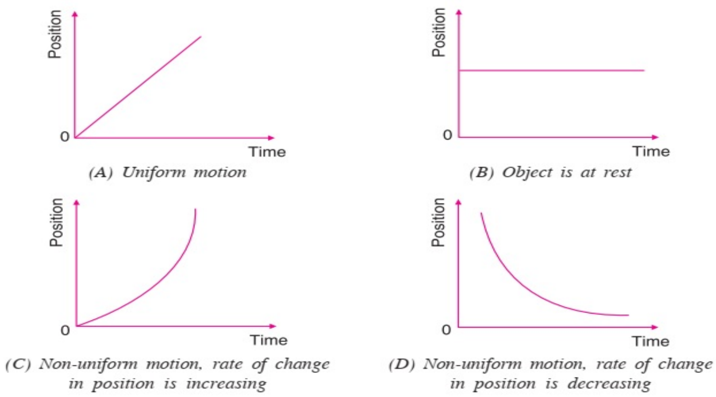


Fig. 12 Placement graphs (Motion, n.d.)

2. The second decision regarding the functions was that the functions should not be tangent to each other especially at the connection point because then the tangent line (f') at that point (ξ) in the new function (adjunct function) cannot be drawn as it is shown in Figure 13. At that point, according to the "Mean Value Theorem" as illustrated by Figure 13, the function (road) is not differentiable at x=0. For the students, in the game, it meant that the cars could not turn to drive on the joint function. Hence, they were not able to drive further and were stuck at that point. Therefore, they had to either choose another function (or another segment of it) to begin with or replace the second function with another one (Figure 14). The students could take notes regarding their try-outs and observations in the table provided in the instruction handout.

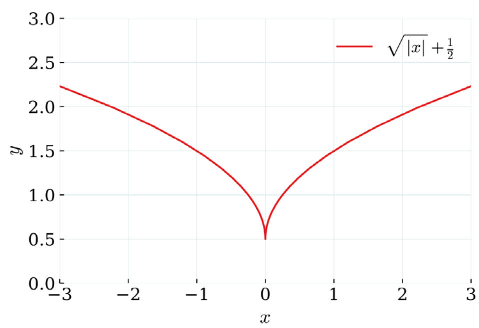


Fig. 13 A continuous function but not differentiable at x=0 ("Differentiable Function," 2021, October 08)

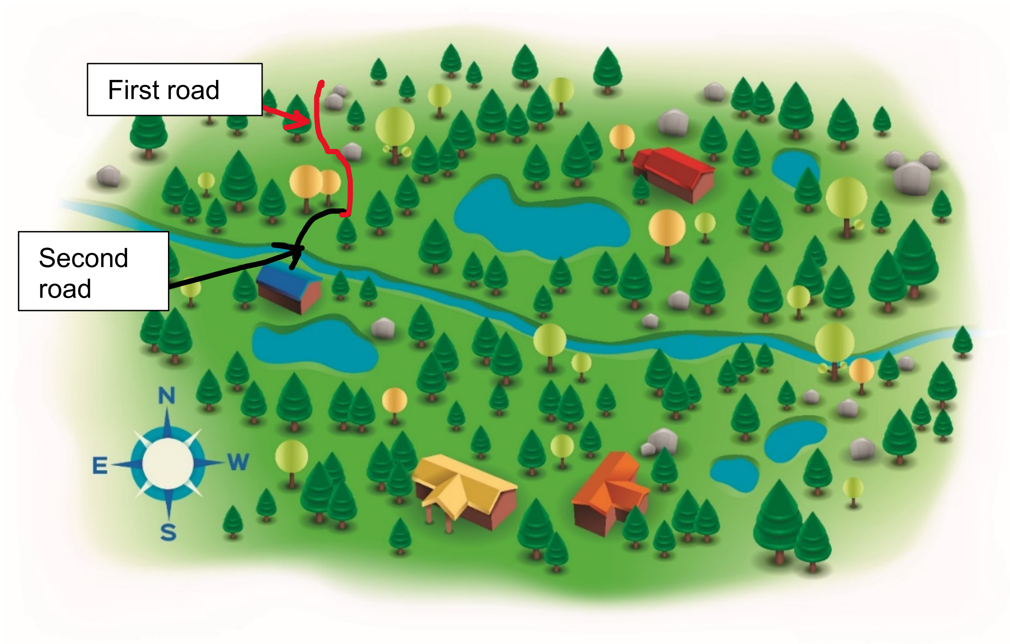


Fig. 14 Example roads on the board

3. As mentioned previously, understanding the importance of critical points (maximum, minimum, or saddle point) is another overwhelming topic. Building up the roads helped the students visualise why these points are important in mathematics by:

a. If there is no turning point as illustrated in Figure 13b, the car cannot move forward (not differentiable). Hence, they needed to adjust the roads or put the stop sign there to indicate that the road is dead-end (differentiable from one/two side(s) but not at that point).

b. If the road is turning drastically, then the chances of an accident happening is the highest; as a result, they should put their traffic lights on such a spot. Because, for instance, the car that is coming from the left part of the road has a small room to manoeuvre thus the possibility of an accident happening is remarkably high at that point; especially if two cars are driving toward each other instantly.

c. They needed the safest place to build the parking lot, so they looked for

i. Where the cars can drive slowly (the function is steady or smoothly increasing or decreasing). For instance, in Figure 15, the best place would be at the end of the roads because along the way there are three turning points.

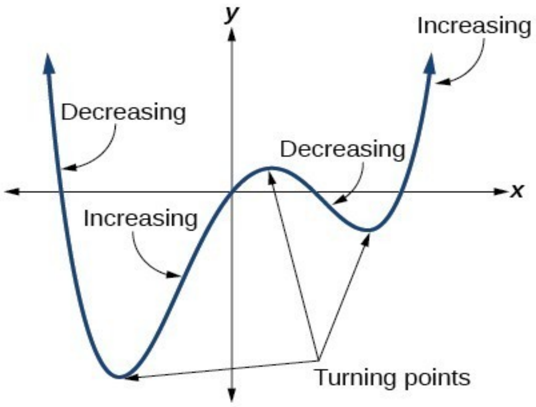


Fig. 15 Behaviour of a function and turning points (Course Hero, n.d.)

ii. The cars at the very end of the graph have an open vision of the road as well as other cars if coming to the parking lot or leaving it. (No turning point at all)

iii. There is no construction or damage in the roads signalled by the traffic cones (discontinuity in the functions unlike point a/b/ or c in the Figure 16). In such areas even though the cars can drive from right and left, at such points they must stop and cannot pass through (Figure 17). The mathematical interpretation of the situation is that the values of the below limits are not equal.

$$\lim_{x \to x_0} f(x) \ , \lim_{x \to x_0+} f(x) , \lim_{x \to x_0-} f(x)$$

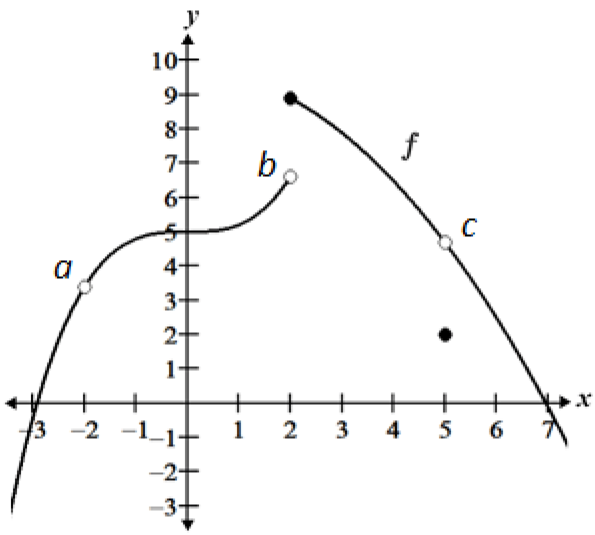


Fig. 16 Discontinuity of a function at a specific point (Discontinuity, n.d.)

Fig. 17 Discontinuity of the roads on the board

iv. If there are any smooth turning points, the roads can be two-way and that is where they should put their two-roads sign (Figure 18). Mathematically it means that in that interval the function is differentiable. Because the limit from both left and right exists and they have equal values to the value of f'(x) at that point.

$$\lim_{x \to a} f(x) = \lim_{x \to a^+} f(x) = \lim_{x \to a^-} f(x) = L$$

Fig. 18 No disjoint or saddle point: cars can drive two-way

4. For the optimal speed limit, the students needed to apply the correct derivative rules for their functions at different points and decide on the

   a. *Average speed*: at this step, students faced some challenges:

      i. Some of the groups forgot to apply the absolute value and ended up with a negative number.

      ii. Some others could not apply the derivatives rules correctly.

      iii. In some groups, the researchers did not know how to have input. For instance, they had difficulty with finding the correct derivative rules. On the contrary, the groups that the researchers were more actively and successfully involved could enjoy doing the calculations. They were proud of their progress and collaboration.

   b. *How dangerous are the roads?*

      i. Should their speed limit be less than average? What should be the fine for over-speeding?

      ii. If the roads are moderately easy to drive on, should their speed limit be greater than the average? What should be the fine for over-speeding or driving too slowly on such roads?

   For the students who have been able to calculate the correct average speed, answering these questions was fun and easy. Some of them decided on an exceedingly high fine for several reasons such as earning more money or deterring the risk. Since there was no clear instruction about the ratio, they randomly assigned a fine.

5. All the speakers of groups presented their plans (roads), explained their calculations, and received feedback from their peers. Even though some performed better than the others, interestingly, it was observed that they showed less anxiety in speaking up even if they have made many mistakes compared to their performance in the simulation lesson. They were more motivated to understand where and why they had made those mistakes.

The mayor (the teacher) chose the winning group. The prize (a bag of M&M chocolate) was delivered to the winners. The last step for the participants was to answer the post-test questionnaire. The teacher (author of this study) collected the post-test questionnaire to be analysed in the next phase.

5 Methodology and Evaluation Phase

This project aimed to answer the main question of whether using a simulation and a Serious Game can have a positive influence on the degree of motivation and the anxiety level of first-year Electrical Engineering students at Amsterdam University of Applied Sciences (AUAS). To do so, three sub-questions were formulated. The first sub-question focused on finding any increase in the level of motivation and the second one explored a potential decrease in the degree of anxiety in the experiment group while learning mathematics via playing a simulation and a Serious Game. The third sub-question compared the effects of the teaching methods (implementing the simulation and the Serious Game versus traditional) on the participants' degree of motivation and anxiety. In this chapter, the participants, research instruments, results, limitations, and recommendations for further investigations are discussed.

Respondents

The respondents in this project were first-year students enrolled in the Network Theory course of the Electrical Engineering department at Amsterdam University of Applied Sciences (AUAS). The students were divided into groups by AUAS for administrative purposes and the teachers were not involved in this process; this study hence assumes that a random distribution of students has taken place. Fifty-eight students out of ninety-five participated in this study: the experiment group (thirty-seven students) was taught via playing a simulation and a Serious Game while the control group (twenty-one students) was taught exclusively via traditional teaching methods.

The students were specifically asked not to provide any personal information on the questionnaires except for their group numbers. The rationale was to protect students' privacy and confidentiality, to prevent any fear of (non)involvement in the project, and to allow them to respond unhesitatingly. Based on the group number, the teaching method could be identified. Therefore, no individual or personal information regarding the students or the teachers was required; the same teacher taught both groups. Additionally, since the focus of this study is on the effectiveness of the simulation and the Serious Game of this study rather than their effect on each individual student, no personal information from the students' side was needed. Furthermore, the Electrical Engineering program coordinator and the Faculty director did not authorize any usage or recording of personal information.

Research Instrument

To measure the students' degree of motivation and anxiety, the Questionnaire on Current Motivation and Anxiety (QCMA) (Appendix A) from the existing literature was used without any adaptation (Rheinberg et al., 2001). The mentioned instrument has been developed by scholars in the field of educational psychology and aims to assess both the levels of motivation and anxiety by using four subscales: the *Challenge, Interest, Probability of success, and Anxiety* (Vollmeyer & Rheinberg, 2006).

a. *Challenge (C)* assesses whether the students find achieving a goal or succeeding in a task particularly important. The Challenge subscale monitors the change in the students' attitude toward understanding the importance of learning mathematics if traditional teaching methods are replaced by playing a simulation and a Serious Game.

b. *Interest (I)* refers to the personal interest of the students in learning a subject. For this project, this subscale evaluates how the simulation and the Serious Game versus traditional teaching methods have changed the students' interest in learning mathematics.

Probability of success (P) evaluates how confident the students feel while doing a task. Task in this project refers to learning mathematics via either traditional teaching methods or playing a simulation and a Serious Game.

c. *Anxiety (A)* represents the fear of failing to achieve a goal or to succeed in a task. This subscale allows us to compare the difference between the anxiety level of the experiment group and the control group.

The items in the QCMA were scored on a 1 (completely disagree) to 5 (completely agree) scale. Several studies have claimed the validity of this questionnaire. For instance, Rheinberg et al. (2001) noted that the scale is well established and convenient to use by showing that the factors were related to learning behaviours and outcomes. The reliability of scales employed with the current research was analysed through computing Cronbach's alpha. Cronbach's alpha is defined as "an index of reliability associated with the variation accounted for by the true score of the underlying construct'' (Santos, 1999, p. 7). An α of 0.6-0.7 indicates an acceptable level of reliability, and an α of 0.8 or greater confirms an exceptionally satisfactory level (Emerson, 2019).

Before the reliability of motivation-anxiety questionnaire was analysed, the third and the fourteenth questions in QCMA were reverse-coded because the verbs of these two items are negative (See Appendix A). Hence, they were reverse-coded to become compatible with the other items of the questionnaire. Reliability analysis on the 18 items of the QCMA scale was conducted for each subscale separately. The Cronbach's alpha was 0.641 for the

"Challenge", 0.640 for the "Interest", 0.598 for the "Probability of Success" and 0.675 for the "Anxiety" subscales. All the Cronbach's alphas are accepted as reliable.

"Task" refers to learning and practicing a new mathematical topic via traditional teaching methods in the pre-test and the post-test questionnaires for the control group. The students were encouraged to consider the below questions while responding to the questionnaires:

Do traditional teaching methods motivate them to learn mathematics? How anxious do they feel about learning mathematics via these methods? Do they feel competent and confident that they have learned the topics successfully after a lecture is conducted based on these methods? Do these methods affect their interest in learning mathematics?

"Task" in the pre-test was defined the same as above for the experiment group. However, in the post-test questionnaire "task" was defined as learning and practicing mathematical topics via playing the simulation and the Serious Game designed for this study. Hence, the students of the experiment group needed to consider these questions when filling in the post-test questionnaire:

Does playing the simulation and the Serious Game motivate them to learn mathematics? How anxious do they feel about learning mathematics via this method? Do they feel competent and confident that they have learned the topics successfully after a lecture is conducted based on this method? Does this method affect their interest in learning mathematics?

5.1 Procedure

This study was conducted over four weeks. Students were informed about the procedure and asked to fill in the pre-test questionnaire in week one. The experiment group played the simulation in week two and the Serious Game in week three. In weeks 2 and 3, control group was taught the same topics via traditional teaching methods by the same teacher. In week four, the post-test questionnaire was distributed to both groups. All responses were quantified and analysed by the SPSS software through simple statistical analysis. A detailed comparison of these sets of data shows the difference between the students' motivation degree and anxiety level while learning mathematics via playing the simulation and the Serious Game of this study versus traditional teaching methods. The results are discussed in sections 5.2 and 5.3.

Methods

In this study, data is analysed by conducting an Independent Sample Test for both groups. Levene's test is considered because the sample sizes are slightly different. This test examines the equality of population variances and the homogeneity assumption (Einspruch, 2005). Based on the Levene's test results, equal variances may or may not be assumed for the experiment and the control groups' participants, and the four main constructs of the pre-test and post-test questionnaires in these groups.

Secondly, since we are interested in comparing the means for two distinct groups (experiment and control), a t-test for independent samples was conducted to evaluate the hypotheses of this study and to see whether there is a relation between the students' motivation and anxiety level and teaching methods (playing a simulation and a Serious Game versus traditional teaching methods). However, a t-test only helps us determine whether there is a significant difference between the mean values of the two groups (Lee, 2016) and not the size of these differences (Lakens, 2022). Lastly, since these benchmarks are unable to show the magnitude of the effect of the difference, analysing Cohen's standards was crucial for this study. Cohen uses three categories to decide on the size of the effect [small (d= 0.2), medium (d= 0.5), large (d= 0.8)] (Sullivan & Feinn, 2012).

Results

The data was scrutinized for any potential extreme outliers to guarantee the reliability of the results. No strong outliers affecting the means of the four main constructs in neither the pre-tests nor in the post-tests results was detected. Afterwards, the data was examined to pinpoint any possible rejection of the null hypothesis.

Homogeneity and t-test results of the Experiment Group

The results suggested that the null hypothesis was not rejected and normal distribution could be assumed within the experiment group for all the constructs. The Levene's test of the Challenge (p= .67) and the Interest subscales (p= .70) showed that equal variances should be assumed. The Levene's test results of the Probability of success (p .06) and the Anxiety (p= .07) subscales had the closest p-value to 0.05; yet, since these values were not less than 0.05, equal variances were assumed for both of these constructs.

The Challenge level of the participants in the experiment group after playing the simulation and the Serious Game has not increased. It indicated that there is no difference between the level of Challenge from the pre-intervention to the post-intervention in the experiment group. The t-test results of this subscale did not reveal meaningful findings after the intervention [t(.72)= -.61 and p= .95].

The Interest level of the participants in learning mathematics from before to after immersing in the simulation and the Serious Game has remained the same; it did not show an increase after participation. The t-test of this subscale resulted in no significant findings as well [t(.72)= -.403 and p=.69].

After playing the simulation and the Serious Game, the Confidence level of the participants in the experiment group regarding learning mathematics has noticeably increased. The t-test results of the Probability of success subscale was able to lead to significant findings [t(.72)= -1.92 and p=0.05].

The anxiety level of the participants in the experiment group has not decreased after immersion in the simulation and the Serious Game. The average level of Anxiety from pre-intervention to post-intervention remained the same for this construct. The t-test of this subscale did not reveal any significant results [t(.72)= -.112 and p= .91].

Homogeneity and t-test results of the Control Group

The results showed that null hypothesis was not rejected and the normality assumption was affirmed for the control group for all of the constructs. For the Challenge subscale (p= .49), the Interest subscale (p= .85), the Probability of success (p=.54), and the Anxiety subscale (p= .45), the Levene's test led to the assumption of equal variances.

After being taught via traditional teaching methods, the initial Challenge degree in the control group's participants has shown a neglectable decrease. The t-test of this subscale did not reveal statistically significant results [t(.40)= .75 and p= .45].

The Interest level of the participants in the control group while learning mathematics has shown a non-significant decrease. The t-test results of this subscale could not yield significant findings either [t(.40)= 1.02) and p= .31].

The Confidence level of the respondents in the control group has shown an insignificant increase after being taught via traditional teaching methods. The t-test results of this subscale failed to reveal meaningful findings as well [t(40)= - 1.05 and p= .30].

The Anxiety level of the participants has increased significantly after following the lectures that were conducted based on the traditional teaching methods. However, the t-test results did not yield meaningful findings [t(.40)= -1.77 and p= 0.08].

Comparison of the Four Subscales in the Experiment Group and the Control Group

Table 12 presents the descriptive statistics of each subscale for the experiment group and the control group from pre-test to post-test.

Table 12

Descriptive statistics of subscales for the experiment group (n=37) and the control group (n=21)

	The experiment group (N=37)	**The control group (N=21)**

	Pre-test	*Post-test*		*Pre-test*	*Post-test*	
	Mean (SD)		*p*	*Mean (SD)*		*p*
Challenge	3.7 (.46)	3.7 (.50)	.95	3.6 (.42)	3.5 (.49)	.45
Interest	3.4 (.62)	3.4 (.65)	.68	3.3 (.45)	3.1 (.45)	.31
Probability of Success	**2.5 (.77)**	**2.9 (1.07)**	**.05**	2.8 (.60)	3.0 (.72)	.30
Anxiety	3.0 (.73)	3.0 (.92)	.91	**2.9 (.78)**	**3.2 (.64)**	**.08**

The initial Challenge level of the participants in both groups were almost equal which indicated the similarity of level among all the participants. Even though after the intervention, the participants in the experiment group showed a higher level in the Challenge subscale than the ones in the control group, it was not statistically meaningful. The Challenge subscale has shown a large p-value and a small Cohen's d-value in both groups. Therefore, no statistically meaningful difference between the two teaching methods in terms of challenging the learners was observed.

Similarly, the Interest subscale had a large p-value and a small Cohen's d-value in both groups. Hence, this subscale also failed to yield statistically meaningful outcomes about the influence of the teaching methods on the learners' interest level in learning mathematics.

On the other hand, the Probability of success subscale results suggested that the participants of the experiment group felt more confident while learning mathematics after immersing in the simulation and the Serious Game in comparison with the control groups' participants. The Cohen's d-value (.45) of this subscale in the experiment group had a medium effect size suggesting a statistically meaningful outcome. The slight increase in the mean value of the Probability of success subscale in the control group is non-significant. Therefore, immersion in the simulation and the Serious Game has resulted in a higher level of confidence while learning mathematics for the participants of the experiment group in comparison with ones in the control group.

In the experiment group, the Anxiety level of the participants after playing the simulation and the Serious Game has not decreased. On the contrary in the control group, a considerable increase in the Anxiety degree of the participants after being taught via traditional teaching methods was detected. However this discrepancy is not statistically meaningful despite having a medium Cohen's d-value (.55). Hence, statistically no considerable difference between the impacts of these teaching methods on the learners' Anxiety level was found.

5.2 Discussion

This study aimed to assess the impact of playing a simulation and a Serious Game in comparison with traditional teaching methods on the level of motivation and the degree of anxiety of first-year Electrical Engineering students at Amsterdam University of Applied Sciences (AUAS) while learning complex numbers and examining differentiability of functions. Three hypotheses were formulated: a) playing the simulation and the Serious Games can increase the motivation level of the students while learning mathematics; b) playing the simulation and the Serious Games can decrease the anxiety degree of the students while learning mathematics; and lastly, c) immersion in a simulation and Serious Game will increase the students' degree of motivation and decrease their level of anxiety while learning mathematics compared to being taught via traditional teaching methods.

The only subscale that was in alignment with the assumption of the first hypothesis was the Probability of success construct. It indicates that the students can feel more confident in learning and practicing mathematics via playing this simulation and Serious Game. This outcome is in alignment with the outcome of similar studies in the literature. For example, Pareto et al. (2011) found that even though playing Serious Games does not necessarily change the students' attitude towards mathematics, it still enhances their self-efficacy. Liu and Koirala (2009) also found out that self-efficacy directly influences the students' confidence in the way they perform mathematical tasks.

Having a higher self-efficacy and confidence may also increase the interest of the students (Vongkulluksn et al., 2018). However, the results of the Interest subscale in this study did not correspond to the findings of Vongkulluksn et al. (2018) in this regard. A potential explanation for the results pertaining to the Interest subscale can be the focus of the game. Breuer and Bente (2010) found that when the fun element of the game is violated, since the focus is on working to learn and not playing to enjoy, the outcomes might be compromised.

The students' reaction to the Challenge subscale did not reveal substantial alteration of attitude and emotions toward learning mathematics either. It might be linked to the lack of relevance of these mathematical concepts to the students' daily and professional life. As Harris et al. (2015) argued the decontextualization of mathematics, especially in the field of engineering, damages the students' perception regarding the pertinence of learning mathematics. If the students cannot connect mathematics to their daily life, it may reduce the importance of learning mathematics for them.

The results of this study did not support the second hypothesis. In other words, playing the simulation and the Serious Game of this study failed to decrease the anxiety degree of the students in the experiment group. This outcome may be explained by the students' mathematical ability which is in alignment with the findings of Vandercruysse et al. (2016). Vandercruysse et al. (2016) emphasised that the outcomes of the Games can vary according to the students' mathematical ability. The participants of this study do not have strong mathematical abilities as it was mentioned in the problem statement (Hogeschool van Amsterdam, n.d.). Thus, it can be deduced that the results of this study failed to find supporting evidence due to the students' inadequate mathematical ability.

The third hypothesis was not confirmed by the obtained data either as no significant differences between the methods was observed. According to the Table 12, none of the motivation constructs (Challenge, Interest, and Probability of success) after the intervention yielded supportive evidence for this hypothesis. Hence, neither playing the simulation and the Serious Game nor traditional teaching methods changed the students' degree of motivation. This may be related to the way that students have been taught before. Consistent with Cusatis and Martin-Kratzer (2009) findings, there is a relation between the teaching methods that students are already familiar with and the way they gain new knowledge. Hence, novelty of the method on the one hand and familiarity with the traditional teaching methods on the other may have affected the results. Consequently, no significant differences between the results of either of the methods in terms of motivation could be deduced.

Similarly, the results of the Anxiety subscale did not reveal any differences between the teaching methods. Even though the mean values pertaining to the participants in the control group suggested that the increase of the anxiety in this group could be meaningful, it was not supported by the results of the t-test. Despite the fact that the Cohen's d-value for the Anxiety construct shown a medium size effect in the control group, the p-value (.08) was not less than .05. Therefore, it was difficult to decide whether there was a meaningful increase in the anxiety level of the participants who were taught via traditional teaching methods in comparison with the ones who played the simulation and the Serious Game. Hence, replication of this study in different settings can bring about more clarifications regarding the results.

5.3 Limitations

This study aimed at investigating the influences of a simulation and a Serious Game on the participants' degree of motivation and anxiety while learning complex numbers and testing the differentiability of functions. The outcomes of the data analyses were not consistent with the hypotheses of the study. Nevertheless, these findings are of interest because these results can initiate further investigation in the field of Serious Games and their effects on mathematical ability and performance of the engineering students in other programs.

Two important aspects of assessment affected the results of this study. Firstly, the alignment between the teaching and the assessment methods was missing. The simulation and the Serious Game were only used to teach, not to assess the knowledge gain. Kiili and Ketamo (2018) found that embedding assessment in games can lead to decreasing test anxiety and increasing engagement. Secondly, since five hundred students must take the same exam annually at the Faculty of Engineering, maintaining an optimal constructive alignment for this study was not possible.

Additionally, this intervention was implemented in two lectures. Understanding the impacts of an intervention needs to take place over longer periods. Several studies have found out that the duration of the process can influence the outcomes. For example, Mavridis et al., (2017) underline the importance of the continuation of the learning process via games. Rincon-Flores et al. (2018) also emphasize having a “consistent didactic task” to facilitate the application of gamification continually in the curriculum. Therefore, playing a simulation and a Serious Game in only one or two lectures is insufficient to draw strong conclusions.

Moreover, there might be a link between the findings of this study and the teaching efficacy because the same teacher taught both groups. Several studies have found that teachers can affect the level of students’ mathematics anxiety directly. For instance, Alsup (2005) found out the students’ mathematics anxiety was more influenced by the teachers’ attitude than the teaching methods being investigated (constructivist versus traditional teaching method in mathematics education). Thus, we can conclude that no difference between playing the simulation and the Serious Game versus traditional teaching methods could be found due to the impact of the teaching efficacy.

5.4 Recommendations for Further Research

To better evaluate the effects of the simulation and the Serious Game on the motivation degree and anxiety level of the learners, constructive alignment should be maintained. In this project, the mathematical topic of the game was not included in the assessment. For this reason, students could participate in this project voluntarily, which reduced the possibility of manipulation of the results as emphasized by Breuer and Bente (2010) that the students should not feel obligated to play. Nonetheless, one negative result of voluntary participation was the non-inclusion of the topic in the assessment, which possibly led to a loss of motivation within the learners to achieve the learning goals. Consequently, a recommendation for future projects is to add the topic in the assessment to increase the importance of learning the topic and interest in achieving the learning goals for the students.

Additionally, the implementation of the simulation and the Serious Game should take place in a process rather than singular experiments in two lectures to have more reliable results regarding their effects on the students’ motivation and anxiety. Garris et al. (2002) emphasise the importance of using games in a process to reach the desired learning outcomes. Hence, it is recommended to replace the traditional teaching methods in a course for an entire block or semester.

The effects of Serious Games on motivation and anxiety of students can also be explored by digitalisation of the game. This can help the students to practice more intrinsically and have a deeper understanding of the topic (Coller & Shernoff, 2009; Garris et al., 2002). Nevertheless, the effects of digital games on the students' motivation and anxiety levels can differ from analogue games. Thus, further investigation in a digital environment is recommended.

Lastly, the effect of the simulation and the Serious Game was not investigated for each individual participant before and after the intervention. In this project, the program directors did not authorize using the students' personal information. Hence, it was not possible to do a more detailed investigation regarding the effectiveness of the methods in question for each participant separately. The only information regarding the students was to which group they were assigned. Thus, further investigation can be conducted to explore the effects of the individual learners' motivation and anxiety degrees while learning mathematics via these methods.

5.5 Conclusion

This project hypothesised that playing the simulation and the Serious Games will increase the motivation degree of the students and decrease their anxiety level while learning mathematics. One simulation and one game were designed to assess the effectiveness of this teaching method on the students' emotions while learning mathematics. According to the data obtained, this simulation and Serious Game could not increase the motivation degree or decrease the anxiety level of the students. Lastly, no noticeable difference between the impacts of the traditional teaching methods versus immersion in the simulation and the Serious Game on the students' motivation and Anxiety was found.

6 Reference List

A brief history to imaginary numbers. (n.d.). BBC Science Focus Magazine. Retrieved January 14, 2021, from https://www.sciencefocus.com/science/a-brief-introduction-to-imaginary-numbers/

Alsup, J. (2005). A Comparison of Constructivist and Traditional Instruction in Mathematics. *EDUCATIONAL RESEARCH QUARTERLY*, *28*(4), 3–17. WorldCat.org.

Annetta, L. A., Minogue, J., Holmes, S. Y., & Cheng, M.-T. (2009). Investigating the impact of video games on high school students' engagement and learning about genetics. *Computers & Education*, *53*(1), 74–85. https://doi.org/10.1016/j.compedu.2008.12.020

Ashcraft, M. H. (2002). Math Anxiety: Personal, Educational, and Cognitive Consequences. *Current Directions in Psychological Science*, *11*(5), 181–185. https://doi.org/10.1111/1467-8721.00196

Bigotte, E., Fidalgo, C., & Rasteiro, D. (2012a). *Understanding the Difficulties in Mathematics of Engineering Students in the Transition from High School to Higher Education*.

Bigotte, E., Fidalgo, C., & Rasteiro, D. (2012b). *Understanding the Difficulties in Mathematics of Engineering Students in the Transition from High School to Higher Education*.

Binary logarithm. (2022). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Binary_logarithm&oldid=1076848920

Boaler, J. (2002). *Experiencing School Mathematics: Traditional and Reform Approaches to Teaching and Their Impact on Student Learning*. Routledge.

Breuer, J., & Bente, G. (2010). Why so serious? On the relation of serious games and learning. *Journal for Computer Game Culture*, *4 (1)*, 7–24.

Brown, J., Ortiz-Padilla, M., & Soto-Varela, R. (2020). Does Mathematical Anxiety Differ Cross-Culturally? *Journal of New Approaches in Educational Research*, *9*, 126–136. https://doi.org/10.7821/naer.2020.1.464

Casad, B., Hale, P., & Wachs, F. (2015). Parent-Child Math Anxiety and Math-Gender Stereotypes Predict Adolescents' Math Education Outcomes. *Frontiers in Psychology*, *6*, 1597. https://doi.org/10.3389/fpsyg.2015.01597

Coller, B. D., & Shernoff, D. J. (2009). Video Game-Based Education in Mechanical Engineering: A Look at Student Engagement*. *International Journal of Engineering Education*, *25*, 308–317.

Coller, B., & Shernoff, D. (2009). Video Game-Based Education in Mechanical Engineering: A Look at Student Engagement. *International Journal of Engineering Education*, *25*.

Course Hero. (n.d.). Retrieved June 24, 2022, from https://www.coursehero.com/study-guides/ivytech-collegealgebra/understand-the-relationship-between-degree-and-turning-points/

Cusatis, C., & Martin-Kratzer, R. (2009). Assessing the State of Math Education in ACEJMC-accredited and Non-accredited Undergraduate Journalism Programs. *Journalism & Mass Communication Educator*, *64*(4), 355–377. https://doi.org/10.1177/107769580906400402

Dicheva, D., Dichev, C., Agre, G., & Angelova, G. (2015). Gamification in Education: A Systematic Mapping Study. *Educational Technology & Society*, *18*, 75–88.

Differentiable function. (2021). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Differentiable_function&oldid=1048851162

Discontinuity. (n.d.). Retrieved June 24, 2022, from https://www.math.net/discontinuity

Divjak, B., & Tomić, D. (2011). The impact of game-based learning on the achievement of learning goals and motivation for learning mathematics—Literature review. *Journal of Information and Organizational Sciences*, *35*, 15–30.

Einspruch, E. L. (2005). *An introductory guide to SPSS for Windows* (2nd ed., Vol. 1–1 online resource (ix, 145 pages) : illustrations). Thousand Oaks, Calif. Sage Publications; WorldCat.org. http://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=3032277

Emerson, R. W. (2019). Cronbach's Alpha Explained. *Journal of Visual Impairment & Blindness*, *113*(3), 327–327. https://doi.org/10.1177/0145482X19858866

Even/Odd Functions. (n.d.). Retrieved December 2, 2021, from https://www.varsitytutors.com/hotmath/hotmath_help/topics/even-odd-functions

Fessl, A., Maitz, K., Dennerlein, S., & Pammer, V. (2021). *The Impact of Explicating Learning Goals on Teaching and Learning in Higher Education: Evaluating a Learning Goal Visualization* (pp. 1–15). https://doi.org/10.1007/978-3-030-86436-1_1

Fink, L. D. (2013). *Creating significant learning experiences: An integrated approach to designing college courses* (Revised and updated edition). San Francisco. Jossey-Bass.

Foshay, W. (2014). *What Makes Serious Games Effective? 5 Questions to Ask When Evaluating Serious Games in the Workplace*.

Garris, R., Ahlers, R., & Driskell, J. (2002). Games, Motivation, and Learning: A Research and Practice Model. *Simulation & Gaming*, *33*, 441–467. https://doi.org/10.1177/1046878102238607

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning*, *29*. https://doi.org/10.1111/j.1365-2729.2012.00489.x

Harris, D., Black, L., Hernandez-Martinez, P., Pepin, B., Williams, J., & Team, with. (2015). Mathematics and its value for engineering students: What are the implications for teaching? *International Journal of Mathematical Education in Science and Technology*, *46*. https://doi.org/10.1080/0020739X.2014.979893

Hiller, S., Kitsantas, A., Cheema, J., & Poulou, M. (2021). Mathematics anxiety and self-efficacy as predictors of mathematics literacy. *International Journal of Mathematical Education in Science and Technology*, 1–19. https://doi.org/10.1080/0020739X.2020.1868589

Hoffman, B. (2015). *Motivation for learning and performance*. Boston. Elsevier Academic Press.

Hogeschool van Amsterdam. (n.d.). *Engineering Studiekeuze*. Retrieved December 2, 2020, from https://www.hva.nl/binaries/content/gallery/programmes/ft/studieincijfers/2020/toelichting/engineering-tl.png

Hong, E., & Karstensson, L. (2002). Antecedents of State Test Anxiety. *Contemporary Educational Psychology*, *27*(2), 348–367. https://doi.org/10.1006/ceps.2001.1095

Huang, X., Zhang, J., & Hudson, L. (2019). Impact of math self-efficacy, math anxiety, and growth mindset on math and science career interest for middle school students: The gender moderating effect. *European Journal of Psychology of Education*, *34*(3), 621–640. https://doi.org/10.1007/s10212-018-0403-z

Hunicke, R., Leblanc, M., & Zubek, R. (2004). MDA: A Formal Approach to Game Design and Game Research. *AAAI Workshop - Technical Report*, *1*.

K. Kiili & H. Ketamo. (2018). Evaluating Cognitive and Affective Outcomes of a Digital Game-Based Math Test. *IEEE Transactions on Learning Technologies*, *11*(2), 255–263. https://doi.org/10.1109/TLT.2017.2687458

Keller, J. (1987). Development and Use of the ARCS Model of Instructional Design. *Journal of Instructional Development*, *10*, 2–10. https://doi.org/10.1007/BF02905780

Kishore, A. (2018). Application of ARCS Model and Motivational Design in Engineering Subjects – A Case Study. *International Journal of Mechanical and Production Engineering Research and Development*, *8*, 27–34. https://doi.org/10.24247/ijmperdfeb20184

Kors, M. J. L., van der Spek, E. D., & Schouten, B. A. M. (2015). A foundation for the persuasive gameplay experience: 10th International Conference on the Foundations of Digital Games (FDG 2015), June 22-25, 2015, Pacific Grove, CA, USA. *Proceedings of the 10th Annual Foundations of Digital Games Conference*.

Lakens, D. (2022). Why P values are not measures of evidence. *Trends in Ecology and Evolution*, *37*(4), 289–290. WorldCat.org.

Lee, D. K. (2016). Alternatives to P value: Confidence interval and effect size. *Korean Journal of Anesthesiology*, *69*(6), 555–562. PubMed. https://doi.org/10.4097/kjae.2016.69.6.555

Leemkuil, H., & Harmanus, H. (2006). *Is it all in the game? : Learner support in an educational knowledge management simulation game /*.

Liu, X., & Koirala, H. (n.d.). *The Effect of Mathematics Self-Efficacy on Mathematics Achievement of High School Students*. 15.

Logarithmic Functions and Their Graphs. (n.d.). Retrieved December 2, 2021, from https://saylordotorg.github.io/text_intermediate-algebra/s10-03-logarithmic-functions-and-thei.html

Matsumoto, D. R. (Ed.). (2009). *The Cambridge dictionary of psychology*. Cambridge University Press.

Mavridis, A., Katmada, A., & Tsiatsos, T. (2017). Impact of online flexible games on students' attitude towards mathematics. *Educational Technology Research and Development*, *65*(6), 1451–1470. https://doi.org/10.1007/s11423-017-9522-5

McKenney, S., & Reeves, T. C. (2014). Educational Design Research. In J. M. Spector, M. D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of Research on Educational Communications and Technology* (pp. 131–140). Springer New York. https://doi.org/10.1007/978-1-4614-3185-5_11

Moore, K., Paoletti, T., Gammaro, J., & Musgrave, S. (2013). *Covariational reasoning and graphing in polar coordinates*.

Motion. (n.d.). Retrieved June 24, 2022, from https://www.studypage.in/general-science/motion

Nguyen, G.-N. (2011). *Teacher Knowledge of Students and Enactment of Motivational Strategies in Teaching the Concept of Function*.

Nguyen, G.-N., & Goodin, J. (2016). Bringing Students Back to Mathematics: Classroom Knowledge and Motivation. *Journal of Humanistic Mathematics*, *6*, 47–83. https://doi.org/10.5642/jhummath.201602.06

Norton, A., Seok, Y., & Choi-Koh, S. (2019). Examining Mathematics Anxiety of Undergraduates Using a Brain-Based Measurement, EEG. *Journal of Behavioral and Brain Science*, *09*, 195–209. https://doi.org/10.4236/jbbs.2019.95017

Novianti, Martadiputra B.A.P., Priatna N., & International Conference on Mathematics and Science Education 2019, Icms. 2019. (2020). Mathematical connection ability of middle school students in solving quadrilateral. *Journal of Physics: Conference Series*, *1521*(3). WorldCat.org. https://doi.org/10.1088/1742-6596/1521/3/032099

Palha, S., Bouwer, A., Bredeweg, B., & Keulen, S. (2020). Self-construction and Interactive Simulations to Support the Learning of Drawing Graphs and Reasoning in Mathematics. In V. Kumar & C. Troussas (Eds.), *Intelligent Tutoring Systems* (pp. 364–370). Springer International Publishing.

Pareto, L., Arvemo, T., Dahl, Y., Haake, M., & Gulz, A. (2011). A Teachable-Agent Arithmetic Game's Effects on Mathematics Understanding, Attitude and Self-efficacy. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial Intelligence in Education* (pp. 247–255). Springer Berlin Heidelberg.

Piu, A., & Fregola, C. (2011). *Simulation and Gaming for Mathematical Education: Epistemology and Teaching Strategies*. https://doi.org/10.4018/978-1-60566-930-4

Rheinberg, F., Vollmeyer, R., & Burns, B. (2001). QCM: A questionnaire to assess current motivation in learning situations. *Diagnostica*, *47*.

Richardson, F. C., & Suinn, R. M. (1972). The Mathematics Anxiety Rating Scale: Psychometric data. *Journal of Counseling Psychology*, *19*(6), 551–554. https://doi.org/10.1037/h0033456

Rincon-Flores, E. G., Gallardo, K., & Fuente, J. M. de la. (2018). Strengthening an Educational Innovation Strategy: Processes to Improve Gamification in Calculus Course through Performance Assessment and Meta-evaluation. *International Electronic Journal of Mathematics Education*, *13*(1). https://doi.org/10.12973/iejme/2692

Romero, M., Usart, M., & Ott, M. (2014). Can Serious Games Contribute to Developing and Sustaining 21st-Century Skills? *Games and Culture: A Journal of Interactive Media*, *10*. https://doi.org/10.1177/1555412014548919

Santos, J. R. A. (1999). Cronbach’s alpha: A tool for assessing the reliability of scales. *1999/4*, *37*(2).

Schell, J. (2008). The Art of Game Design: A book of lenses. In *The Art of Game Design: A Book of Lenses*. https://doi.org/10.1201/9780080919171

Sengupta, A. (2021). *Introductory Calculus Notes*.

Simanihuruk, S., & Nasution, A. (2021). *PSYCHOLOGICAL FACTORS IN LEARNING MATHEMATICS*.

Sine and cosine. (2022). In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Sine_and_cosine&oldid=1094302899

Siregar, R., & Daut Siagian, M. (2019). Mathematical connection ability: Teacher's perception and experience in learning. *Journal of Physics: Conference Series*, *1315*(1), 012041. https://doi.org/10.1088/1742-6596/1315/1/012041

Small rural landscape with trees, lakes, rivers and homes from above... (n.d.). iStock. Retrieved December 1, 2021, from https://www.istockphoto.com/nl/vector/small-landscape-trees-and-homes-map-gm465110134-59597778

Spangenberg, E., & Putten, S. (2020). RELATING ELEMENTS OF MATHEMATICS ANXIETY WITH THE GENDER OF PRESERVICE MATHEMATICS TEACHERS. *Gender and Behaviour*, *18*, 15631–15641.

Spector, J. Michael. (2014). *Handbook of research on educational communications and technology* (4th ed., Vol. 1–1 online resource (xxxv, 1005 pages) : illustrations (some color)). New York, N.Y. Springer; WorldCat.org. https://doi.org/10.1007/978-1-4614-3185-5

Stein, D. J., & Hollander, E. (Eds.). (2002). *The American Psychiatric publishing textbook of anxiety disorders* (1st ed). American Psychiatric Pub.

Stoehr, K., & Olson, A. (2021). Elementary prospective teachers' visions of moving beyond mathematics anxiety. *Mathematics Education Research Journal*. https://doi.org/10.1007/s13394-021-00379-6

Sullivan, G. M., & Feinn, R. (2012). Using Effect Size-or Why the P Value Is Not Enough. *Journal of Graduate Medical Education*, *4*(3), 279–282. PubMed. https://doi.org/10.4300/JGME-D-12-00156.1

Tarnopolsky, Oleg. (2012). *Constructivist blended learning approach: To teaching English for specific purposes* (Vol. 1–1 online resource (text (254 pages)) : illustrations). London. Versita; WorldCat.org. http://www.degruyter.com/viewbooktoc/product/205438

The Elements of Game Design. (2012, July 5). *Lakitu's Dev Cartridge*. https://lakitusdevcartridge.wordpress.com/2012/07/05/the-elements-of-game-design/

Thompson, P. (2011). Quantitative reasoning and mathematical modeling. In *New perspectives and directions for collaborative research in mathematics education* (pp. 33–57).

Thompson, P., & Carlson, M. (2017). *Variation, covariation, and functions: Foundational ways of thinking mathematically* (pp. 421–456).

Turner, P., Johnston, E., Kebritchi, M., Evans, S., & Heflich, D. (2018). Influence of Online Computer Games on the Academic Achievement of Nontraditional Undergraduate Students. *Cogent Education*, *5*. https://doi.org/10.1080/2331186X.2018.1437671

Vanbinst, K., Bellon, E., & Dowker, A. (2020). Mathematics Anxiety: An Intergenerational Approach. *Frontiers in Psychology*, *11*. https://doi.org/10.3389/fpsyg.2020.01648

Vandercruysse, S., Vrugte, J., Jong, T., Wouters, P., Oostendorp, H., Verschaffel, L., Moeyaert, M., & Elen, J. (2016). The effectiveness of a math game: The impact of integrating conceptual clarification as support. *Computers in Human Behavior*, *64*, 21–33. https://doi.org/10.1016/j.chb.2016.06.004

Vaz de Carvalho, C., González González, C., Popescu, E., & Rugelj, J. (2021). *Serious Games*. https://doi.org/10.3389/978-2-88966-944-8

Vollmeyer, R., & Rheinberg, F. (2006). Motivational Effects on Self-Regulated Learning with Different Tasks. *Educational Psychology Review*, *18*, 239–253. https://doi.org/10.1007/s10648-006-9017-0

Vongkulluksn, V. W., Matewos, A. M., Sinatra, G. M., & Marsh, J. A. (2018). Motivational factors in makerspaces: A mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions. *International Journal of STEM Education*, *5*(1), 43. https://doi.org/10.1186/s40594-018-0129-0

Wang, T., Lan, M.-C., Giamellaro, M., derek, Z., Birkby, E., & Ruiz-Primo, M. (2012). *Knowledge of Learning Goals as a Navigation Tool in Curriculum Implementation*.

Wiggins, G., & McTighe, J. (1998). What is backward design? *Understanding by Design*, 7–19.

Wood, E. F. (1988). Math Anxiety and Elementary Teachers: What Does Research Tell Us? *For the Learning of Mathematics*, *8*(1), 8–13. JSTOR.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). Our Princess Is in Another Castle: A Review of Trends in Serious Gaming for Education. *Review of Educational Research*, *82*(1), 61–89. https://doi.org/10.3102/0034654312436980

Zettle, R., & Raines, S. J. (2000). The relationship of trait and test anxiety with mathematics anxiety. *College Student Journal*, *34*, 246–258.

7 Appendices

Appendix A- The Questionnaire

Group:

Questions QCM Scale	Answers				
	Completely disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Completely agree (5)
1. I like riddles and puzzles. (I)					
2. I think I am up to the difficulty of this task. (P)					
3. I won't manage to do this task. (P−)					
4. While doing this task I will enjoy playing the role of a scientist who is discovering relationships between things. (I)					
5. I feel under pressure to do this task well. (A)					
6. This task is a real challenge for me. (C)					
7. After having read the instructions, the task seems to be very interesting to me. (I)					
8. I am eager to see how I will perform in the task. (C)					
9. I'm afraid I will make a fool out of myself. (A)					
10. I'm really going to try as hard as I can on this task. (C)					
11. For tasks like this I don't need a reward, they are lots of fun anyhow. (I)					
12. It would be embarrassing to fail at this task. (A)					

13. I think everyone could do well on this task. (P)	
14. I think I won't do well at the task. (P−)	
15. If I can do this task, I will feel proud of myself. (C)	
16. When I think about the task, I feel somewhat concerned. (A)	
17. I would work on this task even in my free time. (I)	
18. I feel petrified by the demands of this task. (A)	

Appendix B- GAMMA Project at Amsterdam University of Applied Sciences

In the GAMMA project, we aim to develop teacher competencies in Game-Based Learning (GBL) and encourage teachers to apply digital technologies in their practice. The first GAMMA training contributes to these aims by offering a varied programme of training activities about GBL. In total there are three plenary sessions, two workshops, four working sessions, and three discussion group sessions.

Appendix C- Instructions for the Simulation (Euler's Formula)

The learning context.

Imagine you are working for an airline company. On a special occasion, five airplanes at the same time will fly on five different *circular* routes: three of them clockwise and two counter-clockwise. They will throw money all over the city. Your bosses call you to their office and ask you and your partner to produce appropriate routes.

The learning objectives of this course

You will learn how to

1. rotate a point 90 degrees (multiplying by j)
2. pinpoint negative and positive degrees
3. convert a complex number into its polar form
4. not only perform but also justify the operations with complex numbers

The learning procedure.

Hints from previous lessons: $j^2 = -1$, r =, $\theta = \tan^{-1}(\frac{y}{x})$

1. Please select a point on the board that is at 45 degrees angle and name it "point A". Write its coordinate here.
2. Without any calculations rotate this point by 90 degrees on the board. Name it "point B." Write its coordinate here.
3. Without any calculations rotate this point by 90 degrees on the board. Name it "point C." Write its coordinate.
4. Without any calculations rotate this point by 90 degrees on the board. Name it "point D." Write its coordinate.

If you connected them, what kind of shape would you have?

5. Now please check your answers by multiplying points A, B, C, and D by "j". What do you see?

A.j=

B.j=

C.j=

D.j=

6. Now please check the angles that points A, B, C and D are on and call them A_1, B_1, C_1, D_1.

7. Put each of those angles (A_1, B_1, C_1, D_1) in this equation $\cos\theta + j\ \sin\theta$. You will have 4 new points and name them A_1, B_1, C_1, D_1. (Ex: = 0.93+0.34j, either form is acceptable)

8. Find these points on the board. What do you see? Is there any relation between A_1, B_1, C_1, D_1 and where the original points A, B, C, and D stand?

If you connected them, what kind of shape would you have?

9. please try to find new points by using

   a.

   b.

   c.

   d.

and then rotate them each separately 90 degrees (the same way you did to find A, B, C and D)

10. Have you been able to see your circular routes yet? What would be the solution?

11. Now find the centre of your colourful squares. Pile your papers from the biggest (at the bottom) to the smallest (on top) by passing your pin through them. Put

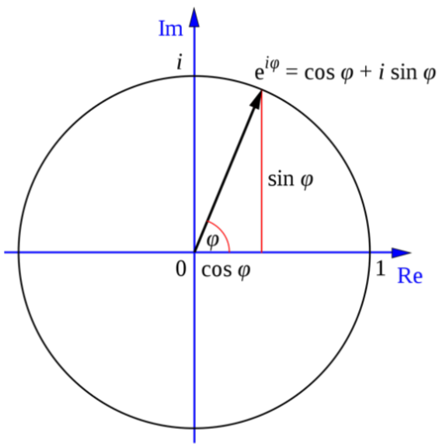
your pin at the centre of the graph. Turn the papers slowly one by one. What kind of shape do you see?

Mathematically: What would happen if you rotated each angle with 1 degree instead of 90 degrees? For instance, you write the coordinates of a point at 30 degrees and then rotate it by one degree and find the coordinates of a point at 31 degrees and so forth until you reach 390 degrees or in other words you are back to where you began? :)

Conclusion

What did you learn from this simulation?

Euler's formula:



Appendix D- Game Instructions for the Players

Context

Imagine you are working for a construction company. A construction project for new roads is being discussed. Before it can start, the mayor expects you and your team to do some risk calculations.

After the construction of the roads is completed, the mayor wants to try and see what happens if two autonomous vehicles (driverless cars) drive towards each other to guarantee the safety of the drivers and the other ones with them. So, the mayor is taking this project very seriously and will promote the team that proposes the best graph.

To complete this project, you are expected to

1. Find the best spot for traffic lights. To do so, you need to decide where the possibility of an accident taking place is the highest.

2. Find the best location for a parking lot and decide how much you would charge per hour.

3. Find the optimal speed limit; what would be fine if a driver passes that limit?

4. You have only 40 minutes to complete this project; good luck.

Instructions for forming a group

Please distribute the responsibilities below among your group members. Please pay attention to COVID-19 measurements and do not get too close to each other

Role	Responsibility	Name of the student	Why the best fit?
Note-taker (writer)	Should take notes about - the steps taken - bullet points of the group discussions (agreements and disagreements)		
Speaker	Should be able to		

	- share the conclusion drawn by the group with the entire class - defend and justify the conclusion (if correct) - explain what went wrong (if incorrect)		
Player	Should be able to - collect all the required equipment for the game - implement the steps of the game on the map		
Researcher	Should be able to - collect the required data from book/ online - make sure that the required information is accurate and sufficient		
Team leader	Supervises others, tracks time, makes sure everyone is actively participating		

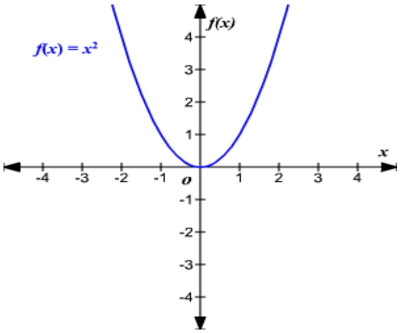
Important notes:

1. Check the goals regularly and see if you are on the right track! Keep an eye on time

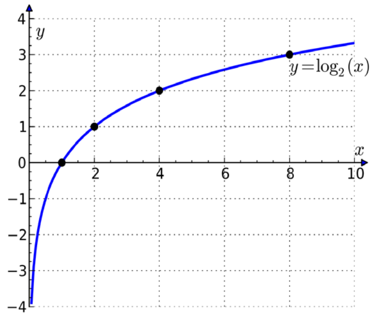
2. Please keep in mind that all group members should contribute to the calculations and discussions!

Let us get to work: You must decide how to connect these roads together in a way that you meet the goals of this project. Keep an eye on them!

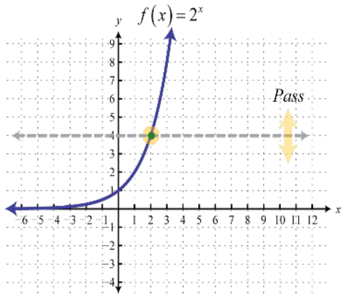
Graph 1 *[3] (Even/Odd Functions, n.d.)*



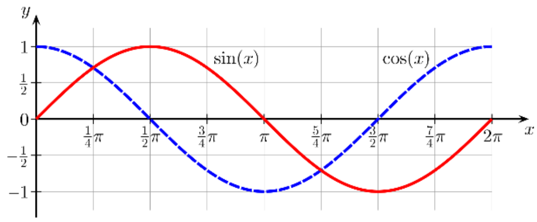
Graph 2 *(“Binary Logarithm,” 2022)*



Graph 3 (Logarithmic Functions and Their Graphs, n.d.)



Graph 4 (“Sine and Cosine,” 2022)



Step 1:

Analyse the graphs; compare them with each other. Decide which one would fit your goals the best to begin with. Note down your discussion points here.

Step 2: Use the table on the next page to write your answers

<u>**Important Note:** the graph that you are about to draw is a displacement graph. It means it shows the location of the car at a specific moment.</u>

[3] Varsity Tutors (n.d.). *Even/Odd Functions*. Retrieved 2 December 2021, from https://www.varsitytutors.com/hotmath/hotmath_help/topics/even-odd-functions

For instance, if you start with $F(x)=x^2$ then your car location at t_0 is the origin or at t_2 it is at 4. In other words, your function should look like $x=t^2$.

1. Start with one of the graphs. choose one part of it. for example, from x_0 until x_5. Regardless of your choice, you should start at the origin. (Do not forget that x shows the location and t is for time)

2. choose one random point on your graph. put your "traffic reflective warnings" on that point.

   a. What is the location (x)?

   b. At what moment (t)?

3. Drive two cars towards that point in opposite directions (one from right and the other one from left). For example, if you have chosen point (4) at the 2nd second on the function $x=t^2$, then one of your friends should start driving from point 1 at the first second, and the other one from 9 at the third second.

   a. Where is the location of your first car at which moment?

   b. Where is the location of your second car at which moment?

   c. Start to drive them slowly towards your point.

   d. As you get closer towards that point, does the risk of an accident increase or decrease?

   e. What should you do to prevent accidents at that specific point and moment? Which one of the options below do you think would be the best approach here? explain why you made that choice? Do not forget to use the stop, turning or two-way sign wisely

      i. Stop the cars so close to that point yet not at that point? (What happens to the velocity of the cars if you stop them? what are the locations of the cars?)

      ii. Make the displacement graph discontinuous? (For example, the police officer says that only car A can pass and move on, and car B cannot move further?)

4. Now repeat steps 1 and 2 for each graph that you add to your existing graph.

Graphs	Point (x,t)	Location of the first car/moment	Location of the second car/moment	Increase/decrease?	Option i or ii? why?
Graph ……………					
Graph ……………					
Graph …………….					
Graph ……………...					

Decisions to make: according to the data that you have collected in the table,

1. Put your traffic light in the place that you as a team believe is the best spot.
2. Chose a location for your parking lot and write the price next to it
3. Write your optimal speed limit; what is the fine for over-speeding, for instance?