Serious game supplementing higher level mathematical education

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Abstract

This paper presents the results and methodology surrounding a preliminary project done in relation to a master thesis. University level mathematics is a challenging topic, covering a broad spectrum of different concepts. Research show that students find these concepts difficult, and often cite the conventional method of teaching as a main concern. We devise a design for a mathematical serious game, surrounding a singular topic within calculus. This projects goal is to validate design decisions and gather feedback from target audience members through user testing. The prototype consists of a single case regarding applying newtons law of cooling in a private investigator style serious game. We find that students validate our game design decisions and enjoy the total experience, but found the mathematics difficult. We found that most students have trouble applying prerequisite concepts to solve the differential equation given. We conclude that the design is valid, and it allows for future work and research in the master thesis.

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1 Introduction

1.1 Project Description

University level mathematics is a challenging topic, covering a broad spectrum of different concepts that often requires prerequisite knowledge of earlier concepts. Many students enrolled in STEM fields find these concepts difficult to grasp and understand, let alone apply them to real life contexts and larger non-standard, cross disciplinary problems. As shown by Klymchuk and Zverkova, calculus students have difficulties translating word problems into mathematical formulae [1]. Their research showed that given the average time a student had to solve a given problem on a test, only about 5 out of 100 students were able to set up the correct function [1]. In the US alone, science and engineering enrolled students students have up to a 50% dropout rate, with most citing the conventional teaching method as a main concern [2]. In recent years there has been an increased focus on studying serious games, mathematical and otherwise [3](see figure 1 and section 2). We want to apply this new research to investigate if we can effectively supplement higher level conventional classroom instruction.

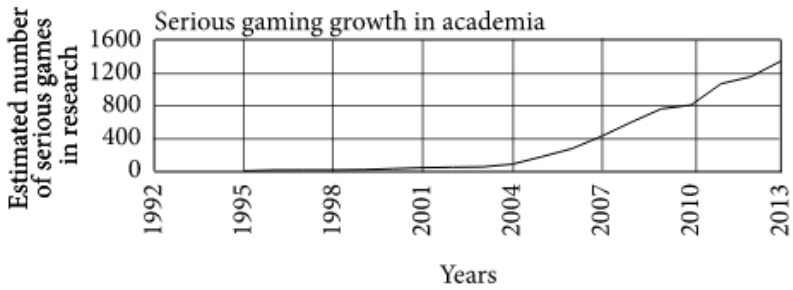

Figure 1: Serious games growth in the research field based on surveyed papers in ACM digital library and IEEE Xplore. Graph by Laamarti et al. [3].

This project is intended to function as a preliminary project for a master thesis where we develop and test a prototype. The thesis project itself will entail creating a serious game [4], in which players will have to apply their knowledge of higher level mathematical concepts in various scenes. The goal is not to replace the standard curriculum, but rather supplement it. We want to give students another angle of approach to an otherwise often dull and straightforward, albeit challenging subject. Our goal is to further engagement, motivation and interest for students that are having trouble dealing with the conventional method. The full detail about the thesis is out of scope for this report, and is described in a separate project planning report[5]. The target audience will be third year high school students, as well as first, and second year university level students taking higher level mathematics. For high schools in Norway this would be R2 mathematics[6], and calculus at university level[7].

1.2 Research Questions

Validating design decisions made when developing the proof-of-concept prototype of the serious game described throughout this paper through user testing is the purpose of this preliminary project. It is important for the development cycle, and research in future work to get feedback on design decisions early, allowing analysis and reflection to shape the development of the final product. Specifically we are looking to answer the following research questions:

1. What do students think about the game's design and user experience?
2. Which aspects of the game, if any, do students find challenging?

2 Related Work

In order to make educated decisions regarding our project, it is necessary to have an idea about what has been done in similar fields. Specifically for our project, there are three distinct areas that needs to be investigated. These are related to the mathematical challenges faced by students, serious games and their effectiveness, and lastly serious game design and related games. They are detailed below in subsections 2.1, 2.2 and 2.3. The related work research was done in conjunction with our thesis project plan description research [5]. As such, there will be similarities between these two documents.

2.1 Mathematical challenges

Discussion with lecturers responsible for calculus courses at our university showed us that there are improvements to be made when it comes to mathematical education. In the US, science and engineering enrolled students have upwards of a 50% dropout rate. The majority of these students cite the conventional teaching methods (in addition to other reasons) as a main concern [2]. Quantitative evidence show that the lecture format is ill-suited to learning, leading Mayo to postulate that serious games can come to the rescue due to their scalable, accessible, and compelling solutions [2].

Klymchuk et al. show that many students of mathematics have trouble interpreting information in word problems, transforming them into real world applications due to two main issues. First of is the students understanding of the wording of the question, with some students being unable understand the intention and goal of the question. 48% of users in their New Zealand test group responded they had this issue, and 36% in the German group. Second is the issue related to the identification and usage of the formula required, with 35% and 42% of respondents claiming they had difficulties formulating the problem [1]. Berry and Nyman claim that students enrolled in calculus often go through their first course only manipulating the symbols. Lacking a conceptional understanding, but able to work through the procedures [8]. A true understanding of calculus should give students "the ability to explore the facts, rules and concepts, and how they connect within the mathematical context" [8].

2.2 Serious games and effectiveness

Serious games are generally said to be "games that are specifically designed to achieve some change in the player" [9]. This can be a change in knowledge, health, motivation, ability, etc. [9]. They are often classified into categories of taxonomies including games for education, health, and training [9, 4, 3]. Another definition of a serious game can be "any video game built to differ from pure entertainment" [10], meaning any games that have a purpose other than just providing the user with entertainment [3]. According to Laamarti et al. basing the definition on the intentions of the designer may not be good enough [3]. A developers intentions are rarely accessible [11]. As such, Laamarti et al. define serious games as "An application with three components: experience, entertainment, and multimedia." [3]. Our game will be classified as a game for mathematical education, narrowing our search space of what has been done in the area. All games that

fit the category of games for education can still be considered relevant. It is important to note that playing a game for education does not appeal to everyone, it is not a silver bullet so to speak [12].

The positive and negative effects of serious games have been widely researched in recent years. Gonzáles-Gonzáles and Blanco-Izquierdo concludes that it is important to have an adult supervisor, or tutor, present to help reflection and transfer of knowledge into the real world [13]. Their study is mainly aimed at children, but it may be relevant to university level education as well. The lecturer may need to help students process the knowledge they have gained and applied in the game, and how to extrapolate it for use in the future. This is backed up by Chatterjee et al. who show that students benefit more when it is presented in a pedagogical context [14]. Vogel et al. show in their meta analysis that students using interactive simulations or games report higher cognitive gains and attitudes towards learning compared to traditional teaching methods [15]. Similarly, Wouters et al. show that serious games are in-fact more effective than conventional instruction methods [16]. Their research show that serious games are an effective tool when used in groups [16]. This is also backed up by McCallum, who claim that games that include social aspects provide shared experiences. These experiences can be opportunities for both in and outside class discussions, enabling a sense of community [9]. In addition, Wouters et al. also demonstrate that the knowledge gained is retained long term [16]. This is an important point, as we want students to retain what they learn, and be able to build upon it for future mathematical concepts. Neither Voget et al. or Wouters et al. found in their meta-analyses any evidence for increased effectiveness of photo-realism on the perspective of learning [15, 16].

Wong et al. showed that in comparison with a game, the text format was perceived as less educational, it did not result in a comparable increase of interest. In addition, the sustained knowledge gain was smaller in the text condition [17]. Their data supports the fact that learning the content through a game, or another interactive medium, is more enjoyable than through traditional text book formats [17]. For simulation games, used in training, the results are also favorable. Showing outcomes superior to the comparison group [18]. As a summary of the section, we can confidently say that a serious game can be an effective tool if applied correctly.

2.3 Game design

Having concluded above that serious games are effective, we turn our focus towards which elements of design and games are relevant for our work. Wouters et al. show that a heavy narrative may be counter productive to learning outcomes, but a theme that is closely related to the goal may improve the effect [16]. As student motivation is a key predictor of successful education outcomes [19], we need to build a system that helps students become more motivated. However, it is challenging to design a game that is intrinsically integrated. It has to be integrated with a specific set of concepts, that is hard to generalise to other concepts and subjects [20]. To take advantage of students intrinsic motivation, we need to create a context supportive of autonomy, competence and relatedness, that are shown to be important factors[21, 22]. As a consequence of this the design needs to facilitate feelings of autonomy, competence and relatedness. Autonomy concerns the sense of volition. In other words, is the activity done for personal value and interest, or is it forced upon them by an external factor (such as a lecturer). Competence

correlates to the feelings of effectance and the need for challenges[21]. Is the player able to master new concepts and ideas, is the player challenged appropriately? This in turn relates to the concept of flow [23], where we want the player to be challenged, but not so much so that it feels impossible. The well known graph of flow illustrates this beautifully. Similarly, bad controls may negatively affect motivation, because they are associated with control, freedom and the sense of competence [21]. Ryan et al. show that gaming motivation and enjoyment can be accounted for by experiences of competence and autonomy, and that feelings of achievement and relatedness increases the number of hours per week spent [21]. Likely due to the self-determination theory principles of agency and autonomy, making playing the game compulsory may have a negative effect [12]. Another interesting note is how to deal with failure. Research show that failure may cause frustration, as a result playing a very difficult game may be unattractive [12], reducing adaption of the game. This again relates back to the concept of flow [23], the player should not be challenged too greatly, unless this is of the players own volition, through a difficulty setting or similar. A game allows students to develop an understanding through building, tinkering, or a more direct experience. In opposition to the more conventional method of listening to lectures and reading texts [12]. This is more akin to how learning works in the real world [12]. A relatively similar game to what we are attempting to create is "DiffGame", where they attempt to teach differentiation through a serious game [24]. They demonstrated learning gains for all students, with students in the middle tier showing the largest benefit. Another similar game that was created by Faghihi et al. show that a game can be used to successfully teach aspects of college algebra, measured by formula retention[25]. They also claim that no real solutions for teaching college math exist at the time of writing. Dimenxian [26] is another game aimed at teaching algebra. Mayo discussed the academic improvement of playing this game, citing a 30% improvement over the control [2]. It's a deal is a game aimed at teaching business English, showing empirical data in support of the learning effectiveness of the game [27]. To summarize, there are similar games out there, though not strictly aimed at calculus level mathematics that we can utilize when it comes to looking at the design.

3 Methodology

This section outlines our choice of methodology for how to tackle the three different aspects related to the project. They are broken down into their own sections.

3.1 Mathematics

Having set supplementing mathematical education at higher levels as a goal, it is important to choose a mathematical concept to focus on that is both applicable for the target audience, and that can be a good fit for a serious game. We will determine the concept and formulae by having discussions with a mathematical adviser, currently in charge of calculus level courses at NTNU. We are confident this will enable us to determine an appropriate, and factually accurate concept.

3.2 Prototype Development

We will need to develop a prototype for the game, including coming up with the design idea for how to incorporate the chosen mathematical concept into a game. Preferably we will develop a system where it is possible to include several different mathematical concepts, without breaking the general theme. Deciding upon the tools and resources to use, and finding a fitting theme is important. We will discuss design with several advisers and professors at NTNU, finding inspiration in the games discussed in the related work section. We will attempt to use concepts already proven to be functional in AAA games on the market today, especially when it comes to user interface and controller scheme design. As our related work research shows, it is important to stay adherent to self-determination theory [21, 22] principles such as autonomy, competence and relatedness. It is also important to consider the story of the game, as Wouters et al. showed in their research, a heavy narrative may negatively effect the learning gains [16]. The general idea for our design then, is to develop a system where we can have mathematically themed aspects, preferably several different ones to choose from, that work without too heavy a narrative.

3.3 Playtesting and questionnaire

To get relevant feedback on our design decisions to answer our research questions and validate our design, we will recruit members of the target audience to do play testing. These sessions will be done one-by-one under the observation of an observer (the author). We will be visiting several different mathematics classes at NTNU in Gjøvik, presenting the prototype, explaining the goal and methodologies, and asking for volunteers. All the classes are taking "Matte 1" [7] covering calculus. The testing itself will be done over the course of a week, with volunteers being given a time slot. The testers will be expected to play the game, solve the case through their mathematical skill, and give feedback through a questionnaire. The questionnaire will be designed to extract relevant information from the testers. The majority of the questions will be designed to fit a 5-point Likert scale [28], with some exceptions. These include questions enabling more detailed, qualitative user feedback, as well as question designed to gain some insight into

the testers background and previous experiences. The planned questions can be divided into a few concrete categories as follows:

- Game design.
- Background information and preferences.
- Mathematical
- Generic (None, or multiple categories)

The questions in the game design category will seek to answer questions regarding design decisions made, such as the general game experience, size and complexity of the scene, difficulty of finding information, etc. The mathematical questions will ask for previous experience with the mathematical concept, the perceived difficulty of the math, and others. The section regarding background information will ask questions about topics such as the testers general viewpoint on games, how often they play games, which language they prefer to play games in, etc. A full list of the final questions and their descriptions can be found in appendix D.

Finally, we will analyse the data gathered, and draw some conclusions based on the answers given to us. We will utilize averages and standard deviations to create charts showing the general feedback of the Likert scale questions, and elaborate on the textual feedback questions.

4 Results

In this section we outline the results found in the various aspects regarding the development of the proof-of-concept prototype. Each section will contain references to eachother as they are closely related. We have outlined the resulting mathematical concept, the development of the prototype, and the results from the play testing. For a detailed discussion of the results, refer to chapter 5.

4.1 Mathematics

Discussions and meetings with a mathematical adviser quickly lead us to differential equations, specifically first order separable ones. There were already a number of textual problem sets for this that we could choose from to implement. In the end, we selected Newton's Law of Cooling for the first prototype. Further discussion lead us to a problem where the students have to ascertain the time of death of a dead body, by applying Newton's Law of Cooling. This was chosen based on the mathematical advisers previous experience using this in her class, and its perceived affinity with working in a serious game. The goal here is to integrate this equation into a scenario within the game. The decisions made regarding how to create a design able to utilize this is explained in section 4.2.

In essence the mathematical aspect of the game that should be done by our players can be broken down into these steps:

1. Investigate and determine the necessary variables
2. Separate out T (4.2)
3. Set up two equations for two measurements (4.3, 4.4)
4. Substitute equation 4.3 into equation 4.4 solving for $-k$. (4.5)
5. Solve for t. (4.6)

A solution is shown here in its entirety, in the generic form, as a reference for future programming and implementation, and for readers of this paper. Students that are working through it will have an easier time as they can shorten it quite a bit by doing the calculations and summations while solving it. I.e $T_0 - T_e$ could be written as 18.3, shortening and simplifying it. A solution with variables from the test scene built can be seen in appendix C. First of all, an explanation of the variable nomenclature can be seen

below:

$$
\begin{aligned}
T = T(t) &\mapsto \text{ Temperature at time } (t).\\
k &\mapsto \text{ a constant. } \textit{Can be found mathematically.}\\
T_e &\mapsto \text{ environment temperature. } \textit{Can be found in the scene by looking at a thermometer.}\\
T_0 &\mapsto \text{ Temperature of a living human (Assumed roughly.) } \textit{This is assumed prerequisite knowledge.}\\
x &\mapsto \text{ Time difference between measurements. } \textit{Can be found in the scene by checking the clock.}\\
T(t) &\mapsto \text{ Temperature of the body at measurement 1. } \textit{Is given to the player through the Journal.}\\
T(t+x) &\mapsto \text{ Temperature of the body at measurement 2. } \textit{Measured by the player in the game, x time later.}
\end{aligned}
\tag{4.1}
$$

First we solve for T:

$$
\begin{aligned}
\frac{dT}{dt} &= -k(T - T_e)\\
\frac{1}{T - T_e} dT &= -k dt\\
\int \frac{1}{T - T_e} dT &= \int -k dt\\
\ln|T - T_e| &= -kt + C\\
\ln(T - T_e) &= -kt + C\\
\ln(T - T_e) &= -kt + \ln(T_0 - T_e) \rightarrow \text{Replace C by solving for T(0).}\\
e^{\ln(T - T_e)} &= e^{-kt + \ln(T_0 - T_e)}\\
T - T_e &= e^{-kt} e^{\ln(T_0 - T_e)}\\
T - T_e &= e^{-kt}(T_0 - T_e)\\
T &= T_e + (T_0 - T_e)e^{-kt}
\end{aligned}
\tag{4.2}
$$

We set up two equations, one for each measurement to allow for comparison and substitution. Measurement 1:

$$
\begin{aligned}
T(t) &= T_e + (T_0 - T_e)e^{-kt}\\
T(t) - T_e &= (T_0 - T_e)e^{-kt}\\
\frac{T(t) - T_e}{T_0 - T_e} &= e^{-kt}\\
e^{-kt} &= \frac{T(t) - T_e}{T_0 - T_e}
\end{aligned}
\tag{4.3}
$$

Measurement 2, where variable x represents the time differential between the two measurements in hours, minutes or seconds. It does not matter as long as it is consistent, and you are aware that your answer will reflect your choice:

$$
\begin{aligned}
T(t+x) &= T_e + (T_0 - T_e)e^{-k(t+x)}\\
T(t+x) - T_e &= (T_0 - T_e)e^{-k(t+x)}\\
\frac{T(t+x) - T_e}{T_0 - T_e} &= e^{-k(t+x)}\\
\frac{T(t+x) - T_e}{T_0 - T_e} &= e^{-kt-kx}\\
\frac{T(t+x) - T_e}{T_0 - T_e} &= e^{-kt}e^{-kx}
\end{aligned}
\tag{4.4}
$$

We substitute e^{-kt} in equation 4.4, with equation 4.3, solving for -k:

$$\begin{aligned}
\frac{T(t+x)-T_e}{T_0-T_e} &= \frac{T(t)-T_e}{T_0-T_e}e^{-kx} \\
\frac{T(t+x)-T_e}{T_0-T_e}\frac{T_0-T_e}{T(t)-T_e} &= e^{-kx} \\
\frac{T(t+x)-T_e}{T(t)-T_e} &= e^{-kx} \\
\ln\frac{T(t+x)-T_e}{T(t)-T_e} &= \ln e^{-kx} \\
\ln\frac{T(t+x)-T_e}{T(t)-T_e} &= -kx \\
\frac{1}{x}\ln\frac{T(t+x)-T_e}{T(t)-T_e} &= -k
\end{aligned} \tag{4.5}$$

We substitute $-k$ with equation 4.5 in equation 4.3 solving for t:

$$\begin{aligned}
e^{\frac{1}{x}\ln\frac{T(t+x)-T_e}{T(t)-T_e}t} &= \frac{T(t)-T_e}{T_0-T_e} \\
\ln\frac{T(t)-T_e}{T_0-T_e} &= \ln e^{\frac{1}{x}\ln\frac{T(t+x)-T_e}{T(t)-T_e}t} \\
\ln\frac{T(t)-T_e}{T_0-T_e} &= \frac{1}{x}\ln\frac{T(t+x)-T_e}{T(t)-T_e}t \\
\frac{\ln\left(\frac{T(t)-T_e}{T_0-T_e}\right)}{\ln\left(\frac{T(t+x)-T_e}{T(t)-T_e}\right)} &= \frac{1}{x}t
\end{aligned} \tag{4.6}$$

Finally, this gives our generic formula for finding the time spent cooling up to this point. Keep in mind this is in relation to measurement 1.

$$t = \frac{x\ln\left(\frac{T(t)-T_e}{T_0-T_e}\right)}{\ln\left(\frac{T(t+x)-T_e}{T(t)-T_e}\right)} \tag{4.7}$$

4.2 Prototype design

To build the prototype case, we decided upon using Unreal Engine [29], specifically version 4.13. Using a game engine rather than spending valuable development time writing our own comes with the advantage of rapidly being able to create a prototype scene. There were three major reasons for choosing Unreal, in addition to the prototyping speed. First, is the benefit of being able to seamlessly fit in realistic looking object models with Unreal Engines great lighting and shadow systems. Second, is the possibility of using blueprint, their visual programming language, to do some of the coding. This enables truly rapid prototyping, and provides easy to see visual connections of code. Third, is the possibility of adding virtual reality support in the future, see section 5.4. A combination of these factors, and the authors previous experiences, lead us to choose Unreal above Unity or other competitor engines that could equally have worked well.

Having chosen both tool and fitting mathematical concept to implement, the next step was to design the scenario itself. The scenario would have to enable the student to find the information required to solve the mathematical equation, as well as a way for

the student to use this information in some intrinsically meaningful way. As described in section 4.1, we built a prototype surrounding the finding of a dead body, and calculating time of death. For this purpose, a murder case was devised, where a body was found in a high-rise apartment, with security cameras showing three different culprits leaving the building at various times of the night. The user will have to use their wits and mathematical knowledge to find the clues needed, apply them mathematically, and lastly make an informed choice of culprit. A brief description of a players experience can be summarized as follows. The player will act as a private investigator, or police officer, responding to the scene. After entering the building (automatically for this early prototype), the player will be given a description of the case, and previously known data to work with. The player then has to find the body, measure it for needed information (specifically body temperature), and look around the scene for further clues. We wanted to build the clues into the scene itself, simulating more closely how you would have to act in the real world. This means that in the scene there are items such as a clock and a thermometer that you can walk up to, and see for yourself what the values are. They will not be provided through text. We added some purposeless variables into the scene, serving as obfuscation, so that the player needs to think a bit about which variables are necessary to gather. It also helps serve the purpose of allowing the player to explore the scene in more detail, when there are more items that are interactable. As such, there are other items in the scene that may draw their attention, but that do not serve any particular purpose. We wanted the players to want to playfully explore the apartment. Specifically, the purposeless variables are body height, and body weight in this scenario, as well as an interactable book and television.

An important aspect of the prototype was figuring out how to deliver required information to the user. The player should be able to access this information at any time, and more than once if desired. To serve this purpose we came up with the idea of creating a detective journal. The journal contains a general description of the case, as well as hints as to what information the users will have to gather. It also contains the most important information, the formula for Newton's law of cooling, and an explanation of the variables contained. An explanation of the clues that can be found (*and where to find them*) is shown below:

- Environment temperature (*look at a thermometer*).
- Body temperature (*measured from the body*).
- Previous body temperature (*provided in the journal*).
- The time when previous measurement was made (*provided in the journal*).
- The current time (*look at a clock*).
- Body weight (*Measured from the body, purposeless*).
- Body height (*Measured from the body, purposeless*).

After gathering the clues, and working through the mathematics, the player can exit the apartment through the door. The user will then be prompted to select a culprit, based on the descriptions given, and after making their choice given feedback on whether or not

they chose correctly. See section 5.4 and the thesis planning document [5] for more detail about the surrounding game system, that is out of scope for this preliminary project.

4.3 Prototype development

A Github repository was created, containing the created assets and the code[30]. The prototype also utilizes different external assets, free and paid, that are not included in the repository due to either copyright, or file sizes. This means that you have to manually add these assets to the project through Unreal Engines content manager to run the game. A comprehensive list of these external assets can be seen here:

- Realistic Rendering template [31].
- Ground and Walls Texture pack [32].
- Dynamic Clocks [33].
- Thermometer [34].
- Unreal Starter Content.
- Third person starter template mannequin (Serves as our dead body).

The game relies especially heavily upon assets from the "Realistic Rendering" template[31] due to its free to use nature, and its particular correspondence to our project. A screenshot from the prototype's high-rise apartment can be seen in figure 2. Here you can also see the thermometer [34] implemented, with an on-screen prompt explaining its use to the player. The player will have to read the number off of the thermometer to use in their calculations. Three various temperatures for the thermometer were added, but the prototype only uses the value 18.7. Section 5.4 discusses potential future implementations of randomness.

Figure 2: A view of part of the murder scene from the prototype's high-rise apartment. A player can look at the thermometer to extract the environment temperature.

The detective journal is an integral part to the game. It is where the user acquires

the background information necessary to solve the case. It tries to model a notebook of sorts that an officer or detective might carry around (although it may be a bit large in the prototype). The content it contains includes the story itself, and several clues as to what the player will have to gather in the scene to solve the case. The differential equation for Newton's law of cooling is also shown within, with a short explanation of the variable nomenclature. A screenshot of the journal can be seen in figure 3, with the text in Norwegian. Section 5.4 discusses potential improvements to this design.

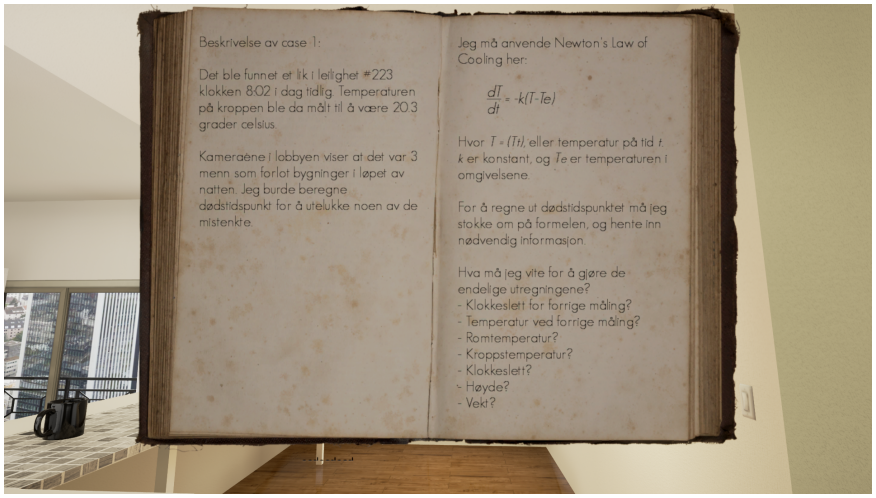

Figure 3: The detective journal from Case 1: High-rise apartment.

We developed a suspect lineup of sorts so users could select a culprit after calculating the time of death. The calculation to determine time of death to generate the timestamps for the images can be seen in figure 5. The prototype does not involve any randomness however, giving the same experience, mathematical equation, and murderer for all testers. The time of death, and suspect images seen in figure 4 are therefore static. We made this decision both for the simplicity to create it, and because it will make it easier for the observer during playtesting to spot mistakes in the mathematical calculations done by testers. Specifically, figure 5 represents equation 4.7, seen on page 10 in visual code. Additional screenshots of the game can be seen in appendix B.

4.4 Playtesting

Testing was done one-by-one, with an observer present to record the session, and if necessary provide guidance through hints. Hints are defined here as any interaction with the observer, when the tester was stuck, primarily on the mathematical aspect of the game. This approach was considered necessary for this project to avoid testers getting entirely stuck on the mathematics, then giving up. It also has an equally important role of identifying which concepts and areas of the mathematics the testers were having issues with, as it would have been entirely unreasonable to provide any and all hints within the games prototype. The number of hints a given player were given has been noted, as well as time spent on solving the case.

The majority of the students in the target audience were in "exam mode" when playtesting was being done, with some claiming genuine interest in the project, but unable to dedicate the time with exams and semester end compulsories around the corner.

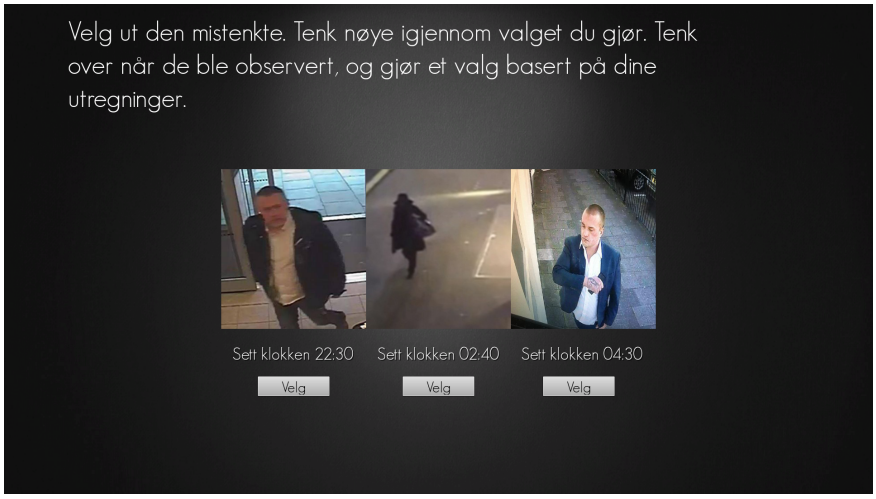

Figure 4: The screen where players choose between culprits.

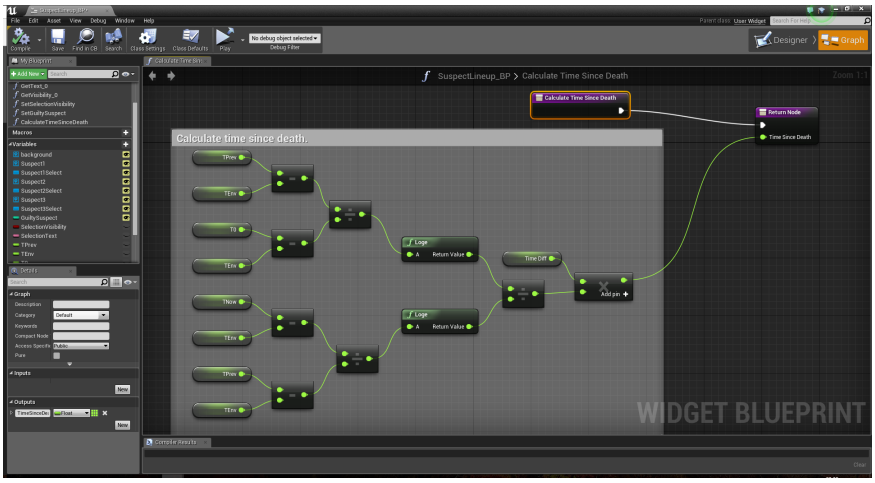

Figure 5: The final formula to calculate time of death in blueprint.

As the playtesting was done rather late in the semester due to development time etc. this is understandable. In total the test group ended up being 10 students. Their recorded hints needed and time spent can be seen below in table 1. Time spent represents the amount of time the tester spent solving the case and selecting a culprit. The time spent was recorded down to the nearest minute, not including the time it took to answer the questionnaire itself. Sadly, there were two students who did not show up for their allotted time slot.

As can be seen by the number of hints needed per user, with a fairly large variance, all students needed a helping hand to work through the problem. This backs up our decision to have an active observer present. It is important here to note that no user required any hints to solve the game aspect of the case. No information other than the initial information given to the tester as the general introduction, and the journal was necessary. However, a few issues about the game were identified by observation. First of all, when measuring the body temperature etc. the text that pops up only stayed on-

Tester	Hints needed	Time Spent
1	N/A	Did not show
2	8	40 minutes
3	N/A	Did not show
4	11	40 minutes
5	5	41 minutes
6	9	48 minutes
7	9	46 minutes
8	25	55 minutes
9	8	53 minutes
10	11	38 minutes

Table 1: Shows the number of hints needed and time spent on the task per tester.

screen for about 3 seconds. This was too short, as all students wanted to write down the information given. The end result here was a rather cumbersome exercise where the user was clicking interact, multiple times, with one hand and writing down the information with the other. Second, the wall clock in the game was running in real time. It started at roughly 10:05 for every launch of the game, and then running along at a real time pace. This was as intended, with the user resetting the clock when selecting a culprit. The problem arises in two different cases, one is when the user does not look at the clock for a long period of time, in excess of 30 minutes, changing the result of the calculations. The interval between suspects should be enough to cover this, but it will have to be taken into account. The second case here is when the game is left on in-between testers for a long period of time. The clock may then be an hour or two later than intended if the observer does not reset the game manually before the next player. The third issue observed was the font size of the journal. Several users had to move closer to the screen, or awkwardly rotate the book upwards to be able to properly read the text. Ideas for how to imrpove this will be detailed in the future work section (5.4). One student managed to fall through the floor when playing around with the jumping ability of the character. As the floor is a solid collision object, how this was possible is unknown. We suspect it may be due to the floor being relatively thin, only about 2cm in-game. The player may have fallen through if it did not update for a couple of frames.

It is important to note, again, that the majority of the time, and all of the hints were spent on the mathematical aspect of the game. Only three users were able to go from the base form, to the secondary form needed to solve the task at hand, without a lot of hints. None however, were able to utilize this to make an educated and correct decision as to who the culprit was without assistance. Observations showed that the main issue the testers had were with previous mathematical concepts that they were assumed to know, such as exponent rules and equation substitution as needed in steps 4.3 and 4.5 of the solution. This is backed up by research done by Klymchuk et al. who showed that one cannot rely upon assumptions made about students previous knowledge and completed modules [1]. Given that the students had covered the topic of differential equations the previous three weeks of the semester, we assumed the majority would be able to apply this knowledge to at least work through and rearrange a separable differential equation. This does not seem to be the case. Whether this is caused by the setting, a lack of knowledge transfer, or a mixture of both is unknown.

4.5 Questionnaire

The results from the questionnaire will be broken down by the categories shown in section 3.3, beginning with background information and preferences, which consisted of 4 questions. Two of which were on a 5 point Likert scale, with the remaining two being general multiple choice questions. For a full detailed listing of all questions and their descriptions, see appendix D. The Likert scale questions will be shown in graphically charted form, collected by category. The more general questions with textual replies, or multiple choice answers, will be detailed in text or in tables. For background questions we asked users: if they would prefer to solve this in groups, with $\frac{1}{8}$ of students answering yes. On the question regarding which language they would prefer to play in, we had $\frac{4}{8}$ answer Norwegian, $\frac{2}{8}$ answer English, and $\frac{2}{8}$ answer other. Both respondents who answered other verbally claimed that they were indifferent, and they selected other only because there was no option for indifferent. Below you can see a graph showing the averages with standard deviation shown for the remaining questions in the category.

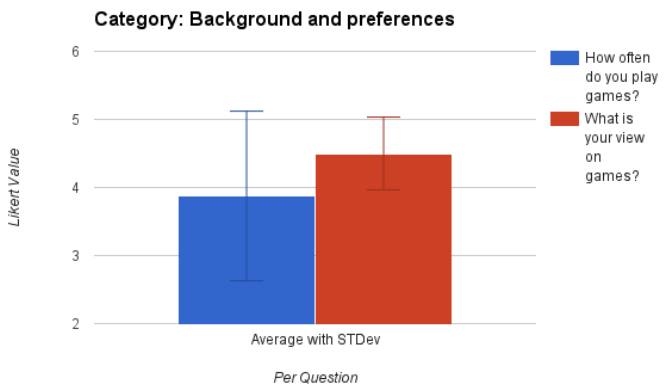

Figure 6: Breakdown of answers to background information and preference related questions. 5 point Likert scale.

For the following results, refer to the figures on page 17 and 18. In the mathematical category there were three questions, all of which fit a 5 point Likert scale. The results are shown below in figure 7. The largest category of questions were the game design category, containing twelve questions. Eight of these are set on a 5 point Likert scale, with the rest being a mixture of textual input, multiple choice and select all that apply. Answers given to the question regarding the information portrayed in the journal can be seen in figure 8. Regarding the question of whether or not the controls were intuitive, which is an important gatekeeper for autonomy [21], $\frac{8}{8}$ or 100% of users answered yes. Given the choice between a game like this, and a normal compulsory delivery, all users answered "the game". For this question, all users were asked to elaborate on the reason for their choice. The answers can be seen in table 2. The results of the remaining Likert scale plottable answers in the game design category are shown below in figure 9.

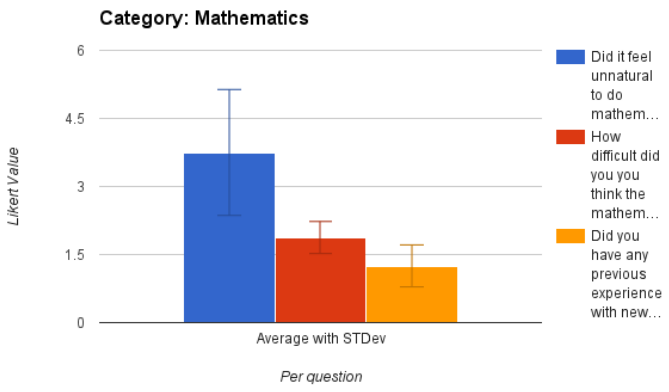

Figure 7: Breakdown of answers to mathematical related questions. 5 point Likert scale.

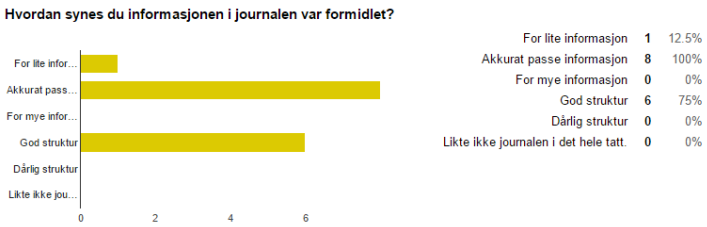

Figure 8: All answers pertaining to how journal information was portrayed.

Norwegian	**English**
Spillet gjør at det blir mer interresant å jobbe med matematiske formler	The game makes it more interesting to work with mathematical formulae.
Lettare å setje seg ned med eit spel, i staden for rett på penn og papir med ein vanleg oblig.	It's easier to sit down and play a game, instead of using pen and papir with a normal compulsory.
Det blir ikke like kjedelig som bare med papir. Kan lage mer interessante scenarioer. Fungerer bra som et visuelt hjelpemiddel.	It does not get as boring as with paper. It's possible to create more interesting scenarios. It works well as a visual aid.
Mer engasjerende og lettere og se hvilke informasjon som er nødvendig. Også morro å se resultatet av det man regner.	It's more engaging, and easier to see what information is necessary. It's also fun to see the result of your calculations.
Kjekkere å spassere rundt å samme kloos, enn å jobbe med noe selvpåfunnet.	It's nicer to walk around collecting clues than to work with something you came up with yourself.
synes det hadde vært bedre med spill en oblig grunnet at du får mer utbytte av et spill som dette enn eventuelt en veldig enkel oblig.	I think it would be better with a game than a normal compulsory because you gain more from a game like this than a potentially very easy compulsory.

Table 2: Ad verbatim answers and translated elaborations to the question where they were asked to choose between the game and a compulsory delivery.

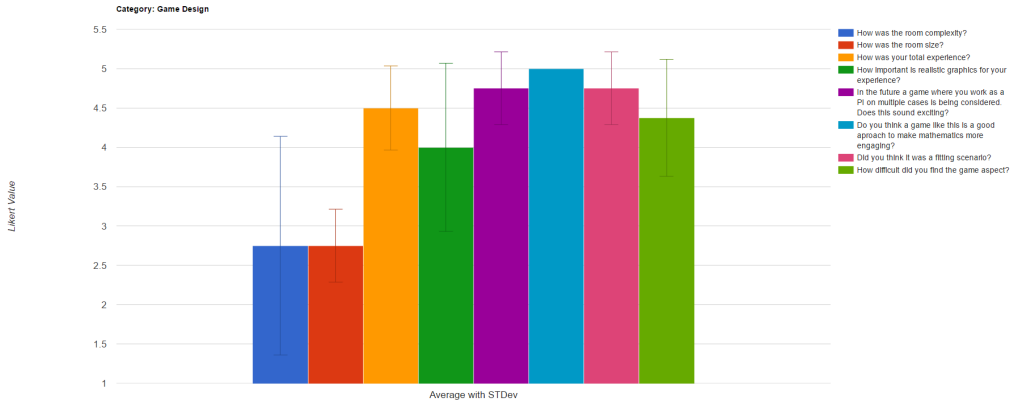

Figure 9: Breakdown of answers to game design related questions. 5 point Likert scale.

There were two questions in the generic category, both of which were optional, and both of which were textual input fields. The first was the question whether or not anything during game play made the user frustrated, and if so, what. There were no answers to this question, with no user claiming any frustration. The last question was if the user had any extra comments they wanted to add. There were 2 users who answered this, reflected ad verbatim and translated below in table 3.

Norwegian	**English**
Savnet Zoom.	I missed zoom.
Veldig fint med denne oppgaven var at man får en fin oppsumering av alt. alt fra potensregler, likninger osv.	What was very nice about this task was that you got a good summary of everything. From exponent rules, to equations, etc.

Table 3: Ad verbatim and translated answers to the extra comments question.

A graphical breakdown of each individual question can be seen in appendix E. This only applies to the questions that are chartable or graphable, and not the textual replies shown above.

5 Discussion

In the following sections we discuss the implications of the results found in the various categories. We look at challenges faced with the mathematics, the design and development, and playtesting and lessons learned. We also discuss some limitations to the methodology and testing, and further discuss some future work opportunities. As a summary of background information (figure 6) we can deduce that all volunteers can be considered gamers. They have a positive view on games, and they play at least weekly. This shows at least in part, that gamers are interested in using a game when doing mathematics at a higher level. It also adds a factor of uncertainty to our project, as it may stop us from being able to generalize our results for the broader demographic the calculus classes consist of. For the continuation of the project in the thesis work, we may want to recruit a more broad audience. On another note, as Squire has shown, games do not appeal to everyone [12], and it may not be necessary to reach those who have no interest in games. Our sample size of eight students is enough to provide us valuable feedback, but is still a limitation to consider when drawing conclusions.

5.1 Mathematics

Our results show that our choice of mathematical formula worked fairly well, albeit quite difficult. As can be seen in figure 7 on page 17, students found the formula either very difficult or difficult. None of the students in the test group had any particular experience with Newtons law of cooling. This is in line with our discussions with our mathematical adviser, who referred to the problem as "above averagely difficult". The formula fits well within, and helped form, our idea of the broader game design. We identified a few areas where multiple students had issues solving it, we will refer to the numbered equations shown in section 4.1. First off all, no students had any particular problems finding the necessary variables. The only issue most students had with this was the question of T_0, which we had assumed students would be able to deduce as roughly 37.0 degrees. The majority of testers had to ask for confirmation for this. In hindsight we should have specified this within the game, as it was not an intended obfuscation area. Equation 4.2, which was first and foremost the goal for students to be able to do due to competence goals within calculus [7], gave students a lot of trouble. Only $\frac{3}{8}$ students managed to do this part with a minimal amount of hints necessary. Specifically, students faced the issue of remembering how to deal with the initial condition ($+C$, solve for $T(0)$), and how to solve for T. Remembering how to apply natural logarithms was also an issue for most students here.

Most students were unable to set up two different equations, one for each of the measurements provided and done in the scene, in a system, utilizing substitution to calculate $-k$ and t in equations 4.3, 4.4, 4.5, and 4.6. Here we saw a mixture of troubles from all students, mostly related to concepts that should be prerequisite knowledge of concepts for students of calculus. Troubles included equation substitution, exponent rules, and dealing with e and natural logarithms. We also had a couple of students unable to divide two fractions. This is backed up again, by Klymchuk et al. who show that we cannot

rely upon students' competence in previous areas [1]. We had not adequately predicted the range of mathematical issues faced by students, and our game alone would not have been ready to help students in this situation without an active observer present. Our future work section (5.4) discusses some ideas for how to dynamically deal with these issues.

5.2 Playtesting

Our primary goal for this preliminary project is to validate design decisions through user testing, resulting in a variety of questions asked of users in this category. Beginning with the size and complexity of the scene, we can see from the results in figure 9 that students felt the room size and complexity was just about right, but a bit on the small side of things. In combination with other cases and the surrounding game system added in the thesis, it will be interesting to see what students think then. We learned here however, that we should not create scenes that are a lot more complex for students to sort through and find clues. All testers reported that a game such as this would be a good way to make mathematics more engaging for them, and the game design envisioned for the thesis project sounds exciting. In addition, we got very positive replies for how fitting the scenario was with the mathematics. We have yet to determine of course if this is just a novel feeling of something new, or if it will have the same effect in the long run. Users found the game aspect of the experience quite easy, with no real trouble finding the clues or moving around. We had all users reply that the controls were intuitive, which is important due to the feelings of competence in self-determination theory [21]. When it comes to graphical fidelity, we had users report that they found the realistic looking graphics important for their user experience. There has not been found any link to increasing the learning outcomes by using realistic graphics [16, 15]. However, if users find it an important aspect of their user experience, the learning outcome itself may not be the most important factor here. For our purposes, the workload does not significantly increase by utilizing high fidelity assets, and we will continue using a similar style. Our testers all reported that their overall user experience was very good. We take this as a sign that our general design is moving in the appropriate direction. As the user group is rather small and limited in demographic complexity, we can not confidently say we have found the perfect design, but it will be worth moving forward with for further testing in the thesis. One of our main concerns for the design and playtesting method was regarding how doing the mathematics alongside the game, on pen and paper, affected user experiences. We asked users for feedback on this (see figure 7), with only one user claiming it was unnatural. A breakdown of answers for this problem can be seen in the appendix, figure 26. As can be seen by the average and standard deviations, our users felt it was between OK and entirely natural. Another issue we did run into was that a couple of the variables should have better better explained. The first and foremost issue that all our students had to ask about was regarding T_0 or the initial temperature of the body. In our calculations we used 37.0c as temperature, and we had assumed that students would know this, or a temperature close to it. In hindsight we see that all our students had to ask for confirmation if this was the case. Adding further description of the variables should be done, even if only to say that T_0 is the temperature of a living human.

The journal was another aspect we were interested in exploring and getting valuable feedback on. We asked our users to select all that applied for their experience. The an-

swers can be seen in figure 8. All users answered that the informational content was just right. We also had one answer, claiming that we had too little content in the journal. As there were only eight students doing the testing, we had one tester answer both. In general the feedback on the journal was good. The content structure worked well, and users felt they got the information they needed from it. However, during observation, a couple of issues here were spotted. Specifically, the majority of the testers had trouble reading the text due to the font size chosen to fit the content into the journal. During the authors preliminary testing, the screen was closer due to no math being done, and it was not an issue that was thought of then. You could turn the book upwards to get it closer to your face, but this was a rather cumbersome exercise. This is also backed up by one of the comments to our "extra comments" question, who wrote down that he wished the game had zoom. The issues with font size will have to be taken into account in future work. See the future work section (5.4) below for further detail on how to solve this. During testing we also spotted some spelling errors in the journal. None of these proved to be of any particular nuisance, but they will be remedied for any future implementations.

Finally, we asked users to provide us with extra information in two textual input questions, which can be seen above in tables 2 and 3. All except two of these replies are in conjunction with the "Would you rather play a game such as this, or a standard compulsory", and "if so, why?" question. The general consensus in the replies are that they find it more engaging, it gets less boring, and that it is easier to sit down and play with the game, rather than with pen and paper. One user elaborated that they thought it would be better with a game like this precisely because he found it more challenging than a potentially very easy, self-picked compulsory. In general the total feedback on the experience is in favor of the design having potential to work in a real life setting. We need to do further testing on the final prototype in the thesis to draw any real conclusions however. Another avenue of interest for us here, and in the thesis, is in which scenarios and aspects of the schools curriculum teachers would want to use a game such as ours. Would it be a substitute for a compulsory, or is it a supplement while working on lab exercises? The design of the game may have to change depending on the answers here. If it targets lab exercises, we can assume that a lecturer or TA is present to help those in need of aid mathematically. If we target home usage and compulsories instead however, we need a higher focus on the self-helping aspect of the game. We do not necessarily want to provide the entire solution to our users either, but incur discussion in the class, or provide an opportunity for students to ask meaningful questions of their teachers and TAs.

5.3 Other limitations

The methodology itself also contains some limitations that should be addressed. We felt it was necessary for this prototype, but we do not want an active observer playing a part in future test sessions. If we do need a mathematical adviser present to get a better grasp on the mathematical difficulties the students are facing, it would be better to have a dedicated mathematical adviser present. Preferably we want there to be no other contact at all, to better create reproducibility and accuracy in our results. It is difficult to only give similar advice, and stay in contact as little as possible during each observation. Even with a standard introduction to the case, with users asking different questions, it is difficult to stay truly objective. We can justify it for this prototype to determine where

users are stuck, and get feedback for our hints in the coming work. We can see from our results that users faced a wide variety of mathematical issues, and we did not predict the majority of them. See future work (5.4) for a more detailed description of how we want to implement hints and help in the future.

Another thing to note when it comes to hints given during our testing, is that we only recorded the number of hints needed and roughly where they needed it. It would have been advantageous to record this data in much more depth. Exactly where they were in their calculations, and exactly what the question they asked were. In hindsight this is clear, and in addition with better time keeping are the two main limitations of the methodology. We should have noted more accurately where users spent their time, not just record their total as we have done. It would be interesting to see that users spent, i.e 20 minutes, on equation 4.3 and only 4 minutes on equation 4.7 etc. These would be useful data points for analysis. It is certainly something to keep in mind when designing the user testing in the coming thesis project.

The number of cases, and consequently, the number of mathematical concepts covered, is severely limited in this prototype. We can only test for understanding of the one mathematical concept implemented here. It is impossible to generalize from this to all mathematical concepts. This is a known problem for serious games that work toward intrinsic motivational goals, they are often very limited in scope due to their targeted nature [20]. We will attempt to better generalize through utilizing a larger variety of cases and scenarios within the game, each one being focused on a single concept or formula, but as a whole it may cover a larger area within the curriculum. The surrounding game systems such as the economy system and the case selection system, with rewards etc. built in is missing as well. This limits the decisions we can make based on the prototype severely. For further research we need to have the surrounding game systems built in. We will also need to expand upon the culprit selection screen. An idea for this is to create the detectives office, and have to player return there and choose from suspect files or similar lying around the scene. Our design philosophy keeps the world as interactable as possible, the player should as almost never lose control over the character, staying true to the first person controller schema.

An important limitation to discuss here is the size of our test group, in addition to the fact that we only have one group to test. We cannot draw any real conclusions about the games effectiveness above the conventional way from this preliminary project. As the goal for this preliminary project was to draw conclusions about the games design, not its apparent effectiveness compared to the conventional teaching methods, this is not in and of itself a problem. It is however an important limitation to consider when reading this paper and its discussions.

5.4 Future work

As this project is a preliminary project for a master's thesis, this section will mostly outline the work that will be done in the thesis. Some aspects discussed here are will also be out of scope for that project however, and can be interesting angles of approach later on. A detailed project planning report [5] has been written that contains detailed planning on how to implement some of the changes discussed in this section and more.

We have conceived of a game design idea that we are planning on implementing in the thesis. Its main purpose is to build on the prototype case, and make it into an actual

game. At the moment the prototype is more of a simulation, without any large amounts of gameplay. The general idea here is to have the player become a private investigator, taking on various cases similar to the one shown here in the prototype. A user would select a case from a variety shown in a selection or overworld screen of sorts, or select them from folders within the detectives office. The player would then solve the chosen case for a set amount of money based on the difficulty, time spent, amount hints needed etc. We want the economic model here to act as the score for the player. It is necessary to build a hint-giving system into the game, as well as a tutorial of sorts for explaining how the cases work, what you need to do, and how to solve them. Asking for hints would have a negative effect on the monetary reward for solving a case. The current design idea we have for this is that the player calls in consultants for various fields and practices, that cost a certain amount of money. A user may need assistance on newtons law of cooling, and calls in a mathematical consultant. This consultant then needs to be paid, a certain percentage yet undecided, of the economic reward the players gets for solving the case. This in turn will reduce the players overall score. We may utilize these scores in class, institution, country or world based leaderboards, but this is not something we have decided upon at the moment of writing. There are some ethical considerations to this, as it will reflect a players ability to work through the mathematics.

Future iterations of the project would benefit from including voice acting. As the amount of dialogue and background story for each of the cases is very limited, acquiring the voice acting for it should be an achievable goal. Having the textual case descriptions read to them, in addition to being able to read it themselves, will give users another method of acquiring the information needed. This will also help slow readers and dyslectic users acquire the information quicker and easier. On a similar note, future iterations should strive to incorporate sound effects and background music.

For this to be truly useful, we need users to want to play our game, as well as to cover several topics within the mathematics curriculum. It is also paramount that we do not need to have an active observer that can answer questions on the go. We think our private investigator theme is a good fit for this, with the possibility of incorporating different concepts of mathematics, for different cases to solve. They can also have a varying degree of difficulty, to support multiple levels of mathematics proficiency. We would like the system to provide some sort of scaffolding so users who are unable to continue can get meaningful help. This is a challenging question when dealing with mathematics done on pen and paper. Perhaps we need to find a method of incorporating the mathematics into the game itself instead, allowing the computer to crunch the numbers if the user is able to fill in the necessary information and formula. Another option here, is to do ask the user questions to find where they are stuck, perhaps through a binary search of the questions to narrow down the search space. The challenge here is to devise appropriate questions, and not making it tedious for the players who are stuck near the deepest leaf nodes. A third option is to have the user select an appropriate consultant themselves, when calling for help. All of the options requires us to have a deeper understanding of where students are stuck on the exercises we give them, and will require further work. As mentioned in our project plan [5], we may not necessarily want to avoid all questions from users. If we can get students to ask meaningful questions, and prompt discussion in class, it will likely be a positive influence regardless.

To be able to utilize the final product better in a real world setting, we would like

there to be some amount of randomness involved for each student. For this prototype, this would entail generating various environment temperatures, start times for the clock and body temperature for both the current measurement and the previous one made. Then using these values to calculate a time of death, and utilizing this number to generate three separated observation times of the suspects. This should make it harder for users to just select a culprit based on what others have done, although how to work out the formula, or the solution for it, can still be shared. This is no less true for existing compulsories however, and can be considered a non-issue for the scope of this project. In addition to this, for us to be able to test the product better, we should try and have a larger sample size of students, and an additional control group for comparison. Our current plan of action for the continuation of the work is to have two groups, one doing the work on pen and paper, and one doing it through the game. Each consisting of around 12 students, enabling a deeper comparative analysis. Longitudinal studies that investigate the long term usage of the game, and its effect on motivation, learning outcomes, and adaption is out of scope for these projects. If we are able to validate our designs, and see a positive outcome in the thesis project, it will be an avenue for further research. To better see the actual results of the game, it would be important to study entire classes' usage of the game over the course of entire semesters. Looking at things such as time spent in the game, grades and learning outcomes, percentage of students using the game, which areas the game can be applied, etc. This is reliant upon a positive outcome for our thesis, and will require the game to be expanded further to cover a larger section of the curriculum.

Another interesting avenue to explore in the future is virtual reality. VR is well supported in Unreal Engine, making it possible to use a variety of virtual reality headsets [35][36][37][38]. It is out of scope for both this project and the thesis, but it would be interesting to attempt to include VR in the future. For this you would have to change several aspects of the game, perhaps include an in-game whiteboard or similar for the user to interact with instead of having them do the work on pen and paper alongside the game. Even if we ignore the barrier of doing everything in VR, another potential issue here is cybersickness [39], with up to as many as 60% of users affected after only a ten minute immersion session[40]. This would be a deal breaker for our purposes, considering we expect players to play for at least 45 minutes to an hour. We don't think motivating people to do higher level mathematics while being nauseous is an achievable goal. There are certainly solutions to these problems as well, but they are out of scope for this discussion and project.

6 Conclusion

In conclusion we received enough positive feedback about the concept, and how it was to play, that we are confident we can push forward with the development. The majority of our testers wanted to see something akin to this, and felt it was useful for a variety of reasons. Even given the small, and seemingly homogeneous test group, we know that at least a portion of the users in a class will find this useful. Whether or not this has an academic impact remains to be seen, but we are hopeful it will at least provide a subset of students with another angle of approach to higher level differential equations and similar concepts.

All students seemed to be able to find the information necessary within the game to solve the problem fairly easily. Even if they did have trouble doing the mathematics itself. They did not seem to have any trouble understanding how to complete the game however, with everyone happily exploring the scene and finding the necessary clues. Our feedback from the questionnaire shows that the majority liked the information shown in the journal (see figure 8), and felt it was enough information portrayed to solve the case. Similarly we only had one student respond that it felt unnatural to solve the mathematics next to playing the game, with the rest answering from neutral to completely natural, as can be seen in figures 7 and 26. Our results and discussion show that students did find the mathematical aspect challenging, but they did not find finding the clues within the game difficult. Students found the total experience to be good and engaging, and they reported interest in seeing our design ideas implemented in the future. Given this we are confident we have answered the questions we set out to answer sufficiently to continue development in our thesis project. We are looking forward to continuing the project, improving it, and testing the results in its completed state.

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Appendices

A Acronyms and abbreviations

AAA - Triple-A games. An informal classification used for games with the highest development and marketing budgets.

NTNU - Norwegian University of Science and Technology

TA - Teaching Assistant

US - United States

VR - VIrtual Reality

B Additional screenshots of the game

Figure 10: Another view of the apartment scene.

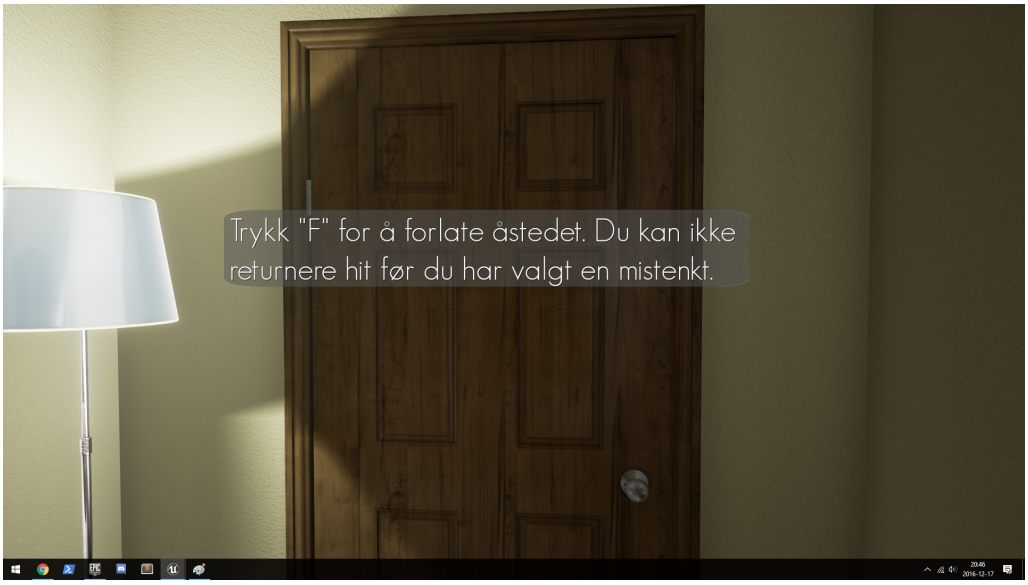

Figure 11: A view of the exit door.

Figure 12: A different viewing angle.

Figure 13: A closer look at the body, and the surrounding cityscape.

C Mathematical solution using test scene variables

Given the variables found in the example scene (See equation 4.1 on page 9 for a full detail about variables and their significance), a possible solution for time of death is as follows:

$$\begin{aligned} T &= T(t) \\ k &= \text{a constant.} \\ T_e &= 18.7 \\ T_0 &= 37.0 \\ x &= 2 \\ T(t) &= 20.3 \\ T(t+2) &= 19.4 \end{aligned} \tag{C.1}$$

First we solve for T inputting our known variables:

$$\begin{aligned}
\frac{dT}{dt} &= -k(T-18.7) \\
\frac{1}{(T-18.7)}dT &= -kdt \\
\int \frac{1}{(T-18.7)}dT &= \int -kdt \\
\ln|T-18.7| &= -kt + C \\
\ln(T-18.7) &= -kt + C \\
\ln(T-18.7) &= -kt + \ln(37.0-18.7) \rightarrow \text{Replace C by solving for T(0).} \\
e^{\ln(T-18.7)} &= e^{-kt+\ln(18.3)} \\
e^{\ln(T-18.7)} &= e^{-kt}e^{18.3} \\
T-18.7 &= e^{-kt}(18.3) \\
T &= 18.7 + 18.3e^{-kt}
\end{aligned} \tag{C.2}$$

Given this we fill in to set up our two measurement equations:

$$\begin{aligned}
20.3 &= 18.7 + 18.3e^{-kt} \\
20.3 - 18.7 &= 18.3e^{-kt} \\
\underline{e^{-kt} = \frac{1.6}{18.3}} \\
19.4 &= 18.7 + 18.3e^{-k(t+2)} \\
19.4 - 18.7 &= 18.3e^{-k(t+2)} \\
\frac{0.7}{18.3} &= e^{-k(t+2)} \\
\underline{e^{-kt}e^{-2k} = \frac{0.7}{18.3}}
\end{aligned} \tag{C.3}$$

Then we substitute e^{-kt} in equation 2 with equation 1 to find $-k$.

$$\begin{aligned}
\frac{0.7}{18.3} &= \frac{1.6}{18.3}e^{-2k} \\
\frac{0.7}{18.3}\frac{18.3}{1.6} &= e^{-2k} \\
\frac{0.7}{1.6} &= e^{-2k} \\
\ln\left(\frac{0.7}{1.6}\right) &= -2k \\
-k &= \frac{1}{2}\ln\left(\frac{0.7}{1.6}\right)
\end{aligned} \tag{C.4}$$

Next, we substitute $-k$ back into Equation 1, solving for t:

$$\begin{aligned}
\frac{1.6}{18.3} &= e^{\frac{1}{2}\ln\left(\frac{0.7}{1.6}\right)t} \\
\ln\left(\frac{1.6}{18.3}\right) &= \frac{1}{2}\ln\left(\frac{0.7}{1.6}\right)t \\
t &= \frac{2\ln\left(\frac{1.6}{18.3}\right)}{\ln\left(\frac{0.7}{1.6}\right)} \\
t &\approx 5.895
\end{aligned} \tag{C.5}$$

This shows us that the murder took place 5.895 hours before measurement number 1. In the scene, measurement number 1 was done at 8:00 am, giving us a murder time of roughly 02:05 am. Given this information, the tester should be able to select a murder suspect based on the images and times given in the suspect selection screen seen in figure 4.

D Detailed list of all questionnaire questions

Below you will find the entire questionnaire, as well as a description of each of the questions alongside the possible answer ranges. The descriptions from the questionnaire are shown in the italicized text, if any were present. As the questionnaire was done in Norwegian, all questions below are translated into English.

1. How often do you play games? (Multiple choice, 5 point scale)
   - Never (1)
   - Yearly (2)
   - Monthly (3)
   - Weekly (4)
   - Daily (5)
2. What is your view on games? (Very Negative - Very Positive, 5 point scale)
3. Did it feel unnatural to do mathematics while playing a game? (Very unnatural - Completely natural, 5 point scale)
   Did it feel natural to break from the game to solve a mathematical task.
4. Did you have any previous experience with Newtons Law of Cooling? (Not at all - Very well known, 5 point scale)
5. How was complexity of the room? (Simple - Complex, 5 point scale)
   Based on the amount of objects and interactive elements in the room/scene.
6. How was the size of the room? (Small - Large, 5 point scale)
   Did you think the room was small? Was it large? Just right?
7. How difficult did you find the mathematical aspect? (Very difficult - very easy, 5 point scale)
   How difficult was the mathematical part of the task?
8. How was your total experience? (Very boring - very engaging, 5 point scale)
   Was it boring? Engaging?
9. Was there anything about the game that made you frustrated while playing? (Optional written reply)
10. How important is realistic graphics for your experience? (Very unimportant - Very important, 5 point scale)
    This game has a fairly realistic graphical style. Should we keep focusing on graphics, or put this time into other elements?
11. How difficult was the game part of the task? (Very difficult - very easy, 5 point scale)
    The game aspect centered around gathering information in amurder investigation setting. How difficult was it to find all the information you needed to solve the task?
12. How did you think the information in the journal was conveyed? (Check boxes, select

all that apply)
Select any that fit with your opinion.

- Too little information
- Just the right amount of information
- Too much information
- Good information structure
- Bad Information Structure
- Did not like the journal at all

13. Were the controls of the game intuitive? (Multiple choice, 3 options)
Did you understand how to control the character in the game? How to get information from the body, and how to open the detective journal?
    - Yes
    - No
    - They can be improved
14. Did you think it was an appropriate scenario? (Very inappropriate - Very appropriate, 5 point scale)
Do you think a murder investigation is an appropriate scenario to apply mathematics in?
15. In the future a game where you work as a PI on several cases is being considered. Does this sound exciting? (Multiple choice, 5 point scale)
Imagine that this is a part of a mandatory exorcise or lab practice. Would you like to see something like this?
    - No, not at all (1)
    - Maybe a little (2)
    - OK (3)
    - A little exciting (4)
    - Very Exciting (5)
16. Do you think a game like that is a good aproach to making mathematics more engaging? (Not at all - definitely, 5 point scale)
17. If you could choose between a larger game similar to this, or a normal mandatory delivery, which would you choose? (Multiple choice, 3 options)
    - A normal delivery
    - The game
    - Something else
18. Give a reason for your previous answer (Optional, text entry)
We value any detailed feedback
19. Would you prefer to do this in small groups (Multiple choice, 2 options)

- Yes
- No

20. Which language would you prefer the game to be in? (Multiple choice, 3 options)
    - Norwegian
    - English
    - Other
21. Any extra comments (Optional, text entry)
    Here you can write any feedback you think is appropriate, but that has not been covered by the previous questions.

E Unordered list of questionnaire results (In Norwegian)

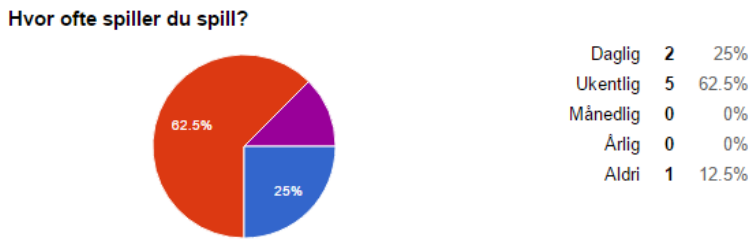

Figure 14: How often do the testers play video games?

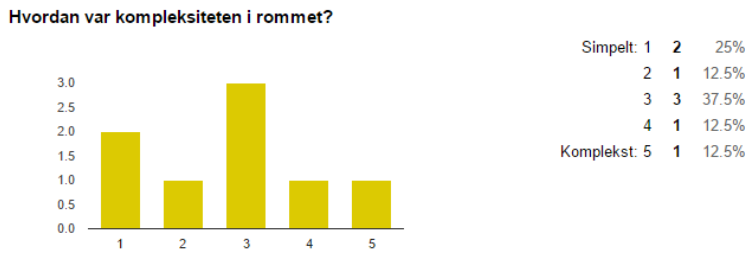

Figure 15: How was the room complexity?

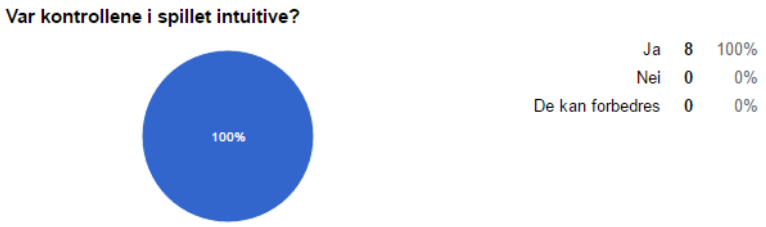

Figure 16: Were the game controls intuitive?

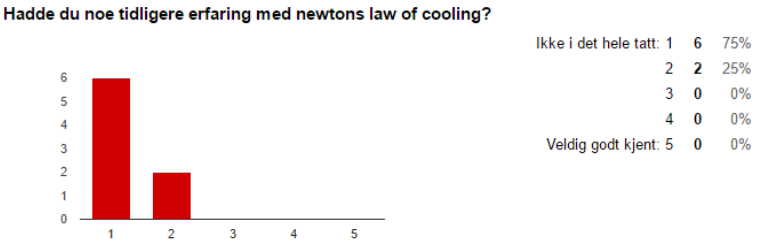

Figure 17: Previous experience with Newton's Law of Cooling?

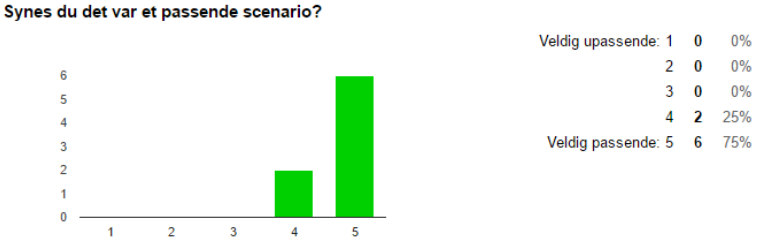

Figure 18: Did you think it was a fitting scenario?

Figure 19: Did you find the game aspect difficult?

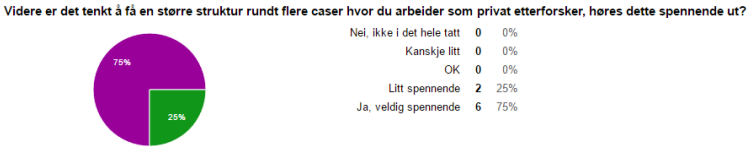

Figure 20: In the future we want to build a system where you work as a private investigator solving several cases, does this sound interesting?

Figure 21: How important is realistic graphics for your experience?

Figure 22: Would you prefer to work on this in groups?

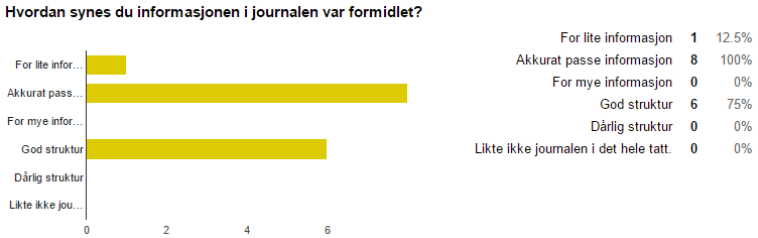

Figure 23: How did you find the journal conveyed the necessary information?

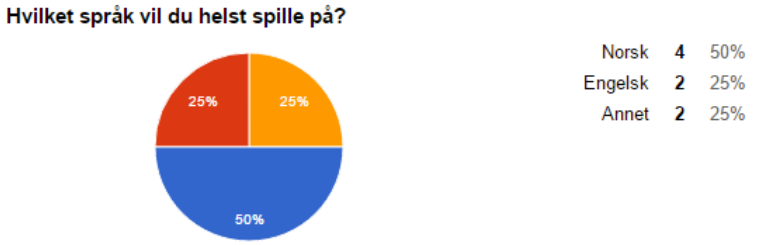

Figure 24: Which language would you prefer to play in?

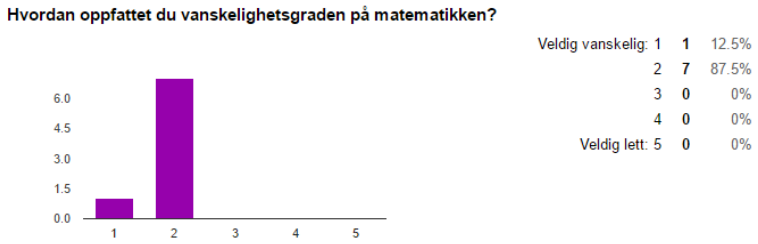

Figure 25: How difficult was the mathematics?

Figure 26: How did it feel to do mathematics alongside playing a game?

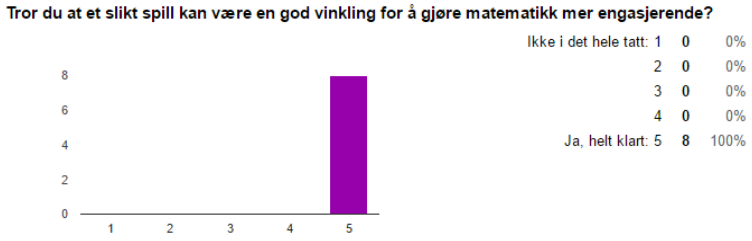

Figure 27: Do you think a game such as thing is a good angle of approach to make mathematics more engaging?

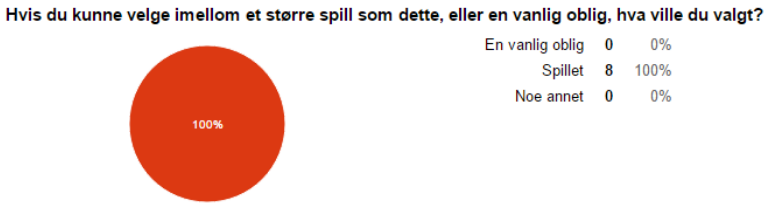

Figure 28: Would you prefer a standard 'oblig' or a game like this?

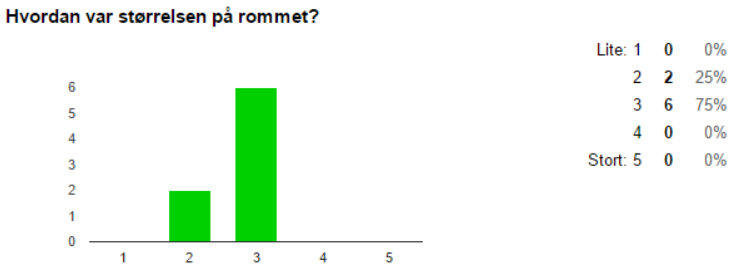

Figure 29: How was the room size?

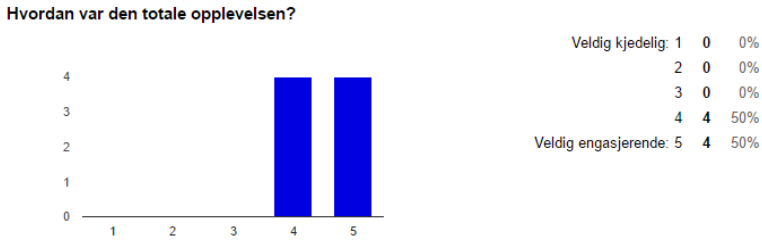

Figure 30: How was your overall experience?

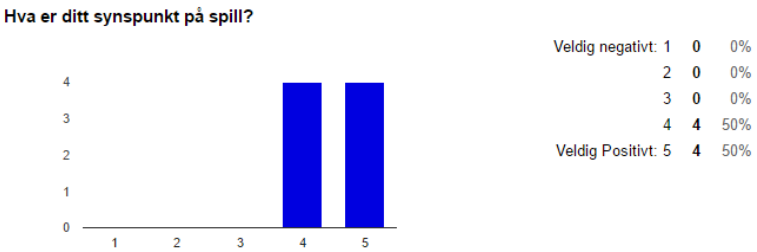

Figure 31: What is your view on games in general?