# Serious game supplementing higher level mathematical education

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**Abstract**

University level mathematics is a challenging topic, covering a broad spectrum of different concepts. Many students enrolled in STEM fields find these concepts difficult to grasp and understand. In the US alone science and engineering students have a 50% dropout rate, with most citing the conventional teaching method as a main concern. Can we apply and build upon recent research within the serious game area with beneficial effects? We plan to contribute knowledge regarding the usage of serious games at calculus level mathematics, and how it compares to the conventional pen and paper way. We will also investigate in which scenarios lecturers would like to see a tool such as this applied. This paper details the plan of action, and analyses surrounding potential issues for this thesis project.

# Contents

# 1 Introduction

## 1.1 Topic covered by the project

The purpose of the project is to investigate the possibility of utilizing a serious game to supplement higher level conventional mathematical education. Specifically the target audience will be students enrolled in R2[1] and calculus [2] level courses. We want to design an expandable game system framework, that students and teachers can make use of to practice and further their understanding of mathematical concepts. We will do user testing to validate design decisions, and get feedback from lecturers on potential areas of application.

## 1.2 Keywords

serious games, games for education, game design, calculus, user testing.

## 1.3 Problem 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 [3]. 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 [3]. In the US alone, science and engineering enrolled students have a 50% dropout rate, with most citing the conventional teaching method as a main concern [4]. In recent years there has been an increased focus on studying serious games, mathematical and otherwise [5] (See figure 1). Can we make use of this research, and apply it to university level calculus with beneficial effects?

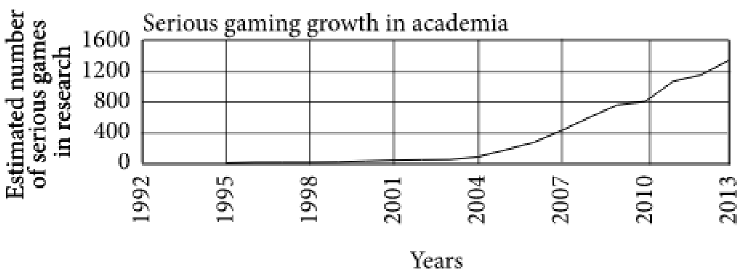


Figure 1: Serious games growth in the research field based on surveyed papers in ACM digital library and IEEE Xplore. Graph by Laamarti et al. [5].

## 1.4 Justification, motivation and benefits

As briefly mentioned above, in the US alone science and engineering students have a 50% dropout rate, with most citing the conventional teaching method as a main concern [4]. About 25% of students report having some level of conceptual difficulties, both for dropouts and those who remain [6]. In addition to this, Berry and Nyam claim that students often go through their first course in calculus without developing an actual understanding of the symbols and formulae, avoiding a true conceptual understanding of the topics involved [7]. Given this in addition to the other difficulties faced when dealing with higher level mathematical concepts, such as word problem understanding[3], and usage of familiar formulae to find functions [3], we claim a serious game can be a worthy addition to the educational toolbox. Research shows that serious games can, if done correctly, be an effective tool for learning and motivation [4, 8, 9, 10, 11, 12, 13]. Utilizing this to help motivate students that may be having trouble with the conventional mathematical education is our goal.

## 1.5 Research questions

The project will consist of three research questions that we will attempt to answer:

1. How does our serious game compare to doing mathematical problems with pen and paper?
2. In which educational settings do teachers envision applying the game?

## 1.6 Planned Contributions

We plan to contribute knowledge regarding the usage of serious games in an educational setting at university level institutions. We will determine how our serious game compares to doing the same task on pen and paper, the conventional way. Specifically, we will provide insight into whether or not students are motivated in the future and in the moment, to do mathematics, if they are more engaged when playing our game, if they spend more or less time doing the work, and the perceived difficulty of solving the task. We will also record quantitative data related to the scores of users in the game, and the time spent on solving the task. We will distinguish between time spent on the mathematics, and the time spent on the game. Investigating in which educational settings a teacher or lecturer will want to make use of the game is an important question to answer as well. We will interview several teachers at the target audiences level of mathematical education, asking what they are looking for in a tool such as this, and in which settings they would apply it given the description. In addition, we are looking to investigate how well our design decisions regarding modular mathematical concepts portrayed through cases work, and how this can be used to build cases about a wide variety of mathematical topics in the future. The process and results will be detailed in a monograph. Upon completion of the thesis and presentation, a separate paper detailing the results will be written.

# 2 Related work

## 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 [4]. 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 [4].

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 [3]. 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 [7]. 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" [7].

## 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" [11]. This can be a change in knowledge, health, motivation, ability, etc. [11]. They are often classified into categories of taxonomies including games for education, health, and training [11, 14, 5]. Another definition of a serious game can be "any video game built to differ from pure entertainment" [15], meaning any games that have a purpose other than just providing the user with entertainment [5]. According to Laamarti et al. basing the definition on the intentions of the designer may not be good enough [5]. A developers intentions are rarely accessible [16]. As such, Laamarti et al. define serious games as "An application with three components: experience, entertainment, and multimedia." [5]. Our game will be classified as a game for education, narrowing our search space of what has been done in the area. 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 [17].

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 [18]. 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


Figure 2: How important is realistic graphics for your experience?

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 [19]. 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 [10]. Similarly, Wouters et al. show that serious games are in-fact more effective than conventional instruction methods [8]. Their research show that serious games are an effective tool when used in groups [8]. 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 [11]. In addition, Wouters et al. also demonstrate that the knowledge gained is retained long term [8]. 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 [8, 10]. Our preliminary pre-project showed however, that students self-reported that realistic graphical fidelity was an important factor for their user experience. Their answers can be seen in figure 2. Considering the power of Unreal Engine and the potential of relatively easily creating a high graphical fidelity scene, we will still aim to create a high fidelity scene.

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 [13]. 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 [13]. For simulation games, used in training, the results are also favorable. Showing outcomes superior to the comparison group [9]. 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. The immediate project that comes to mind must be our pre-project [20], where we have successfully tested and acquired feedback from users on our design decisions. We have also described this further in our feasibility study below (see chapter 5). The pre-project consisted of working through one case of the planned game design (see section 3.2 for more detail), then asking users during playtesting for feedback on various aspects such as mathematical difficulty, room size and complexity, total experience, etc. Important and relevant lessons learned from this are time consumption needed for the development of a scene, the time spent on testing per user, and of course the responses given about our design decisions. We learned that all students that participated thought the case was a fitting scenario, and that they all found the mathematical aspect challenging, while finding the game aspect very easy. In this project we will attempt to alleviate some of this by selecting an easier mathematical concept to compliment the more challenging application of Newtons Law of Cooling.

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 [8]. We want to apply this to our case system described in section 3.2. As student motivation is a key predictor of successful education outcomes [21], 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 [22]. Here again, we will attempt to apply our case system to create a more generalized game supporting many concepts and ideas. 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[23, 24]. 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[23]. Is the player able to master new concepts and ideas, is the player challenged appropriately? This in turn relates to the concept of flow [25], 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 [23]. Our pre-project investigated how test users felt about our controller scheme, with 100% of respondents answering positively. 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 [23]. Likely due to the self-determination theory principles of agency and autonomy, making playing the game compulsory may have a negative effect [17]. Another interesting note is how to deal with failure. Research show that failure may cause frustration, playing a very difficult game may be unattractive [17]. This again relates back to the concept of flow [25]. 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 [17]. This is more akin to how learning works in the real world [17]. A relatively similar game to what we are attempting to create is "DiffGame", where they attempt to teach differentiation through a serious game [26]. 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[27]. They also claim that no real solutions for teaching college math exist at the time of writing. Dimenxian [28] is another game aimed at teaching algebra. Mayo discussed the academic improvement of playing this game, citing a 30% improvement over the control [4]. It's a deal is a game aimed at teaching business English, showing empirical data in support of the learning effectiveness of the game [12]. 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 Choice of Methods

In this section we will detail our methodology. First we will describe how we choose the mathematical concepts we utilize in our cases. Second, we will describe the general game design, and which tools and concepts we will be adding. Lastly, we will describe our plan of action for how to answer our two main research questions through user testing with students and lecturers.

## 3.1 Mathematics

The target audience for our game will be students enrolled in courses covering topics on calculus. As such, determining which mathematical concepts and formulae to include is an important aspect of the project. The preliminary project successfully included a case on the subject of newtons law of cooling and first order separable differential equations. The second case will focus on a different concept, which will be determined early on in the projects life cycle. We will select the formula and concept by closely working together with a mathematical adviser, discussing various options for relevant mathematical concepts. Having selected a relevant concept, we will create a textual problem, or select one that already exists, and begin designing a case that fits well. It is important that it works within the theme described below in section 3.2.

## 3.2 Game design and development

We have chosen Unreal Engine 4[29] as our game engine for the development of the game. This was chosen based on several factors, including the graphical fidelity, speed of prototyping and the potential of using blueprints to create visual code quickly, as well as the authors previous experience working with the engine. The general design for the game, is that the player takes on the role of a private investigator solving various cases from murders to traffic accidents. In all scenarios the player is expected to apply their knowledge of mathematical concepts to solve the case. Depending on the difficulty of the case selected, this may involve pen and paper mathematical work. Successfully solving the case will give a monetary reward, based on various factors such as time spent, and the amount of consultants called in. Consultants will work as the main method for a player to ask for hints when they are stuck either in the game play aspect, or on the mathematical aspect of the game, serving as the main method of scaffolding. For this project, a total of two cases will be available in the system. This includes code and design improvements, if necessary, to the case created in the preliminary project. The system should be expandable in the future, allowing for additional cases to be seamlessly added. We plan on creating an overworld system where the user will select the case they wish to solve, henceforth known as the "crime net" system, which will give them a short description of the mathematics involved, and what they gain from solving it. We want teachers to be able to add modular cases fitting their needs as time goes on. Perfecting this modular system is not the main goal of this research project however, and will not be the main priority when it comes to time commitment. The game design draws inspiration from several well known games, such as L.A Noire[30], Payday 2[31] and others, though less action-packed. Similarly, user interface elements and control schemes will be heavily inspired by blockbuster games currently on the market, as these are successful. This should result in a familiar and intuitive interface for users. Throughout the design process we will be referring to papers discussed in the related work section (Chapter 2). We need to stay persistent with self-determination theory principles, and look to previously created serious games for insight into what works, and what does not. As we have already gathered successful feedback on some design elements in the preliminary project however, the design of the game, and the second case will in all likelihood stay consistent.

## 3.3 User Testing

We will do user testing in two groups, both working with the same mathematical formulae, but using two different approaches, to answer our first research question. We will have one group doing it the traditional pen and paper only way, and the other doing the math alongside our game. We aim to compare the results of each group, looking at factors such as self-reported motivation, engagement, perceived difficulty of the maths, etc. We will gather a mixture of qualitative and quantitative data, using a questionnaire as well as observing the play sessions of the users. We will record time spent on mathematics and gaming separately, and compare the two groups to one another. Do users of the game spend more time than the control, or do they spend less, and how much of this time is spent on mathematics vs. solving the cases within the game? Do the game group perceive the difficulty of the mathematics differently? These are but some of the questions we will ask. The final design of the questionnaire will not be ready until the design of the second case is finished. We will analyze the data gathered here to answer our first research question. The questionnaire will be designed to fit, with a few exceptions (i.e background information), a five point Likert scale[32], similar to the research done in the preliminary project work.

In addition, to answer our second research question, and to attain knowledge regarding possible usage scenarios, we will interview several lecturers responsible for mathematics courses at high school and university levels. The interview questions will be designed early on in the projects lifetime, and will be done through one-on-one interviews that may be recorded for analysis later. Our chapter on milestones (4) will cover more about when this will be done in the project cycle.

# 4 Milestones, deliverables and resources

## 4.1 Project Overview

The project planning is based around an 8 hours a day, 5 days a week schedule for one person, the author. For every week described below, we can then estimate about 40 man hours of work. The plan can be broken down into four general phases or parts:

- Preliminary work
- Software development
- User testing and analysis
- Report writing

The preliminary phase will have to be completed before work can begin on the development. Similarly, development will have to be completed before user testing can be done, giving us the necessary data to analyse. The report writing phase will be continuous throughout the project, but the final draft containing results and analysis will rely upon completed user testing. A detailed view of the timeline, dependencies and estimated work weeks can be seen in figure 3. The project will last roughly 24 weeks, giving us a total of about 900 work hours to plan for. Some amount of room for variations and delays have been accounted for here. If by any chance development progresses significantly faster than expected, a third case may be considered.

## 4.2 Required Resources

Development of the different cases and "crime net" system will require a set of graphical resources and assets. This includes, but is not limited to, 3d models, textures, materials and shaders for different settings. As the second case is not yet designed, a strictly detailed list of which materials, models etc. that will be required is unavailable. We estimate that the majority of the assets can be attained for free, with some exceptions. Depending on the setting, the unreal and unity marketplaces contain a varied selection of asset packs, ranging from $0 to about $150 in estimated cost. If the design of the case requires it, applying for funding for an asset pack may be required. This should be determined in the preliminary work phase of the project. It is also desirable to acquire a set of audio assets, such as different background music and interact sound effects. If time permits, we wish to add voice acting to the game, allowing us to tell the stories related to the cases in a different manner. This will require subtitles as well.

The project also require some human resources. To do the data analysis planned, we require two test groups consisting of roughly 10-12 students each. We are also looking to interview teachers in charge of these, and other students. Recruitment of these students from the target audience is an integral part of the project. The testing itself will require a computer capable of running the testing prototype. As done in the pre-project [20], this can be acquired through the university. If this does not work out however, the authors personal machine can be used as a backup.

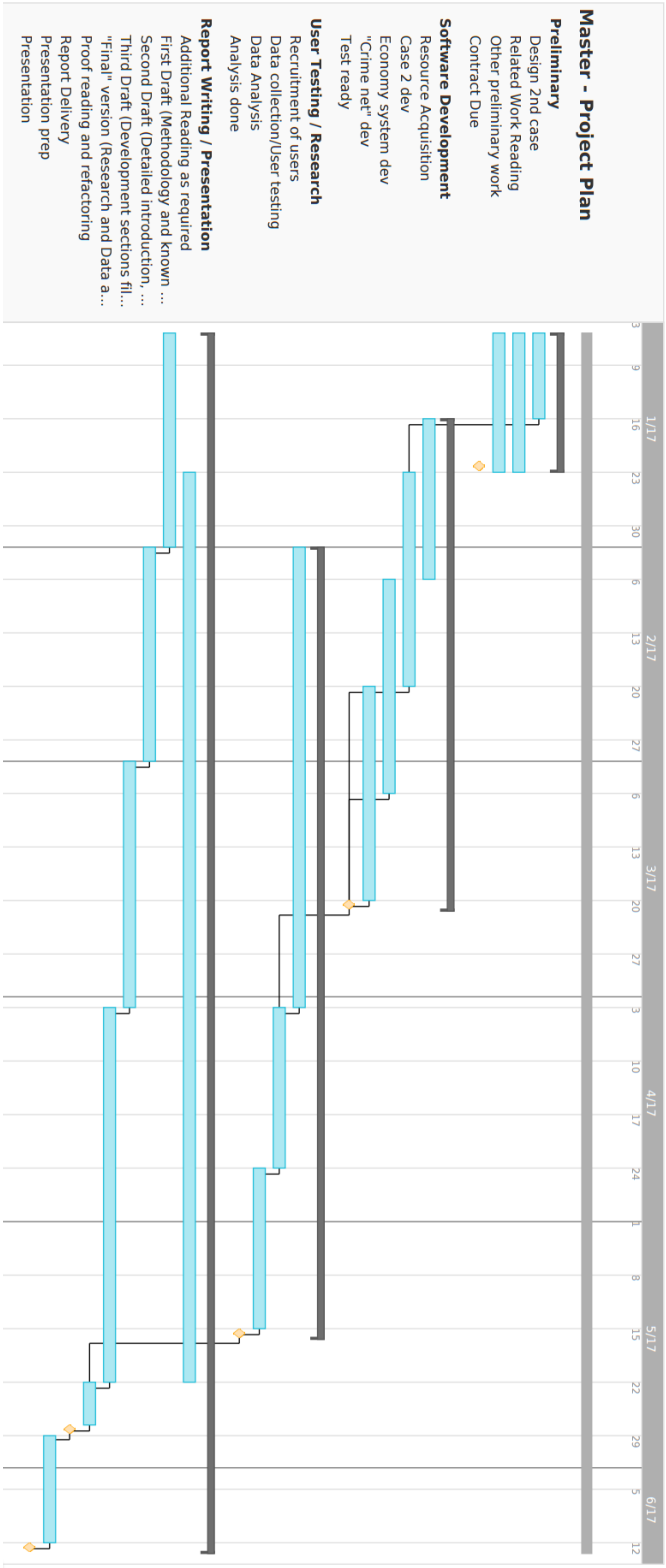


Figure 3: Gantt chart describing the projects workflow.

## 4.3 Preliminary Work

The first three weeks or so of the project will consist of a preliminary work phase. Here we will flesh out the design of the second case, as well as make any design changes, if any, that may be required of the first case created in the preliminary project [20]. The design aspect of the second case will include deciding upon the mathematical concept, or formula, which will be used in the project. Deciding upon the mathematics will be done in cooperation with a mathematical adviser (see chapter 6). At the beginning of January, Wolfram is hosting a webinar about computer based maths[33]. We will likely attend this, as well as the introductory seminar on the 12th of January.

We have estimated a full two weeks of work to do extra reading for related work. During the planning and pre-project we may have missed important papers and reading related to the project, and it will be useful to once again go over related work in the various databases available.

Other preliminary work includes designing the questionnaire/interview questions that are aimed at the lecturers. To be able to incorporate the answers into the design, we should attempt to do this as early as possible. As we need to be able to describe the second case, and the surrounding systems, the interviews themselves will be done at a later date. We will also be determining whether or not we need NSD approval to collect our data[34], and if necessary, apply for the necessary permits in this part of the project cycle. It will be dependent on whether or not we find video/audio recordings of interviews and play sessions necessary. The final milestone for this phase of the project is due the 20th of January, when the deliverable for the project contract with signatures is due. When this is successfully completed, this phase of the project will be officially completed, and development may begin.

## 4.4 Software Development

This phase will consist of 4 sub parts, which will be done somewhat simultaneously due to overlap and dependencies in the code base and functionality. First is the acquisition of resources needed. This refers to the 3d models, materials and textures that are necessary to build the cases. The large majority of resources needed for case one have already been found and used in the pre-project [20]. This means that the design of the case done in the preliminary work phase will determine what models etc. are required. This can range from a similar apartment to the proof of concept prototype, or it can be a car crash, or maybe an open air park. Whatever the case will be, assets will have to be acquired early so we can adapt if it is not possible to attain a certain asset.

Next comes the actual development of the second case. Here the scene itself will be mapped out, and the mathematical formula used written into code. We estimate this will take about 3 weeks of actual development time when the design is already determined. It should take considerably less time than during the pre-project due to a higher familiarity with the chosen tools, and the workflow of using blueprints and C++ interchangeably. The scene will still be edited if necessary in the following sub phases of the development phase. Next comes the development of the economy system where we add the functionality of cases having a monetary reward, as well as the possibility of users spending money on hints or consultants. This will function as the score of the player, and will be determined based on a number of factors determined, including, but not limited to: time spent, our perception of the difficulty, number of hints used etc.

Finally, we will develop the "crime net" functionality of the game. This serves as a sort of overworld, where the user can select and choose cases that "pop up", with information about the reward, estimated time usage, and difficulty. The idea for this is to be expandable in the future, where new cases can be added to the system, without breaking the functionality. When development of this is completed, this phase of the project will be considered complete, and ready for testing.

## 4.5 User Testing and data analysis

We have estimated roughly three weeks of time to perform the user testing and gather the necessary data. We estimate, based on the pre-project [20], that each user will spend in the range of 1-1.5 hours testing the prototype. With our goal of having 20-24 students split over two groups, this should be within acceptable parameters. Before testing, we have estimated using a fairly large chunk of time on the recruitment of testers. We want to begin recruitment relatively early, and well in advance of the actual testing. The plan is to reach out to several high schools in the area, getting into contact with teachers in charge of R2 classes, and looking for students in the target audience. See the section on risk analysis (6) for detail on how to deal with any potential issues here. During the user tester acquisition phase, we will be performing the interviews with lecturers as well.

After having gathered the actual data required, we estimate about two to three full weeks spent on analysing, charting, and going through the data while simultaneously writing it into the report. This can be reduced if necessary to fit in more students, later on, into the testing schedule. Similarly, if testing is finished ahead of schedule, we may push this ahead leaving more time for reflection and writing.

## 4.6 Report writing

The report writing phase of the project will be done throughout the entire duration. It has been split into four different drafts, with more detail added for each one. The plan is to have a new draft version ready with new information added once a month. This should provide ample time to get feedback on the various drafts, make edits, and deliver a well written monograph at the end of the project.

As can be seen in figure 3, we have planned seven different parts for this phase, one for each of the drafts, one for proof reading and restructuring, one for the presentation, and one for additional reading. We want to have some time set aside to read any extra material that comes up during the project. It is impossible to plan for every single avenue that may be interesting to pursue, and it may be necessary to include additional related work and citations as we go. The first draft written should contain a description of the information we know at an early stage of the project, including the methodology, advisers, a quick introduction, etc. The second draft should contain a more detailed introduction, a decently filled in related work section, and an early description of the development already done at this point. The third draft will contain a properly filled out description of the developmental aspects that have been done up to this point, in addition to any rewrites that may be necessary of the previous sections. The fourth, and final draft, will contain the results from the user testing, as well as the data analysis performed. Here we will also add the section for future work and limitations. This will be fairly close in content to the report that will be delivered at the end. The remaining time will be spent on proof-reading, restructuring, and adding missing tidbits of information until the project delivery. The final milestone and phase of the project is the preparation and execution of the thesis presentation and defense. The final two weeks of the project will be dedicated to this, as there are no more changes to be made at this point.

## 4.7 Preliminary Table of Contents

The planned structure for the thesis monograph is as follows:

- Abstract
- Keywords
- Acknowledgements
- 1. Introduction
- 1.1 Covered topics
- 1.2 Problem Description
- 1.3 Motivation
- 1.4 Research Questions
- 2. Related Work
- 3. Methodology
- 3.1 Game Design
- 3.2 User Testing
- 4. Results
- 4.1 Development
- 4.2 User Testing and data analysis
- 5. Discussion
- 5.1 Development
- 5.2 User testing
- 5.3 Limitations
- 5.4 Future Work
- 6. Conclusion
- Bibliography / Reference List
- Appendix A-Z (as necessary)

# 5 Feasibility study

Our trial run during Advanced Project work has convinced us that this project is feasible to complete in the allotted time. The general feedback given from users on our questionnaire was very positive. As can be seen in figure 4, with the exception of room size and complexity, we received positive feedback on all game design related questions. With 3 being "Just about right" on the scale for room size and complexity, we can see that the users found it a bit on the small, uncomplex side. The results proves that there is interest in a serious game similar to what we are creating.

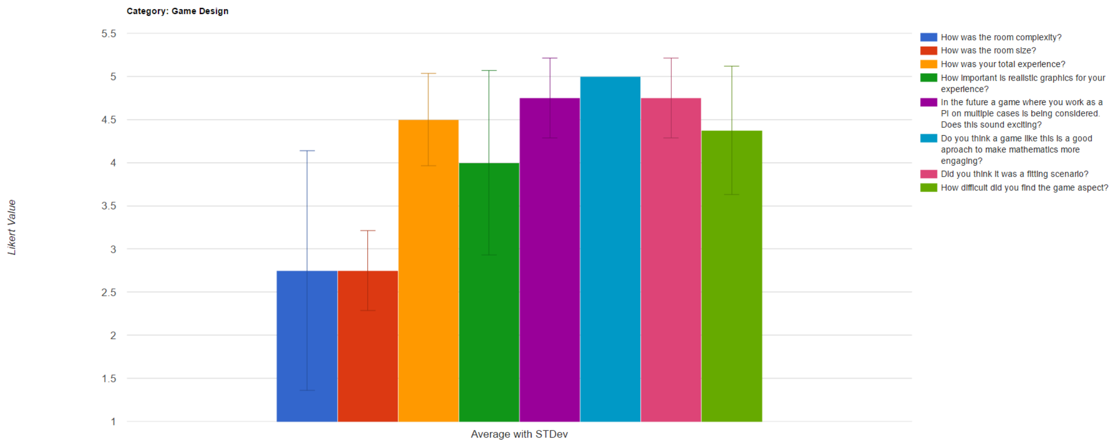


Figure 4: Feedback given on various game design questions during the pre-project, on a 5-point Likert scale.

Pedersen et. al has shown that applying a serious game to physics learning at university level is an effective tool, with the middle tier of students benefiting the most[26]. The game Dimenxian, aimed a teaching algebra[28], has also been applied successfully[4]. Given that there is precedent for similar applications of games at university level, and that we have successfully tested parts of the methodology on a small sample group, we are confident the project is feasible.

The major issues faced in the project to come will be how to deal with users needed assistance. In the pre-project we did this manually, but for the thesis project we need to come up with a method of affording the user with hints dynamically. The concept of consultants described earlier will be used to attempt to solve this problem. We will attempt to do this by utilizing a binary tree styled search to figure out where the user is stuck, narrowing down the search space. Another option we are considering for solving this is to allow the user to ask consultants on specific topics directly. This will enable the user to ask questions like "How can I solve for x in $9 = x^2 + 7x + 3$". This will require a deep understanding of the mathematical issues a user may face during the process. The pre-project did show several areas where multiple users were stuck on the same issue that we can implement for case 1. Regardless, there will still be issues that students will come across that we cannot predict. As the game is intended to work as a supplement however, and not a dedicated teaching tool on its own, this is not necessarily a deal breaker. This can prompt teacher-student conversation, in class or otherwise, or it can help create a feeling of community within the class through discussions[11]. Over time it will allow the creators and managers of the system to add hints that come up often if missed.

# 6 Risk analysis

User testing done in a pre-project helped identify some elements that can be discussed [20]. There are several issues that may arise during the execution of the project. First of all is the informational content of the game being blatantly wrong. It would be destructive both for the projects outcome, and for the users' perception of games for education if this is the case. As discussed below in chapter 7, we should not negatively effect a users end grade level with this, leading to permanent consequences.

On a related note, another issue that may arise, although unlikely, is that we are unable to find a mathematical concept that fits well into our setting and theme. As we have already discussed several alternatives with a mathematical adviser, we do not find this very likely, and can consider it a non-issue for this purpose.

We may also face some issues during the developmental aspect of the project. Particularly, we may be unable to procure the assets necessary to build the themes in the various cases, especially if we want to keep a similar graphical style to one another. We have several possible solutions to this problem. First of all, we can drop the graphical fidelity, making it easier to find assets. Second, we can buy asset packs that are readily available in the marketplaces for both unreal and unity. As long as the licenses allow, the .FBX models can be used interchangeably between these two engines. The third option, although the least likely to be applied, is to commission an artist to create the models necessary. As this is a time-consuming, and likely expensive, process, we will not consider this option unless all others fail. If this is the case however, it is necessary to identify it as early as possible, so we can provide an artist with enough time to create the content required in time.

The main concern for our project however, is regarding getting enough users to form two proper test groups. As we are interested in comparing the motivational effect and interest in the two different cases, we need to have enough volunteers to fill two groups. As described above, we wish to get at least 20-24 students for this purpose. If we are unable to obtain the human resources necessary, the methodology will not be executable. The solution we have to solve this problem is twofold. First of all, we will reach out to potential classes of the target audience across several institutions early in the process. This should allow us to get a large number of students in time for the testing in April. If this does not result in a large enough sample size, we will branch out to also include students enrolled currently in calculus 2, giving us a three-courses wide target audience. Calculus 2 students will have passed the mathematics of calculus 1 recently, and should therefore be familiar enough with the concepts to give valid feedback. We are confident that by applying these solutions we will be able to obtain a large enough sample size to gain useful insight into our research questions.

# 7 Ethical and legal considerations

The project will include quantitative and qualitative studies including test subjects, incorporating both questionnaires and more detailed user-interviews and play testing sessions. There are some legal concerns that have to be addressed. It is necessary to record and analyse the data taken from these sessions, which will be treated anonymously where possible. However, it may prove interesting to compare students grade level to their understanding of the mathematical topics covered in the serious game, as this may be a confounding variable affecting the results. As these grades are supposed to be private, there are some challenges surrounding how to store, treat, obtain and analyse this information. In all likelihood, we will not be accessing grade data, but it is included here for completeness.

In addition, it may be desirable to record play of the game, to ease analysis and retention of input. Here as well, it is important to get sufficient subject approval, before initiating the session. Every test subject should be informed of what the purpose of the study is, why we want to record the session, what we are recording, and how we are going to use and analyse the data. We will take care to follow the requirements for informed consent as described by the data protection official for research [35] in all trials, video recorded and otherwise. If a user does not consent, they are of course free to leave the study with no consequences. It will be important to create a contract testers will have to sign before taking part. This contract should include, but may not be limited to, the following information (we will be referring to the requirements by NSD [35]):

- An explanation of the project and its purpose.
- Contact information for the researcher
- Institution responsible for the project
- The data collection procedure.
- How the data is stored.
- How the data will be analyzed and presented.
- How long the data will be retained (No later than July 31. 2017)
- Name, date and signature for the user.

The study aims to impact a students understanding of mathematical concepts, while taking a mathematics course at a university level institution. It is then important that we avoid any negative impact on their mental models of the concepts. We want to improve the students understanding of the concept, not make it worse. As the students final grade level may be affected by the study, there are some ethical considerations to be made. The solution we have for reducing the effect of this, is to have an adviser of mathematics confirm the concepts validity and correctness. Having this adviser on board also helps to narrow down the areas where we should focus our efforts, and which concepts benefit the most from a solution such as this.

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# Appendices

# A Acronyms and abbreviations

**US** - United States.

**STEM** - Science, Technology, Engineering, and Mathematics.

**R2** - R2 Mathematics at Norwegian High Schools [1].

**.FBX** - A file extension for digital content (3d models).

**NSD** - Norsk Senter for Forskningsdata (Norwegian Centre for Research Data) [36].