DESIGN OF TRIGONOMETRY APPS FOR VOCATIONAL EDUCATION

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ABSTRACT

How can smartphones apps enrich the learning of mathematics in vocational education? This article examines how mathematics teaching can be enriched by apps using smartphone sensors such as gyroscope, compass, camera, and touch screen in a gaming context.

An iterative and participatory design process involving two classes of carpentry students from different vocational colleges resulted in two highly successful and course-relevant games based on trigonometry. Each game consists of quests and missions whose successful completion unlocks more theoretical multiple-choice exercises for the classroom. The combination of competition to unlock exercises, competition for placing on the high-score list, and physical activity proved very motivating for the students and was also approved by their teachers.

In this article we describe our design principles, the overall game architecture and the games themselves. We talk about our experience in implementing our design process and subsequently summarize the pros and cons of the application and the smartphone platform and how the app developed contributes to vocational mathematics teaching.

KEY WORDS

Design, smartphone, mathematics, educational tools, participatory design

1 Introduction

An important part of a carpentry student's education involves trigonometry, which is needed for e.g. building roofs and bay windows. However, most carpentry students do not choose carpentry because of their interest in mathematics, but may instead find it difficult and demotivating.

In this article we present a software system developed for the iOS platform using the iPhone. The system was developed for a vocational education, with focus on carpentry students and their teachers. The design process was iterative and participatory, involving students and teachers from day one [10]. The goals of the system were not fixed beforehand but emerged during the study, partly from discussion and partly from users' experiences when they tested the system at each iteration of the design process.

We believe that smartphones and games can enrich mathematics teaching and have a positive effect on the motivation of students. Smartphones as educational tools is a new area for exploration, their sensors providing exciting possibilities for interaction and participation [8]. We understand learning to be a social practice where the learner is an active participator [14]. Game elements can furthermore enrich the learning process by providing motivation [7].

The study was done in collaboration with two vocational schools: Syddansk Erhvervsskole (SDE) and Erhvervsuddannelsescenter Vest (EUC); the publisher of mathematics books Erhvervsskolernes Forlag (EF); and the University of Southern Denmark.

Our research question is: How can smartphones enrich mathematics teaching in vocational education?

Including the question of how iterative and participatory design enriches the product. We begin by describing the iterative participatory design method and its roots, and presenting the educational game Math Mission. We describe the games designed during this study along with some of the development rationale. Then we take readers briefly through the design process: the initial field studies, the three user trials, and the final trial using naive users.

User and teacher comments and our observation of game trials enabled us to improve the system in relation to usability, emerging learning goals, evaluation of the interaction with the smartphone's sensors, and gaming value.

2 Design methods

This study is inspired by the research fields Serious Games and Pervasive Games [13, 11]. Serious Games combines learning processes, digital media and games [6], whereas Pervasive Games links the physical world and the digital world, so that players play games in the virtual world while interacting with the physical world [11]. Our design approach is inspired by Agile Software Development, Game Design, and Participatory Design [2, 3, 4, 5, 8, 9]. The principles of Agile Software Development [4] include: focusing on being iterative, focusing on the user and the collaboration with the user, promoting better cooperation within the design team, focusing on being creative, and by creating solutions to problems. Game Design [5] focusses on game elements such as the rules of the games, the objectives of a game, and iteration. Participatory Design, as described by Sharp et al, Blomberg et al and Majgaard [8, 3, 10], ensures that the user is heard, improving the usability of the design and adding value to the solution found.

2.1 How the design process is used

The iterative design process is divided into six phases, see figure 1, discussed in more detail in section 4. After some preliminary field work the iterative part of the design process begins: Project iteration, User test, and Process feedback. Project iteration consists of requirement analysis, system design and implementation. The cycle is repeated until the project is completed with a final test. The final test-phase was performed with a naive user group similar to the other group but who had not previously been a part of the project.
A field study was conducted, as proposed by Blomberg et al [3], in order to collect knowledge of the problem domain and the target group. The target group in this study comprised two classes of carpentry students and their mathematics teachers from SDE and EUC. We proposed our ideas and held both formal and informal discussions with two teachers and the Department Head from SDE. We also brainstormed with the publisher from EF, who had a lot of ideas about possible concepts to be applied in field of trigonometry. We later also held discussions with four teachers from EUC.
The knowledge gathered in the Field Study phase was used as input for the next phase – *project iteration*, see figure 1. Requirement and ideas were transformed into software. The software was tested by a class of 12 students from SDE in the *user test phase*. The test was evaluated, giving *process feedback*. The results of this evaluation provided input to a new *project iteration*, where the result was a new version of the software; this iterative cycle was repeated three times during this study.
The *final test* was performed with a class of 16 students from EUC Vest whom had not been involved in designing the system. This was done to ensure that the system is in fact usable by the target group and not just by people who have been part of the evolution of the system. In the *finalize project* phase the project was evaluated.

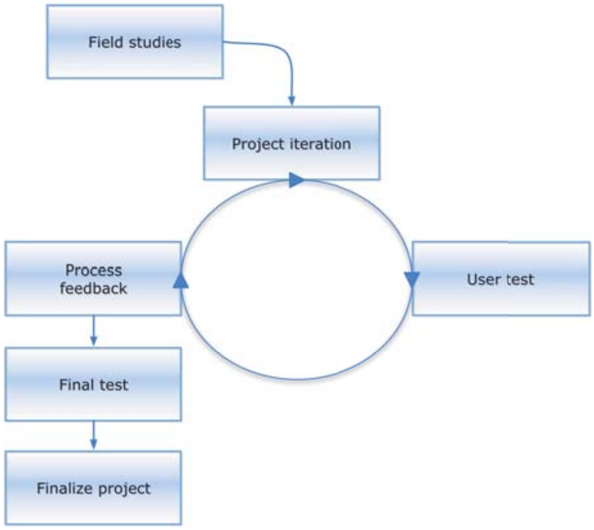

Figure 1: The design process used in the project

3 Math Mission - the games and framework

The following section presents the architecture of the entire system, the application, the games, and how the users can be motivated to play.

3.1 The architecture

The system consists of multiple iPhone 4 clients running iOS 4.3, each client having its own purpose, see figure 2. The Game client is for interacting with games, the Architect client is for providing new context to the system, and the Teacher client allows teachers to e.g. access the students' progress. In this study we implemented only the Game client, however, the system is designed with the other clients in mind. Figure 2 illustrates the clients of the system and their channels of communication, as well as the scope of this project, indicated by red lines.
The clients need to exchange information during execution and it is not desirable to have every client maintaining the business domain, therefore a client-server architecture was used. The server maintains the business logic of the entire system and a three-tier architecture was used to design the system [12]. The architecture design is classic and widely used in cases where the users will be working in parallel on shared data. The three tiers in our architecture are named Presentation, Logic and Data.
The presentation tier includes all of the clients in the system. The users interact directly with this tier, which has responsibility for handling presentational tasks and controlling interaction between users and sensors.
An application kernel in the logic tier performs all business logic operations, e.g. starting new games, representing the current game, and deciding who won.
The data tier stores and retrieves data as required by the logic tier e.g. user information or game rules. The server provides inter-client communication based on REST web

services, which can be accessed by http requests. Design and implementation of the Game client, the web services and communication with Facebook and Game Center (further elaborated in section 3.3) was all part of the project scope, whereas the teacher client and architect client was not, but is scheduled in a possible next generation.

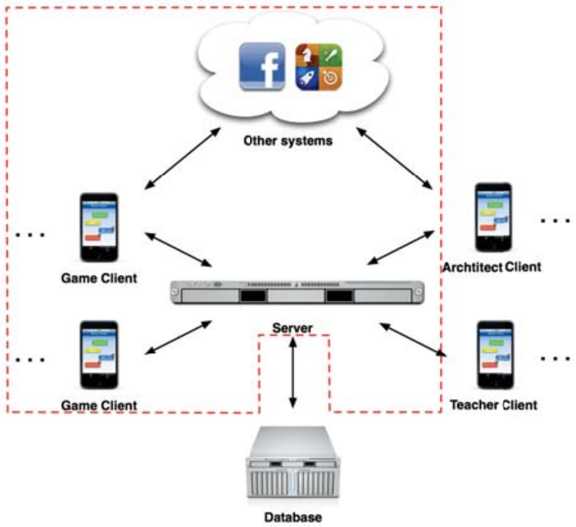

Figure 2: The system architecture and communication channels

This type of client-server architecture and inter-client communication raises questions such as: How effectively is information distributed? Do the clients have the latest available information at all times? These concerns are not discussed in this article but are addressed in Andersen and Bjarke [11].

3.2 The smartphone application

The application consists of several modules for handling user interactions, communication, graphics etc. The user will mainly interact with two parts of the application: the mathematical formulae and the game part. The game part provides the mechanism for games and is called Mission Control (MC), see figure 3 part 1. The purpose of MC is to let the user control all information regarding missions and the user himself; the MC allows the user access to all the missions the user can currently play, which is determined by the user's current skill level. The mathematical formulae provide the user with theoretical knowledge.

If the user chooses to start a new mission in MC, a variety of missions are presented, see figure 3 part 2. The missions are sorted into groups, where each group is connected to a game type. The user finds a mission of the specific game type he wants to play. As the user selects a mission, the user enters the game part of the Game Client. The tab bar and the navigation bar are removed to let the game get the full attention of the user. Depending on the game the user may have the option of playing in single player mode, or against other users, or together with other users: creating a game and inviting other users to join, or looking for currently open games that the user can join, see figure 3 part 3.

Figure 3: 1) Mission Control, 2) list of available missions, and 3) mission start screen (in Danish)

If the user selects the button for creating a collaborative game, a list of possible selectable teammates is presented. If the user wishes to join an existing game, a list of open games is presented. When choosing to play a mission, a description of that mission is presented along with an icon representing the mission: the icons allow the user to easily recognize the selected mission. The mission icons are used throughout the application, to help the user recognize and understand similar information.

3.3 The games

The exploratory field study introduced several games whose types were categorised by which smartphone sensors the game utilized. This exploration also suggested how mathematics assignments could be mapped to games. Take for instance an assignment asking the user to calculate the angles of a triangle: this would be mapped to a quest in which the user would be asked to create triangles with specific angles. When a quest is completed, a classroom exercise is generated or unlocked. So by playing the games the user creates exercises he can use in the classroom to help him work on the relevant aspect of mathematical theory; this feature was specifically requested by the users. A mission consists of multiple quests each mapped to the same mathematical assignment. The quests in a mission can involve different games. Each quest can be solved individually or in collaboration.

As part of the visual interaction, animations are used to provide the user with information and clear feedback during games. Besides the animations, sounds are used to indicate several incidents, e.g. when something positive is happening. This instant audio-visual feedback on the progress of a quest motivates the user to continue.

We designed, implemented, and tested several games. Those chosen for continued development were: “Shape Fight”, “Point a Shape”, and “Physical Shape”. The game “Point a Shape” presented some unexpected difficulties. In this section we will describe the games, their purpose, and how they are played.

"Shape Fight" is a competitive multiplayer game [5] whose objective is recognition of shapes in the environment. One quest could be to discover a triangle with a certain angle, document it by taking a picture with the iPhone, and marking it by touch on the screen. The winner is the player who creates a correct shape in the fastest time. Figure 4 part 1 shows the description of the quest, part 2 is during the game, where the player marks the triangle, and part 3 shows the triangle cut out.

Figure 4: Game screens from "Shape Fight": 1) quest description, 2) during game play, 3) a right-angled triangle.

"Point a Shape" is played outdoors, the GPS and compass functions are used to create the edges of a shape by pointing two iPhone's at each other. However, high sensor inaccuracy was found at short distances, which made for unsatisfying gameplay, see section 4. At longer distances sensor inaccuracy was insignificant and the game play was smooth. This illustrates how game design must take technological limitations into account. "Physical Shape" is based on the same foundation as the "Point a Shape" game, combining physical movement and collaboration between multiple players. The objective of the game is to collaborate on creating a shape using the phone's GPS position sensors. The shape created should match the parameters given in the quest, such as particular angle sizes or the total area of the shape. A quest could be to create a triangle where one angle is 90 degrees. Figure 5 part 1, shows the main screen from the game, in which the player can see other players' actions and react to these (the movement of the players is updated live). Figure 5 part 2 shows three players creating a triangle and the final result, which in this case was correct.

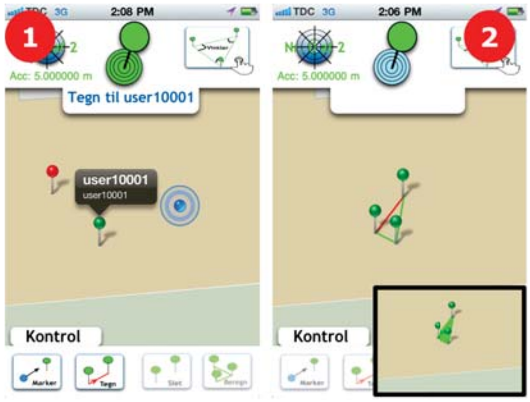

Figure 5: Client screen from the game "Physical Shape"

The main goal of designing and implementing a game type like "Physical Shape" is to encourage physical movement, collaboration, and motivation for learning trigonometry. Working with mathematics visually and physically gives the user the opportunity to experience mathematics from a different perspective than just reading and solving mathematics assignments. Since users discuss how to solve quests, they learn to collaborate on working with trigonometry. This makes the users learn trigonometry not only by understanding what is presented on the application screen but also through experience and discussions.

At the end of a quest a mini-game based on a multiple-choice questionnaire (MCQ) is unlocked. Questions refer to material relevant to the quest just completed. The MCQ was developed during discussions with the users, as they wanted tests to be part of their learning strategy. The goal of the MCQ is to provide the user with additional theoretical knowledge. Figure 6 part 1 illustrates the game screen from the multiple-choice mini-game. Figure 6 part 2 shows how feedback was provided to the user when answering the question. The MCQ is intended to encourage discussions between the users, as well as promoting competition. Competition is a major motivational factor and is encouraged here by giving the user points and achievements during each game. The player then has the opportunity to compare himself to other players and/or see his own progress in terms of improving his score for a mission.

Our application uses Apple's Game Center [1] to give access to high score lists, achievements, and social interaction with other players. The user will also be able to share on Facebook when he has completed a quest, beaten another user, attained an achievement, or got a perfect score in quest: this could motivate other users to try and beat him in a game or get a better score.

Figure 6: Screens from the multiple-choice game (in Danish)

4 Summary of the Design Process

In section 2 we presented the design method used during the study, in the following section we will summarize how we used the method:

- *Initial Field study.* From many meetings with EF, we discussed learning material, our target group, and digitization of books, and exchanged ideas about what the system could contain. EF supplied us with books used on carpentry courses.

  Preliminary meetings with 3 teachers from SDE helped us to understand how a vocational education is put together, what a normal day in a class is like, and the specific learning environment. During these meetings we also discussed how the 12 students would act when they were presented with the application, how to provide the best possible learning experience, and what was needed if the application should be used every day.

  Meetings with 4 teachers from EUC Vest took place during the study. During these we discussed learning material, the target group, and our ideas for the system. We received learning material and mathematics assignments to use as inspiration for the envisioned system. Furthermore, one of the mathematics teachers showed us games he had created and used in his teaching.

- *First user test: Getting to know the target group.* For the first user test a prototype game was developed: a simple multiple-choice game with questions relevant to their education. For each correct answer the students received points, the resulting high score was put on a list to motivate them. The purpose of the prototype game was to observe how the students would react and interact with games on the iPhone and how they used the iPhone. The students could easily understand how to use the iPhone and the game; furthermore it did not take long before they started to compete. Our vision of the system was presented to the students and their teacher, and we stated that when working with mathematics assignments it is important to visualize *how* an assignment should be solved, rather than focusing on the solution itself, as you learn more from the process than from the result.

- *Second user test: GPS and compass app.* "Point a Shape" was tested in the second user test. The test revealed technical issues with the accuracy of the GPS and compass: a side of at least 20m was needed for the triangle tor egister correctly. The students stated in the interview that the game was fun and they understood the game mechanics. However, some of the students wanted more mathematical theory in the games. The procedure for the second user test revealed a few problems, e.g. some of the students had to wait a long time and it was difficult to get feedback during the class-based interview.

  Improvements: As a result of the second user test we improved the test procedure such that the students worked in pairs. An introduction to the test was still used. After the test, the students were interviewed in their pairs. To make the games more directly related to mathematics teaching, we created a function to create exercises based on the result of the games: when a quest is completed the students could return to the classroom and work on the exercise(s) they created. This reduced waiting time which was otherwise disturbing enjoyment of the games.

  We worked on improving the location system resolution and accuracy: after some effort we managed to get relative accuracy to under 5m, although absolute map positions were not perfect. To avoid the problems of calibrating the GPS with the compass a new game was developed which did not use the compass: "Physical Shape". For this game, triangle sides had to be at least 8m long. Since one of the aims of our game is physical activity, we do not consider this length of side to be a problem.

- *Third user test.* "Shape Fight" *and* "Physical Shape". The students enjoyed "Physical Shape" and liked the additions and modifications providing a smoother game flow. "Shape Fight" was well received both in single player and in fight mode. The students soon became involved in the game and its competitive behavior. The students were excited because we had listened to them and implemented their suggestions. Furthermore, both the teacher and students could see the benefit of using the system and games we developed as a supplement to their work with mathematics and became eager to use them.

  Improvements: Improvements following the third user test mainly focused on optimization, bug fixes, and changes in user feedback in the game “Physical Shape”.

- *Final test.* The fourth and final user test was conducted with a naive class of 16 carpentry students from EUC Vest. The students found the system intuitive and easy to use, furthermore they were able to use the system on their own without any instructions, e.g. they were able to start new games unaided. All of the students said that they had fun and could understand how the concepts used supplemented class teaching.

  Improvements: As with the third user test, most of the improvements were focused on technical problems and not so much on the gameplay.

User tests were performed at critical milestones in this study, to evaluate the current iteration of the system with the target group. We received important feedback, suggestions for improvements, ideas for new games, and other information which most likely would not have been possible to obtain without these user tests.

5 Summary and conclusion

Our design presents one solution to how serious and pervasive gaming can be used in an educational context. In the design process we focused on the Game client and interaction with the server, other Game clients, Facebook, and Game Center. Focusing on the Game client allowed development of multiple games, where in each game we focused on a specific iPhone sensor. We explored the use of the compass, GPS, camera and touch sensors.

To ensure the concepts’ usability, students of carpentry and their teachers from two vocational schools tested the games. The result of the user tests clearly indicated that there is a potential in using smartphone apps for mathematics. Especially the GPS games and the camera games were successful. We did not systematically test the use of social media. In the future it would be interesting to explore the potential in combining social media with educational iPhone applications.

Our research question was: How can smartphones enrich mathematics teaching for vocational students? Including how iterative and participatory design enriches the product.

The application we developed enriched mathematics teaching by introducing several modes of participation: (1) Physical activity in the real world; (2) Individual and collaborative interaction; (3) Gaming elements; (4) Aural and visual feedback; and (5) Social media.

The smartphone made it possible to create games where interaction is based on the student’s physical actions, either alone or in groups. The iPhone’s sensors capture the students’ interactions in the real world and translate them to interactions in the virtual world. For example, in the game “Physical Shape”, the students’ current location in the real world is an important element in solving the quests presented, and in the game “Shape Fight” the students have to use the iPhone camera to take a picture of a shape in the real world, use the touch screen to mark a shape and the gyroscope to confirm the created shape. The iPhone’s sensors create a different interaction pattern with students, making it possible to create motivating games involving physical activity, thus combining playing and learning.

Our application supports both individual learning and learning in collaboration. The purpose of the multiplayer-games is to give students an opportunity to discuss and experience mathematical theory in a gaming context. Game elements such as high scores and competition in the games motivated students to learn and solve the mathematical assignments mapped to quests, by creating an eagerness to get higher on the list and beating their friends. Furthermore, using both visual and aural feedback during the games created a more natural interaction for the students and gave instant feedback on the progress of a game. For further motivation and to create a forum for discussion functions from Facebook and the game portal Game Center were also utilized in the application. Facebook was used for posting status updates regarding achievements and high scores to the players’ Facebook profiles, and Game Center for managing achievements and high scores during games.

We believe that social media such as Facebook can be readily used for motivation as they are already part of peoples’ online personality. How much Facebook motivated the users was not measured during the tests, however students stated that the use of game elements did in fact motivate them to continue, which agreed with our observations.

The participatory approach affected the design process positively. The initial field study gave us important information about the target group, their professional level and their level of professional motivation. It was important for us to understand the students, the teachers, their learning environment, and how they worked, in order to make a successful educational tool. The introduction of a smartphone application in the classroom must not add complexity to the learning workflow, it should instead add quality: the system should be intuitive to use and be a digital partner in the learning process. The participatory design process helped us create a more usable software solution, by holding our focus both on the target group and on the technology.

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