Using Game-Based Training to Reduce Media Induced Anxiety in Young Children – A Pilot Study on the Basis of a Game-Based app (MARTY)
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Abstract: Digital games have been successfully applied for the treatment mental health problems such as stress disorders, traumatic disorders, or hyperactivity syndromes. Specifically the treatment of anxiety traits and anxiety disorders such as phobias have been in the focus of game-based treatments in the past. A societal challenge that is increasing in recent times is media-induced fears in young children. While tailored game-based treatments existing for schoolchildren, tailored and theoretically sound solutions for children below the age of eight are sparse and so is the available body of empirical research in this direction. In this paper, we present a game-based training app (MARTY) for teaching young children to cope with their fears. The training is based on standard techniques for anxiety reduction such as breathing techniques and cognitive strategies. We investigated quantitative effects, measured by physiological values such as heart rate and skin resistance (EDA), and qualitative aspects of the MARTY app based on 17 four to six year olds. Overall, we found significant effects of the training on EDA values, as indicators for the arousal and anxiety level of children. No significant differences were found for heart rates. A key finding is that the training effects are positively correlated with the general anxiety level of children, as reported by their parents. The MARTY app may be a promising tool to guide and support parents and young children in reducing fears and anxieties.

Keywords: anxiety disorders, trait anxiety, game-based treatment, cognitive behavioral therapy, physiological measures

1. Introduction

The digital change has arrived in the kids’ rooms, even those of the youngest. Different studies (MIKE study 2017; KIM study 2017; miniKIM study 2015; “From Zero to Eight”) revealed that children use more and more time-consuming electronic media (Genner et al. 2017 Medienpädagogischer Forschungsverbund Südwest (mpfs), 2017; mpfs, 2015; Rideout, 2013). Under 2-year olds spend about 58 minutes per day on digital devices/media, 2-4 year olds about two hours, and 5-8 year olds approximately two and a half hours (Rideout, 2013). The BLIKK study (Büsching et al., 2017) shows that 70% preschoolers use a smartphone for more than half an hour daily and 90% of that time is uncontrolled by adults. The results are severe. Primarily, a high media consumption is considered related to physical inactivity, violence, speech and sleep disorders. A specific risk is the occurrence of media-related fears in children (Cantor, 1994; Holzwarth 2009; Schoneveld et al. 2016; Theunert et al., 1999). The study "Having and showing emotions" (Götz & Schwarz, 2014) demonstrates that every second child between the age of six and nine years is at least occasionally scared of television and a third frequently suffers of nightmares. Such anxiety disorders are the most commonly diagnosed mental health problem in children and the number of subclinical anxieties among children under the age of 15 is estimated at 40%. However, 80% of affected children do not receive psychological or medical assistance (Kataoka, Zhang & Wells 2002). Serious games might be an adequate and natural approach to support children in recovering from anxiety disorders. Fleming et al. (2017) describe the potential of serious games to treat anxiety disorders. Lau et al. (2017) discuss the treatment of depression, post-traumatic stress disorders, autism, attention deficit hyperactivity disorder, functional cognitive disorders, and alcoholism. Recently, a very popular example is the treatment of phobia by exposing patients in the virtual reality. Levy et al. (2016), present a study on the treatment of fear of falling utilizing the strengths of virtual reality. Given the rich potential of digital games for fighting anxiety, the design of anxiety games is an increasing topic in research (e.g., Dekker and Williams, 2017). Schoneveld et al. (2016) presented Mindlight, a neuro-feedback training game for anxiety treatment and prevention for children aged 8 to 16. In a randomized controlled trial study, playing the game significantly reduced the anxiety level. Wijnhoven et al. (2015), showed that the game can also significantly reduce anxiety in children with Autism Spectrum Disorder.

In summary, there is some evidence that digital serious games are an adequate measure to treat mental disorders in general and anxieties (i.e., clinical anxiety disorders as well as aggravating anxiety tendencies, which do not reach the clinical level) in particular. While such games are available for adults and children aged 8+, not targeted game treatments are available for younger children, for example at the kindergarten level. Specifically for this age group, appropriate and child-centered treatments would be of great relevance. In the context of this

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master thesis, we designed, developed, and evaluated an anxiety treatment game for kindergarten children. Based on the research desideratum shown, the article focuses on the following research questions:

1. How high is the children’s anxiety level?
2. Can an increase in the EDA value be achieved over the intervention period?
3. Can the HR value be reduced over the intervention period?

2. Study Design

As part of a mixed-methods design, the anxiety level of the children is to be reduced by means of an intervention as a methodological implementation using the MARTY approach (Medienbedingte Aengste Reduzieren mit TonY [Reducing media related fears with Tony]); whereas Tony referred to the name of the main character of the game-based training app. In order to be able to make quantitative statements, a questionnaire was issued prior to the training to have a baseline regarding the anxiety level of each child and their use of digital devices at home. Also, physiological measurements were taken, using a biofeedback wristband. In order to be able to make qualitative statements regarding the motivation as well as the impressions of the children’s emotional states and opinions about the app and the underlying coping strategies, we kept a detailed log.

2.1 Participants

In total 17 children from two different German day care centers participated in the study, of these 6 boys and 11 girls. On average, the children were 4.74 (SD = 0.87) years old. Location I was a Kindergarten in Munich; here 5 boys and 4 girls participated. The kindergarten is a private institution, the parents are very educated and have a high socioeconomic status. Media are commonplace at home and in the kindergarten. They use tablets, televisions and cameras. Location II was a kindergarten in Leutkirch; here 2 girls and 6 boys participated in the study. The kindergarten is a public institution. The children come from social disadvantaged families. In addition, most of the parents and children can hardly speak German. There is no media use in the kindergarten but TV, tablets and game consoles are often used at home as “babysitters” or to promote language.

2.2 Baseline questionnaire

To identify an initial baseline of the children’s general anxiety level and in particular the intensity of media-related fears a questionnaire was used. The questionnaire was completed by the parents and kept relatively short and simple, so that it can also be filled out by the parents with little German language literacy. The questionnaire was based on the already existing questionnaire „Spence Children Anxiety Scale – The Preschool Anxiety-Scale (SCAS, Muris, Schmidt, & Merckelbach, 2000). „[The scale can be] used for identification of children with elevated symptoms of anxiety and for whom further assessment is recommended to determine need for intervention. Similarly, it provides an indicator of response to treatment. It has also been used in several studies to identify children for whom early intervention or prevention is warranted on the basis of elevated anxiety symptoms being a risk factor for the development of future mental health problems” (Barrett & Turner, 2001). The questionnaire was already used in the ”MindLight” study by Granic et al. (2014) and is summed up for valid and reliable (Schoneveld et al., 2016). In addition, the questionnaires BAV:3-11 (Mackoviac & Lengning, 2002), DISYPS-III:FBB ANG (Döpfner & Götz-Dorten, 2008) and PHOKI (Döpfner, Schnabel, Goletz, & Ollandick, 2006) were used as basis. The questionnaire was divided into five chapters: (i) demographic information, (ii) health related aspects (from a health-related and ethical point of view, only children without psychiatric treatment, heart disease, and clinical anxiety disorders could take part in the study), (iii) media usage, (iv) media literacy, and (v) general anxiety and specific fears.

2.3 The Anxiety Treatment Game

2.3.1 Treatment approach

Different research in the field of cognitive behavioral therapy has shown that children are less responsive to questions and do not like discussions. They prefer to be active and want to play. Thus, it is not surprising, that computer-aided psychotherapy programs especially Internet therapy for anxious children, which are usually performed without therapist accompaniment, provide surprisingly good results. They have a success rate of up to 70%. (Scholz & Heinz, 2015). This result can be justified by the fact that play therapy is a suitable form, especially for younger children. According to Clemens (2019), children are more motivated and this increases the effectiveness of the therapy. It also makes clear that successful anxiety processing is only possible if children are allowed to participate constructively and if they experience demand, support and empowerment (Kahle, 2019). "Much more important in the context of learning-oriented apps is the mental involvement to
demonstrably facilitate learning” (Mertes, 2017). Therefore, the game is particularly suitable, because playing helps to find solutions and supports the childish processing. Very suitable for this are stories (or fairy tales) as well as magical powers, which can be awarded as substitute elements. The study by Allensbach in 2003 discovered that the contents of fairy tales or stories are most effective if they were introduced in an animated situation (Mertes, 2017). Almost as in a lab situation, the child can try out how brave or anxious it is (for example by finding a treasure etc.). By stimulating the children’s imagination and showing them various possible solutions and developmental stages, the child’s flexibility increases with how to deal with fears and conflicts, thereby expanding their repertoire of possible approaches (Wilkes, 2018). The interactivity of the medium leads to a changed perception of one’s own role. Because in these virtual worlds it is possible to take alternative roles and try them out. So it is no longer the main character, it is the players themselves, who significantly shape the plot (Scholz & Heinz, 2015). In addition, the tablet can be considered as a suitable instrument for performing for a media-induced therapy, since, as Mertes (2017) shows, that children have already learnt at the age of about 15 months how to use a tablet. At the same time, compared to television, children can control the processes themselves on the tablet, depending on their age (self-paced learning, repeated tasks and procedures; Mertes 2017).

2.3.2 Structure and content

Most serious games or therapeutic learning games are based on elements of Cognitive Behavioral Therapy (CBT; Kahle, 2019). Playful means in which the ungendered hero bravely uses CBT procedures without showing fear are the best choice. Often, popular heroes do not have a clear gender. The characters are not addressed as he or she within the series and have no gender-specific names or signs (Götz, 2017). In addition, this role model can only be effective if it speaks to the children (Wilkes, 2018). It is also crucial that the figure is not a glorious hero figure, but a person like you and me - who has fear, courage and is brave (Göhlen, 2015). In this app, therefore, plays the gender-neutral character “Tony” the lead role. Tony is a human-like character, because human protagonists show better the emotions and this helps children better to identify and deal with them (Vom Orde, 2014).

CBT relies on the cognitive model of the interactions between cognitive processes, emotional experience and behavior. Therefore, CBT therapy is usually divided into three phases: confrontation with a frightening element, relaxation and the application of problem-solving techniques.

2.3.3 Confrontation and problem-solving

Many studies showed that confrontation in children is the most important therapeutic component in the treatment of anxiety. Fear experts recommend the use of multiple confrontations. Therefore, the children are also offered several confrontations for this app. Since, according to the results of the questionnaire, the children are most afraid of witches, ghosts and snakes, these figures are used. In addition, the confrontation is embedded in a dream, as reflected in a survey of 3000 children. The influence of these contents, happening on the dream is clearly higher to develop fears than experienced on the day (Holler & Mueller, 2014). Therefore, 4 out of 10 children have nightmares from TV (Götz & Schwarz, 2014) and a quarter have nightmares every week or more often (Friecke-Oerkermann, 2014).

Because of that, patients should, as far as possible, engage in confrontation exercises as independently as possible and should be accompanied by therapists only when it is absolutely necessary. A fictional character (Tony in our case), who is exposed to confrontations and copes with them, gives anxiety patients a sense of security. The fictional character is intended to show the children different ways of dealing with confrontations, for example, by trivializing, zooming (e.g., shrinking a scary character), and transforming the scary character into a positive form.

2.3.4 Relaxation

Relaxation procedures provide the foundation of CBT. The abdominal breathing is the most used form. Younger children learn effortlessly when the exercise is incorporated into an exciting story. Most children choose 5-8 seconds per unit (Schmidt-Traub, 2017).

3. The App MARTY

The game features the gender-neutral character Tony (Figure 1). The game-based training approach is designed as an interactive story. Tony lies in bed and has a nightmare. The game has three variants: In the dream, Tony
faces either a witch, a snake, or a ghost (Figure 1, 2nd row). This scene serves the purpose of a confrontation with an anxiogenic stimulus. The intention is to provoke a raising anxiety level, associated with the stimulus. After the confrontation, children have to perform a deep breathing relaxation exercise together with Tony in order to reduce physiological anxiety symptoms again. In a next step, the children learn how to deal with the anxiogenic stimuli (witch, snake, ghost) in sense of CBT. To achieve that, children can, defeat the mean characters together with Tony applying three cognitive strategies, that is, shrinking the character, disembodying the character or doing another relaxation. Following this procedure, Tony wakes up and both Tony and the child are rewarded with a gemstone. The playing/training duration is about 10-15 minutes. The reason for this is that the children experience a loss of attention and difficulty concentrating over a longer period of time, which means that learning, is no longer possible (cf. Mertes, 2017).

The app was created with the Adobe Flash Professional CS5.5 program, Actionscript 3.0. For this, the vector files were called up for the individual scenes and each scene was programmed individually and saved as a swf file. Finally, the individual swf files were linked to codes so that they can be played one after the other. The app can be played on laptops and tablets. In this study, we used Windows-based tablets.

**Figure 1:** Scenes of the MARTY app (from top left): (1) introduction to the main character Tony, (2) Tony has a nightmare, (3) a ghost and a spider appearing in Tony’s nightmare, (4) Tony can transform the ghost into a cute penguin, (5) Tony can select different tools and strategies from the chests to cope with fears, (6) in a tutorial animation the children can learn breathing techniques together with Tony.

### 3.1 Physiological measurements and evaluation

In order to measure the anxiety level of children while playing the game, we used a wearable (Figure 2), developed by HTW Berlin (http://tel.f4.htw-berlin.de/lisa). This device can measure skin temperature, skin conductance (EDA), heart rate (HR), pulse, as well as environmental factors such as air quality. Due to time constraints and reasons of technical implementation, no classical biofeedback training, in which the children received feedback about their biofeedback immediately, instead the training was realized by several training sessions. The obtained measures were used only for evaluation and subsequent analysis. For the app itself, log data were recorded.
Figure 2: The left image shows the LISA wristband, the right image the SmartMonitor app that is connected to the wristband via Bluetooth and that records the physiological data during the training sessions.

3.2 Electrodermal activity (EDA)

The one physiological measure recorded for this study was electro dermal activity (EDA), which is a sensitive indicator for changes in autonomic sympathetic arousal that are integrated with emotional and cognitive states. It is measured by skin conductance and is one of the most accurate methods for measuring human reactions. The EDA is controlled by the autonomic nervous system, which cannot be controlled intentionally. So the EDA value gives answers that cannot be influenced directly. For this study we had a closer look to the phasic EDA, which shows how quickly a child can recover from a stressor. The LISA wristband measures EDA in Ohm (i.e., skin resistance). A higher value indicates a higher relaxation. Although there is a lack of accuracy of EDA measurement using small wristband sensors with a comparably short measurement distance, results provide sufficiently reliable indicators for the children’s arousal.

3.3 Heart rate

The second physiological measure recorded was the heart rate, which indicates the heart beats per minute and is a partial aspect of the pulse, which describes the pulse from beat to beat. Children have pronounced heart rate variability that decreases with age (Rauscher and Neuffer, 2016). Typically, heart rate and heart rate variability should decrease during a relaxed activity, such as breathing exercises or while sleeping. On the other hand, the heart rate increases in stressful situations when the body tries to cope with the demands. The heart rate level is individual for each person and therefore changes from day to day, depending on the activity level and amount of stress (Hoffmann, 2016).

4. The experimental study

4.1 Procedures

The questionnaires has been completed in April 2019. The actual training sessions took place in May 2019. The respective children were visited once a week for a total of 3 weeks. In total, each child participated in 3 sessions. In each session, a different scary character (i.e., ghost, snake and witch) appeared in the app. We ensured prior to each session, that children voluntarily participated in the intervention in order to obtain reliable measurements on the one hand and on the other hand not to cause negative effects that could affect the child’s state of health. Another factor in generating valid and reliable measurements was that all children completed their sessions under same conditions. Therefore, the sessions took place in a quiet room at the day care centers after breaks or relaxed phases of the kindergarten routines. In addition, the sound volume of the respective game was always equal, in order to achieve the same effects, especially with regard to the confrontations.

During each visit the children played one “game session”; either ghost, snake or witch. The order of scary characters the children were confronted with was chosen randomly. All sessions were monitored by a kindergarten teacher. The children put on the wearable LISA and started to play the respective game themselves. The wearable recorded the physiological measures. During the intervention, the children were accompanied by a test administrator to help with technical problems; in order to avoid influences of the administrator, during the sessions the children were given no feedback, praise or calming words. After each session, the children had the opportunity to talk about the game. These statements as well as the statements while playing the game were documented.

To investigate the effects of playing the Tony app and to clarify the initially formulated research questions, we focused on the analysis of physiological measurements and qualitative data obtained from the children. In
addition, the results of the questionnaire were compared with the physiological measurements during the intervention to elucidate certain relationships.

5. Results

Prior to the training sessions with the Tony app, we issued a background survey asking for the children’s media consumption and their general level of anxiousness. The answers were given by the parents.

The parents reported media consumption on a scale from 0 to 5, where 0 means a low consumption (0-15 minutes per day) and 5 a high consumption (more than 120 minutes per day). The most frequent medium consumed by the children of our sample, with an age range between 3.1 and 6.4 years, was television (mean = 2.40, SD = 1.24), which means up to 90 minutes per day. This corresponds to the consumption of books (mean = 2.40, SD = 0.91). Furthermore, the parents reported an average consumption of tablets of about 45 minutes per day (mean = 1.40, SD = 1.14), of Smartphones of about 35 minutes (mean = 1.14, SD = 0.69), of Laptop Computers of about 30 minutes per day (mean = 1.00, SD = 0.71), and of digital games of about 10 minutes per day (mean = 0.75, SD = 0.50). These values are average values and the consumption of different media does not sum up. We also asked the parents as to what extend they are aware of their children’s media consumption (on a 5-point scale from never to always). The parents reported that the children on average use typical apps rarely (mean = 0.63, SD = 0.62) and also reported a low extent to which the children observe others (e.g., their older siblings) consuming media or playing games (mean = 1.50, SD = 1.21). The parents, in turn, reported that they have a medium level of knowledge about what media contents their children consume (mean = 3.00, SD = 1.65) and that they monitor their children’s media consumption on a medium level (mean = 3.21, SD = 1.31). Overall, the extent of children’s media consumption is in line with our expectations, whereas the parental supervision is lower than expected, given the young age of the children of our sample. The following table (Table 1) indicates the anxiety and stress related responses of parents. Overall, we found a very low level of general anxiety, the scale revealed a total average score of 0.796 (SD = 0.945; on a scale from 0 to 4).

Table 1: Children’s level of general anxiety on a scale from 0 (never) to 4 (very often).

<table>
<thead>
<tr>
<th>my child …</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>... has difficulties in coping with sorrows / worries</td>
<td>1.333</td>
<td>0.900</td>
</tr>
<tr>
<td>... is reluctant to ask adults for help</td>
<td>0.625</td>
<td>0.885</td>
</tr>
<tr>
<td>... verifies actions to assure everything is in order</td>
<td>1.125</td>
<td>1.147</td>
</tr>
<tr>
<td>... is reluctant to sleep at friends’ places</td>
<td>1.800</td>
<td>1.699</td>
</tr>
<tr>
<td>... is crying after having seen negative/inappropriate contents on TV/tablet</td>
<td>0.750</td>
<td>1.183</td>
</tr>
<tr>
<td>... is anxious and tense</td>
<td>1.063</td>
<td>0.998</td>
</tr>
<tr>
<td>... is afraid of meeting unknown people</td>
<td>0.875</td>
<td>0.885</td>
</tr>
<tr>
<td>... has to follow exact procedures to assure everything is in order</td>
<td>0.563</td>
<td>1.031</td>
</tr>
<tr>
<td>... is afraid that something negative may happen to parents</td>
<td>0.813</td>
<td>1.328</td>
</tr>
<tr>
<td>... is nervous after having seen negative/inappropriate contents on TV/tablet</td>
<td>0.313</td>
<td>0.793</td>
</tr>
<tr>
<td>... carries worries and sorrows</td>
<td>0.500</td>
<td>0.516</td>
</tr>
<tr>
<td>... is afraid of speaking to unknown people</td>
<td>0.875</td>
<td>1.147</td>
</tr>
<tr>
<td>... has frequently occurring negative thoughts and imaginations</td>
<td>0.563</td>
<td>0.892</td>
</tr>
<tr>
<td>... is afraid that something negative may happen to herself</td>
<td>0.563</td>
<td>0.814</td>
</tr>
<tr>
<td>... reports sickness or stomachache after having seen negative/inappropriate contents on TV/tablet</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>... wakes up at night after having had a bad dream</td>
<td>0.813</td>
<td>0.750</td>
</tr>
<tr>
<td>... has sleeping problems due to re-occurring worries</td>
<td>0.250</td>
<td>0.577</td>
</tr>
<tr>
<td>... mimics characters seen in movies</td>
<td>1.500</td>
<td>1.461</td>
</tr>
</tbody>
</table>

In addition, we asked parents about how different characters or events, as shown in Table 2, scare their children. Again, the data revealed a very low level of anxiousness (on average 0.919, SD = 1.153).
Table 2: Level of fear of different characters or events on a scale from 0 (very low) to 4 (very high).

<table>
<thead>
<tr>
<th>Character</th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darkness</td>
<td>1.500</td>
<td>1.549</td>
</tr>
<tr>
<td>Loud noises</td>
<td>1.438</td>
<td>1.365</td>
</tr>
<tr>
<td>Ghosts</td>
<td>1.333</td>
<td>1.175</td>
</tr>
<tr>
<td>Blood / injuries</td>
<td>1.063</td>
<td>0.998</td>
</tr>
<tr>
<td>Witches</td>
<td>1.000</td>
<td>1.095</td>
</tr>
<tr>
<td>Snakes</td>
<td>1.000</td>
<td>1.155</td>
</tr>
<tr>
<td>Spiders</td>
<td>0.938</td>
<td>1.181</td>
</tr>
<tr>
<td>Fire</td>
<td>0.933</td>
<td>1.163</td>
</tr>
<tr>
<td>Insects</td>
<td>0.750</td>
<td>1.183</td>
</tr>
<tr>
<td>Dead people</td>
<td>0.636</td>
<td>1.120</td>
</tr>
<tr>
<td>Guns</td>
<td>0.615</td>
<td>1.044</td>
</tr>
<tr>
<td>Height</td>
<td>0.563</td>
<td>1.094</td>
</tr>
<tr>
<td>Dogs</td>
<td>0.563</td>
<td>0.964</td>
</tr>
<tr>
<td>Bomb attacks</td>
<td>0.538</td>
<td>1.050</td>
</tr>
</tbody>
</table>

Part of the quantitative analyses was to look into the physiological effects exhibited by the children, measured by the LISA wristband sensors. First, we analyzed the phasic (i.e., short term) electro-dermal activity (EDA), the skin resistance, over time. We could show that EDA values, on average, increased by repeated exposure to the Tony app. Figure 3a shows the mean EDA values for the baseline measurement prior to starting the app-based training. For the first session the mean was 12.86 (SD = 11.52), for the second session 30.92 (SD = 42.78), and for the third session the mean was 44.11 (SD=51.62). The broad variability (i.e., high standard deviations) are explained by large individual differences between children. As Figure 3b shows, the entire EDA activation increased with repeated exposure. For the first session the mean was 12.14 (SD = 1.26), for the second session 34.63 (SD = 2.99), and for the third session the mean was 42.21 (SD=6.04). A univariate ANOVA reported a significant difference across time [F(2, 1350) = 7062; p < .001]. Scheffé post-hoc tests reported that there was a significant increase between each session (p < .001 in all cases). The average EDA activation over time in each of the sessions revealed only small changes; yet, the different parts of the app (i.e., dream, breathing exercise, cognitive strategy, reward) can be identified (Figure 4). Since the children took differently long for the various parts, the curves do not overlay exactly. The distinct amplitude spikes at the end of each session indicate a significant physiological reaction by finalizing the app-based training (i.e., reward part), including the happy ending of the narrative. An interesting effect is that in session 2 this spike has a different direction than those of sessions 1 and 3. We do not have a plausible explanation for this effect, though.

Figure 3: EDA activation for each of the three sessions. Panel (a) shows the initial baseline values, panel (b) shows the means for the full session durations.
Second, we analyzed the heart rate during and over the sessions. The mean heart rate in session 1 was 91.06 (SD = 7.36), in session 2 90.85 (SD = 6.65), and in session 3 90.24 (SD = 6.88). Interestingly, a clear decrease in the baseline measurement was not found; the mean in session 1 was 52.39 (SD = 24.95), the mean for session 2 was 61.87 (SD = 17.37), and for session 3 60.57 (SD = 20.79). As opposed to EDA activation, we found a clear difference in baseline measures and the measures during the app-based training. This is an indicator that children were clearly more excited during using the app, as opposed to their resting heart rate. A univariate ANOVA reported a non-significant effect of sessions [F(2, 1311) = 1693; p = .184]. Figure 5 illustrate these results.

Finally, we were interested in the effects of the training in dependence to the initial – parent reported – general anxiety level. We correlated the change in EDA over the sessions with the initial anxiety score of the individual children. We found a moderate but noteworthy positive relationship between the changes in EDA values with the anxiety level; the correlation of the change in EDA from session 1 to 2 correlates with r = .320, the change from session 2 to 3 with r = .319, and the change from 1 to 3 with r = .353. These results indicate that the higher the initial anxiety level of children the more reduction of anxiety (as operationalized in form of arousal measured by EDA skin resistance) could be achieved by the app-based training. The change in heart rate was not as clear. The change from session 1 to 2 correlates with the anxiety level with r = .228, the change from session 2 to 3 with r = -.161, and the change from session 1 to 3 with r = .298. This indicates, overall, that the higher the initial anxiety level of children the more reduction of anxiety (as operationalized in form of arousal measured by EDA skin resistance) could be achieved by the app-based training.
anxiety level the stronger the change in heart rate. As illustrated in Figure 6, the anxiety level, measured by EDA and HR, could be reduced.

![Graph showing changes in skin resistance and heart rate over three sessions](image)

**Figure 6:** Changes in skin resistance (EDA) and heart rate (HR) over the three sessions. Please note that an increasing skin conductance (blue bars) indicates higher relaxation.

In order to obtain qualitative statements regarding the motivation as well as children’s impressions and opinions we kept a protocol about all statements or the children. These protocols were in turn related to the measurements in order to be able to make statements about the agreement of the qualitative and quantitative results.

Child number 16 (female, 4 years, location I) showed one of the highest EDA levels during all 3 sessions (Figure 7), although according to the questionnaire, the child had a general anxiety level of 1.6 (scale from 0=low level to 4= high level) and has therefore surprisingly one of the highest anxiety-level values of the children. Asking the child for her reasons for selecting certain coping strategies in the game, she stated:

"The card with the breathing exercises is like what my mom always does at home. Like yoga. I always do that with her. And sometimes when I have to cry, I do it with her. Then I often feel better again."

"I think the wand is cool, too. It’s like the one that Bibi Blocksberg has. It can always enchant everything and then it can always help everyone. Then people are better off. And if I take the magic wand, I can do that, too. Then I can help, too. And I enjoy that. That pleases me."

"The potion is for boys. That’s why I used once to see what happens."

It turned out that the child relates different everyday experiences to the strategies. It can identify with them and thus seems to have a positive effect on the child’s wellbeing.

![Graph showing EDA values for three sessions](image)

**Figure 7:** EDA values of child 16 for session 1 (blue, snake), session 2 (orange, ghost), and session 3 (grey, witch).
Another example is child number 3 (male, 5.4 years, location I), which has an anxiety level of 0.8. This child (Figure 8) also shows high EDA values and it seems to become more relaxed from session to session. The child stated:

After session 1:

“I like that I can choose all the things myself and can do as often as I want. I particularly like the card. If I close my eyes and then breathe in and out, I just focus on it. Then I don’t have to think about the bad witch or the bad snake anymore.”

After session 2:

“Yesterday I saw something bad on TV. Then I did that with breathing at home.”

“My mum said that I should always do this before going to sleep because I always wake up and have trouble falling asleep. [...] I always think that a bad man comes in the door and wants to eat me at night. Now my mum has put a potion next to my bed. And when someone comes, I can drink it quickly and the bad man can’t do anything anymore. Then I can transform it.”

Before session 3:

“Look here. I have now built a magic sword. Now I can always take it to bed and then make someone small. Like Tony. Cool, isn’t it?”

Even if, according to the results of the parent questionnaire, the child has a relatively low level of anxiety, it seems that the child is still dealing intensively with the topic and has a high level of speaking about what happens at home and what he can learn from Tony and how he can use the strategies he learned to use.

![Figure 8: EDA values of child 3 for session 1 (blue, snake), session 2 (orange, snake), and session 3 (grey, ghost).](image)

**6. Discussion and Conclusion**

In this paper, we presented a game-based training app (MARTY) for teaching young children to cope with their fears. The training is based on standard techniques for anxiety reduction such as breathing techniques and cognitive strategies. We argued that appropriate anxiety reduction strategies for preschoolers are rare and difficult to realize. However, given the increasing media consumption even of the youngest and the increasing frequency of media-induced fears in children, trainings tailored to young children are of high relevance. We conducted a first study to investigate the effects of the app with 17 kindergarten children from Germany.

Overall, the children’s anxiety level was on average 0.919, (SD = 1.153) with a maximum of 4.0. Compared to results from other studies (e.g. MIKE study 2017; KIM study 2017) this level is significantly lower. This could be
due to the parent’s social desires when filling out the questionnaire. We found significant effects of the training on EDA values, as indicators for the arousal and anxiety level of children. No significant differences were found for heart rates. A key finding is that the training effects are moderately positively correlated with the general anxiety level of children, as reported by their parents. This means that the more anxious children were, the higher was the training effect. The positive effect is emphasized by the qualitative statements of children. A limitation of the study is that no control group design could be realized. Thus, the effects, specifically in EDA, might be due to a general familiarization with the app over the three sessions. Counter arguments are that this effect has not been found for heart rate. This indicates that children still have the same high level of excitement and arousal (cf. Figure 5). Moreover, when looking at the changes in EDA within a specific session, we can identify the differences between the different parts of the game (e.g., intro vs confrontation). These changes are much smaller, though, than the changes between the sessions. This lets us conclude that the found effect is likely due to the theory-based training approach. At the same time, children exhibited a high motivation to use the app. The app is very easy to use. The children can start the respective games themselves and play them without help. There were sometimes technical problems recording the logging-timestamps. Sometimes the app did not save all logging-timestamps in the background. This data could not be used for the evaluation. A revision of this problem is necessary for further research.

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Co-Designing and Learning in Virtual Reality: Development of Tool for Alcohol Resistance Training

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Abstract: This paper presents the design process of a Danish educational virtual reality (VR) application for alcohol prevention. Denmark is one on the countries in Europe with the highest alcohol consumption among adolescents. Alcohol abuse is a risk factor for a variety of diseases and contributes as a significant factor to motor vehicle accidents. The application offers first-hand experiences with alcohol in a safe environment. This is done by simulating a party situation using 125 different 360-degree movie sequences and displaying it in a virtual reality headset. The users create their own experience through a choose your own adventure game experience. The experience is designed to acquire skills for recognizing and handling peer pressure, which has been found to be one of the main reasons for drinking initiation. These skills are acquired through experimental learning. The application is a product of a co-design process involving 10 students (aged 18-28) studying film making and game design at Askov Folk High School (a special kind of Danish boarding school without exams for young adults), Denmark, their teachers, alcohol experts from social services and researchers with expertise within health promotion, social marketing, VR, interaction design and game development. Additionally, 35 students from Askov Boarding School (aged 15-17) participated as actors and extras. This article contributes to research within development of 360-degree video applications for experimental learning with a practical example. The iterative design process of the application, containing exploration of key concepts, concept design, prototype design, pre-usability testing, innovation design and usability test is described, as well as our reflections on virtual experimental learning in the application.

Keywords: Virtual reality, 360-degree video, co-design, alcohol prevention, learning, interaction

1. Introduction

This article is a revised and updated version of Co-designing an Immersive and Interactive Alcohol Resistance Training Tool Using 360-Degree video (Lyk et al., 2019). Additional sections on innovation design, usability test and thoughts on virtual experimental learning are added.

Denmark has one of the highest rates of substance misuse among adolescents (European Monitoring Center on Alcohol and Drugs, 2016) and lately an increase in harmful alcohol use have been reported (Tolstrup et al., 2019). Risky drinking may have many negative consequences, for example higher risk of a wide variety of diseases (Barbor et al., 2010), negative impact on school and education (Wechsler et al., 1994) and plays a significant role in suicides and motor vehicle accidents (Barbor et al. 2010). The earlier adolescents start drinking alcohol, the more likely it is that they will abuse alcohol and other drugs later in life (Jenningson, 2004).

This article describes the development of the educational tool VR FestLab (ed. in English PartyLab). VR FestLab is a Virtual Reality (VR) application, where adolescents aged 15 to 17 can experiment with intake of alcohol without the physical risks this behaviour could lead to in real life. Users are invited to a virtual party, where they
are continuously exposed to decision-making scenarios. These choices shape the plot and thus each user creates their own unique experience. By using 360-degree video, the user gets surrounded by the constructed world and can get an immersive (VR), hands-on experience, which is central in a learning process (Kolb, 1984; Piaget, 2001). Through a gamified user interface, the user can keep track of their current blood alcohol concentration, giving them the opportunity to reflect on their behaviour and change approach if necessary. Moreover, users will experience peer pressure to varying degrees. The goal is that users learn to recognize these situations and develop skills for handling them, so that they are able to make a more educated choice, when they experience similar situations in real life settings.

The application uses the Google Cardboard platform (Google VR, 2019). Google Cardboard is an inexpensive VR headset made of cardboard, in which the user places her phone and together the phone and cardboard headset make up a simple VR headset. Once the application is finalised, it will be available free of charge on both Google Play (for android users) and App Store (for iOS devices). The application is targeted for school use, but with this solution the users can continue their exploration beyond the classroom. For testing the Oculus Quest (Oculus, 2019) was used.

The project was co-created with adolescents and other stakeholders with an empowerment-based living lab approach (Stock et al., 2019; Vallentin-Holbech et al. 2020). The adolescents involved in this project contributed with their experience showing how young people behave and communicate in social contexts and how young people party in Denmark today. This contrasts with most alcohol prevention programs. Often the target group – the adolescents – plays no or a very limited role in the development of teaching material for alcohol prevention. Instead, experts and researchers take the control in the development (Dietrich et al., 2016, 2017; Hurley et al., 2019; McKay et al., 2012a, 2012b; Vogl et al., 2009).

The project consists of seven phases: Exploration of key concepts, concept design, prototype design, pre-usability test, innovation design, usability test and final testing. This article describes phase one to six, focusing on the technical development and the design choices related to this.

2. Background

In a constructivist view, learning happens most effectively when the learner is active and gets first-hand experience with the concept that is to be learned (Piaget, 2001; Papert, 1993; Kolb, 1984). In cases such as adolescent drinking firsthand experience is not desirable as a learning environnement, and alternate settings are needed. New technologies like VR and 360-degree video can be helpful. 360-degree videos can immerse users and it can enable them to take charge. As noted by Papert (1993), best learning takes place exactly when the learner takes charge.

2.1 360-degree video and VR

360-degree videos are recorded in all directions simultaneously. In this project, GoPro Fusion is used (Gopro.com, 2019). When the video clip is played later, the user takes the position of the camera and has full control of the viewing direction. The video can be played in a head mounted display (HMD).

When talking about VR and 360-degree video, immersion is very central. Murray (1997) compares immersion to being enclosed in water and therefore surrounded by another reality. Elmezeny, Edenhofer and Wimmer (2018) have investigated immersion in relation to 360-degree video, comparing 360-degree video with traditional video formats and VR. They describe two main categories of immersion, narrative immersion, which is “... influenced by the setting, as well as by interplay of story, characters, and viewer integration” and technical immersion, which “... manifests through cues to direct the viewer’s attention and cues to acknowledge the viewer as a part of the virtual environment.”

2.2 Experience based learning

According to constructivism learning theory, learning is an active construction of knowledge rather than a transfer of knowledge (Papert, 1993; Piaget, 1947; Kolb, 1984). Learning is constructed though interaction with the world and though this interaction mental schemas are constructed, from which we relate to the world. Papert (1993) mentions computers as a key tool, when trying to make (new) learning more accessible. It is not always possible to let the learner interact with the concept that needs to be learned in a real-world setting.

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However, by making a simulated world, where the learner can experiment, set up hypothesis and test them, the learner can still get a first-hand experience when using technologies.

3. Situating the Design Case

Previously, anti-alcohol campaigns have mainly been based on moral encouragement, fear campaigns, or presenting factual knowledge to adolescents. While some programs have delivered positive outcomes (see Hurley et al., 2019) others have failed to deliver the desired outcome (Faggiano et al., 2017).

Recently, it has been found that one of the main reasons why young people start drinking is peer pressure (Hendricks, Saval and Florence, 2015; Flay, 2000). This knowledge has led to better and more effective anti-alcohol campaigns.

Blurred Minds (Dietrich et al., 2019) is an Australian alcohol prevention program. The program includes the world’s first VR simulation, which aims to train adolescents’ ability to withstand peer pressure. The application is made as a gamified party, where the user makes various choices along the way, and depending on the choices they experience different consequences (Dietrich et al., 2019).

In the current project, a similar application was developed for the Danish context. This project drew on the experience gained by Blurred Minds developers and the feedback they got from their users (Durl, Trischler and Dietrich, 2017). The development took place in a co-design process, where one of the developers behind Blurred Minds was a part of the development group. The group included a diverse range of stakeholders including the Askov Folk High School’s film teacher, film students, a game design teacher, game design students, alcohol experts from social services and health promotion, game design, VR and interaction design experts. 35 students, aged 14-18 years, from Askov Boarding School participated in the production as actors and extras. The Folk High School was selected because it has students from all regions of Denmark, and therefore represents the diversity of potential user groups.

4. Related work

The combination of letting users create their own experience while being immersed in a 360-degree simulation is quite unique. During our literature search we did not come across any similar projects.

However, the idea of letting the users create their own story, by making a number of choices, is not new. In the book series ‘Choose your Own Adventure’ published by Bantam Books the reader is the central character. The reader faces two or three options for every few pages and depending of the reader’s choices the story unfolds in different ways (Kraft, 1981). The Netflix film Black Mirror: Bandersnatch (IMDb, 2019) is inspired from ‘Choose your Own Adventure’. The film consists of several movie sequences, which are put together based on the viewer’s choices, as also seen in the FestLab application.

FestLab builds on experience-based learning. Therefore, we want the user to get experiences as realistic as possible in the application, which is why 360-degree video is used.

360-degree video’s ability to immerse users is utilized in many different contexts, for example it has been proven to be effective for exposure therapy. VR has also previously been used for treatment of alcohol and nicotine addiction (Trahan et al., 2019). Users were exposed to environments activating their cravings, but contrary to the real world, these environments were carefully controlled and customized by a therapist. The same approach has been used for treatment of posttraumatic stress disorder (PTSD), where patients were exposed to trauma relevant environments (Rizzo et. al, 2015) and for treatment of anxiety (Carl et. al. 2019). These projects are good examples of virtual reality being able to foster presence and trigger emotions in users.

In an educational context VR can be used to give students a first-hand experience. In an earlier project VR and augmented reality (AR) teaching material about the solar system was co-designed with 5th grade students and their teacher. The material consisted of a traditional compendium with text and pictures and a mobile application. Most pages had additional simulations (in AR or VR), which could be accessed through the application. As an example, the students were able to take a walk by the Barringer crater or study the planets orbits around the sun in a 3D simulation (Majgaard et al., 2017).
360-degree video has also earlier been used to educate adolescents about binge drinking. In the videos ‘Decisions: Party’s Over’, users can follow a party from four different persons’ perspective and experience the dangers of binge drinking (DRINKIQ, 2018). Contrary to FestLab the videos are not interactive, and the users are locked to a fixed timeline.

5. Methodology

The project is an iterative design process which used the Living Lab approach “co-create innovation through the involvement of aware users in a real-life setting” (Dell’Era and Landoni, 2014). This means that the users are co-creators though the whole process, from the first conceptual development phase through prototyping to launch of the finished product.

The project will go through seven phases, see figure 1 below: Exploration of key concepts, concept design, prototype design, pre-usability testing, innovation design, usability test and finally testing to find the effect on alcohol consumption among adolescents in Denmark. Currently, we are preparing for the last test.

![Figure 1: The seven phases of development.](image)

In the following we describe the design process for the first six phases.
All quotes from interviews were translated from Danish to English by the author.

6. Exploration of key concepts

The first iteration consisted of an exploration of the key concepts and testing the 360-degree camera.

To explore the key concepts, the participants from the development group were invited to test the Australian VR House Party application and were later asked to share and discuss their experiences. The project leader of the VR House Party shared his experiences from developing the application, summarized challenges that they experienced, shared feedback from their users and provided recommendations on how the application could be improved.

Subsequently, the students and stakeholders together made a list of features, which the Danish application should contain. For example, the team wanted a more realistic calculation of the blood alcohol concentration (BAC), which in the Blurred Mind’s VR House Party was deemed to be unrealistic. For example, the user could pass out after as little as three drinks and it did not seem to matter whether you drank 3 drinks in a row or spread them over a longer period.

The new application should also be more consistent in giving instant feedback to the user. Several of the students from the development group had been confused when they suddenly experienced a sudden end to the game. Additionally, an ending scene, which evaluated the evening, was deemed to be a valuable addition. It was also decided that the experience should contain more elements of gamification to further boost engagement. Therefore, mini games based on popular drinking games (e.g. ‘Never I have Never’ and ‘Beer Pong’) were included.
Among the feedback that the developer of VR House Party had received from users was to gain more control over their along the opportunity to make more choices. According to Papert (1993) the best learning takes place when the user controls choices and it was decided that the user should be placed in the middle of the party and be in charge of who to talk to and where to go.

The students in the development team also commented on the distance from the user to other people in the Blurred Mind application, which in some scenes was deemed to be too far, resulting in the user feeling distanced and that they were observing instead of being part of the action. According to Sheik et al. (2016), the right distance between characters and the camera can increase emotional immersion.

7. Prototype design: Writing the story/planning the shooting

After the first session and brainstorming with the development team, the students from the film and game design course and their teachers started working on the manuscript. First, they decided on different types of personalities, made their personas and then flowcharts for each person. The students’ work was accepted by the rest of the development team with minor changes. This made the students feel heard and included in the process. Students reported they felt even more motivated to continue to contribute to the project (Vallentin-Holbech et al., 2020).

Figure 2 shows the scene with one of the main characters. Each oval represents a film sequence and the rhombus the choices the users get. In this scene, the story varies based on the gender selected on entry to the simulation (red and blue).

Figure 2: Flowchart of scene 4.

The finished manuscript ended up with eleven scenes consisting of 125 different film sequences. The students from the film course then casted actors and extras from the boarding school.

8. Prototype design part one: Shooting the film

The recording of the 360-film was completed with a team of film school students. Different roles were assigned including sound technician, line-producer, stage designer and instructor (see figure 3). One of the researchers with VR experience was responsible for the operation of the camera.

One of the challenges of filming 360-degree video is that the film team cannot be present in the room, where the recording takes place – otherwise they are visible in the clips. Therefore, the camera was controlled through the GoPro application on a tablet (GoPro.com, 2019).
Figure 3: Students from Askov Folk School’s Film course getting ready to film.

In some scenes the team took advantage of the fact that the camera filmed two times 180-degree footage, which is not stitched together until afterwards. It made it possible to record background and foreground in two different recordings, so no actors and extras needed to be on the set all the time.

Figure 4. GoPro Fusion setup

Figure 4 shows the setup of the camera. The recordings were made over three days, of which 9 hours were filmed almost without interruptions on the last two days. The camera only holds battery for a couple of hours, so a power bank was connected and placed in a bag, since a wire to a power outlet would have been visible in the recordings.

An external microphone was attached in the middle of the tripod. GoPro Fusion does record audio, but the quality is not good enough for the purpose of this project.

9. Prototype design part two: Development in Unity

The recordings were stitched together afterwards and edited. Sound and movie were combined and then clips were implemented in Unity.

For each scene in the manuscript, a scene in Unity was made. In figure 5, scene 4 the character Liam is seen. At the bottom the flowchart is placed to maintain the overview. Each of the black circles is a sphere with a movie clip.
Figure 5: Scene 4 with Liam in Unity.

The spheres have a specific material, which makes the video play on the inside of it, see figure 6. By placing the camera and thus the users in the middle of the sphere, they are surrounded by the video and get an immersive experience.

Figure 6: Video playing on the inside of a sphere.

The spheres have a canvas and on this the buttons that make up the interaction and links between the clips are placed. They are not visible from the start, but when the video clip is almost finished, the different options for the user are shown. The user now chooses from a list of two to six options. She does this by staring at the button for about 1 second. First a small animation appears to indicate that the button is clickable and then – if she keeps staring – the button will be clicked. The click calls the function SphereChanger if the option leads to a new clip within the same scene and otherwise the script SceneChanger if the clip leads to a new clip in another scene.

To calculate the BAC, the chosen gender and average weight for a 16-year-old female or male and game time were used. One minute in real time corresponds to 30 minutes in the simulation. This was chosen to keep the play time per usage down to 10-12 minutes and thereby preventing users from experiencing too much of the application at first try, which could limit replayability and subsequent class discussions. The time is shown at the top of the screen and is always visible. The BAC is also shown here. It looks like a classic game health bar and shows the BAC in percent, see figure 7. 100% green is sober, and the BAC bar then gets more and more red as the user gets drunk. 100% red corresponds to a BAC at 2, which is very high and results in blackout. When the user chooses to take an alcoholic drink the script BACCalculation is called. This script calculates the current BAC and updates the user interface (UI). It uses the correct algorithm for BAC calculation (Becker & Nielsen, 2019).
BAC calculation algorithm:
Female: Alcohol consumed in grams / (body Weight in kg x 60 %) - (0,15 x hours from drinking start) = BAC
Male: Alcohol consumed in grams / (body Weight in kg x 70 %) - (0,15 x hours from drinking start) = BAC

The BAC bar is updated continuously, so it is visible to the user that the BAC changes over time.

Figure 7: UI: Digital clock and BAC bar.

10. Pre-usability test

When the basic functionality was done, a (pre)usability test was made. The goal of this test was primarily to find bugs, evaluate the interaction and UI and get ideas for gamification of the app.

Four students from a new Askov Game design course volunteered to participate. They were aged 21-24 and therefore they were older than our target group, but for the purpose of a usability test of game elements and potential improvements as well as obtaining ideas for additional gamification elements, they were deemed suitable.

Each of them first tried the application for about ten minutes under passive observation of members of the research team. The researchers made notes of their observations along the way. Afterwards semi-structured interviews of the students took place. The students were interviewed in pairs to make them feel more confident and feel that they could talk more openly. Additionally, it could come in handy when talking about future gamification of the application because the students are used to brainstorming together and often pairs seem to get better ideas than individuals (Fullerton, 2014). The downside of making interviews in pairs is of course dominant respondents, which can influence the other. Sound recording of the interviews were made.

Thereafter, quotes from the interviews and notes from the observations were compared and divided into themes.

10.1 Results and discussion of results

10.1.1 BAC bar – clarification of purpose, virtual position and introducing animations

It was found that none of the students knew the purpose of the BAC bar before they had their first alcoholic drink and one of them did not understand the connection between drinking alcohol and the bar decreasing until he was almost finished playing. It was suggested that the bar should have a caption for example “Per Mille Meter” or the symbol for per thousand. The green/red colors of the bar made two of the participants think of a classic health bar and as a consequence of that, they did not really want to drink alcohol since it would decrease their “health”/”life”. This might limit student’s experimentation in the app, which is the opposite of what we want – the students should experiment as much as possible in this safe environment. This involves both “good” and “bad” experiences with alcohol as our hypothesis is that experiences in the app will give students knowledge and tools they can later apply in these situations in real life. According to Papert (1993) the natural learning path
contains false theories; which students learn as much from as they do from the true ones. Therefore, it is important that they feel that they can experiment freely and do not feel that drinking alcohol in the application is a (completely) unwanted act.

As a solution to this issue one of the participants suggested making the bar all white, because this would be more neutral and most likely not directly make the users think of “loosing life” like in a game. Furthermore, they suggested to make the decrease of BAC over time more visible. For example, only show the decrease on the bar when a scene ended so that the decrease would be bigger. He also mentioned that adding an animation could make it even more visible and more fun to look at.

The association between the BAC bar and a health bar made one of the participants search for a clear goal “…like in a game”. He was uncertain of what to do in the simulation. He and the other participant with whom he was interviewed with, discussed this issue. They knew the simulation was not a game, but the BAC bar made them feel like they needed to “stay alive” to a certain point to face an upcoming challenge. One of them suggested that the goal of the application should be clearer, for example a short explanation in the start menu. The main use of the application will at a later point be in schools, where it will be placed in a didactic context, so in that situation it might not be a problem. But the application will also be available on Google Play (for Android users) and App Store (for iOS users) and in that context the purpose must be clear.

It was also suggested to change the position of the BAC bar and the digital clock. One of the participants felt that the digital clock (at the top of the screen right in the middle, above the BAC bar) amounted to a pressure. He instead suggested to place the clock at the bottom of the screen in the right side, where clocks normally – according to him – are placed in games.

The participants expressed a desire for an opportunity to lower the BAC by other causes than time, for example drinking water or going to the bathroom to pee. But in real life drinking water or going to the bathroom will not reduce BAC (Healthline, 2020) and therefore this feedback could not be implemented.

10.1.2 Interaction and feedback

The gaze interaction worked well according to the participants. They understood how to make choices and praised the interaction. They, of course, have more experience with games (and VR) than the average adolescent.

It was also suggested to add an animation or sound effects when the user drinks and throws up. This could give the user a clear feedback and let them know what is happening, which according to the students was not always obvious. They also mentioned giving the user warnings when they are close to passing out. It could be done with a blurry effect or an animation of blinking slowly.

10.1.3 Immersion

The participants all got caught up in the story and they reported they wanted to experience more. Two students described a feeling of “being there” at the party. One of them said that it was especially in the center point, where the user stands in the middle of the party and can choose whom to go talk to. This is interesting because at this point, the user is standing by himself or herself and they are only observing. It is not an ideal situation for immersion since the users presence in the scene is not acknowledged by the others guests and the narrative is paused (Elmezeny, Edenhofer and Wimmer, 2018). The explanation for this could be that it is at those points in the story that they feel most in control. It was more expected to see immersion in the scenes containing more interaction. The users’ presence is to a greater extent acknowledged there, which is one of the characteristics of technical immersion (Elmezeny, Edenhofer and Wimmer, 2018).

Minor bugs were also found, for example wrong placement of buttons and a line though the picture sometimes.

11. Innovation Design

11.1.1 BAC bar – clarification of purpose, virtual position and introducing animations

Based on the test, the BAC bar got a new look, see figure 8. The colors were changed, so instead of the red and green the bar now has a grey and half opaque background. The time is placed in the same frame as the BAC bar to indicate that they are connected.
Figure 8: The BAC bar was redesigned, and a bubble animation was added each time the user drinks alcohol

11.1.2 Interaction and feedback

To make it clearer to the user that something actually happens when they choose to drink alcohol, more feedback was added; a bubble animation, a drinking sound and an animation of the BAC bar, which makes a shaking movement to attract user attention. A sound effect for when the user throws up was also added

Furthermore, an increasing “dizzy effect” was added. This effect should simulate the user getting drunk by moving the user (the camera) slowly from side to side for a few seconds. The speed and amplitude of the effect increase as the BAC gets higher. This was discussed early in the design process but given the risk of cybersickness (Rebenitsch and Owen, 2016), when moving the user in the simulation, while being stationary in the real world, the idea was dropped. Repeated requests from users made us rethink this and we decided to test if it could work without too many students getting sick.

11.1.3 Ending scene

An ending scene was also added. This scene aims to summarize the evening and provide feedback to the users on her actions during the party. The scene takes place the morning after, where she wakes up in her bed and has a look at her smartphone. Here she will receive different text messages from other participants at the party. The messages received depends on her actions, e.g. if she chooses not to help the very drunk guy, she will get a message from a friend asking if she has seen him (see figure 9). The user navigates through the messages using the gaze interaction which they are already familiar with at this point. They will first see a list with names of the senders. Here they choose which conversation to read and can return to the list by clicking the back arrow. The buttons are placed as on a real mobile phone to make the interaction as smooth and realistic as possible.

Figure 9: If the user chooses not to help the drunk guy, Johan, they will receive this message [translated by author]
The messages and the actions that trigger them were designed by the students (again to make simulation as realistic as possible). Some of the messages contained swearwords, which we chose to remove or censor since the app is to be used in schools. For example, “fuck” was written “F#@&”.

12. Usability and immersion test

After the adjustments from the pre-usability testing, another usability test was conducted. The goal this time was to evaluate the additions and corrections to the app and see if the users got cyber sick with newly added drunk animation.

The test took place in the same way as the last test - each user tried the application for about 10 minutes under passive observation and afterwards they were interviewed. This time the headset was casting to a television through a Chromecast, allowing the observer to see (real-time) what the user was seeing in the headset.

Six students from the next student cohort enrolled in Askov Game design course volunteered for this phase of the study.

Five of the students immediately saw the BAC bar and understood that it illustrated their alcohol intake. The last user said that he did not pay much attention to it to begin with, because he thought that the bar showed the headset’s battery life. In the interview they were asked what happened when they drank alcohol. They did all notice the bubble and drunk animation as well as the BAC bar getting fuller.

12.1 Results and discussion of results

12.1.1 BAC bar

One of the students added that she did not know what would happen when the bar was full, for example if she then would be “… really drunk but having a good time and partying on or passing out and getting game over”. Another student suggested to make the bar gradient from green to red or adding a “… normal happy smiley face to one end of the bar and a smiley looking really bad at the other end”.

This time no one seemed to make the connection between the BAC bar and a health bar. They experimented more freely with alcohol than they were prepared to do in the earlier test and they did not seem to be afraid of filling the BAC bar. Two of the users drank enough alcohol too pass out and got game over. When asked about their tactics afterwards, they both expressed that they were aware of the BAC bar getting fuller, meaning they got more and more drunk, but they consciously kept drinking to see what would happen.

The new placement of the clock also seemed to make a difference. Two users commented on the time passing while playing. One user with the BAC bar two-thirds full said, “I’ll better wait until midnight before I have another beer” and another said “Oh, it is already past 1 o’clock. I better hurry and play beer pong”.

12.1.2 Interaction and feedback

They did all notice the drunk animation, where the user is moved from side to side, and knew that it got initiated by drinking alcohol. They generally liked the animation. One of the users, who got so drunk he passed out and therefore also experienced the animation at its highest, expressed that he was feeling a bit dizzy while using the application. In his view this was not negative “In some way it makes it feel more realistic. When I am drunk in real life, I can also get... Ehhmm... You know this feeling of your head lagging and being mentally behind [lagging: concept used to describe computers responding slower than expected]”. Surprisingly none of the other users felt any cybersickness. This could be due to the BAC bar functioning as a static frame, which reduces the risk of cybersickness (Rebenitsch and Owen, 2016). Further testing will determine if this applies more broadly.

Cybersickness can be a breaker of immersion and the feeling of being present (Weech, Kenny and Barnett-Cowan, 2019). In this application, users could on the other hand expect to feel this discomfort as they get drunk in the simulation, which could – theoretically – increase immersion.

12.1.3 Ending scene

The message system worked as intended. All users knew right away how to choose a message and return to the list. A user expressed “It was funny to see that it actually meant something what I did in the game. I will have to
try again and choose something else. And drink way more alcohol.” Another user described the last scene as “interesting” and added “It made me rethink what I answered and made me want to try again”.

One user was a bit baffled by one of the messages he received. He had talked to the very drunk guy, Johan, in the corner, who tells the user that he is feeling very bad and asks the user what he should do. The user chose to help him go to the toilet to throw up. Johan then says that he is feeling better and the user can now choose between calling the guy’s parents or returning to the party right away. The user chose the last option, which later results in a message from the friend, who invited the user to the party. The message says “So we have an agreement in the class that we call the parents if someone throws up. It wasn’t ok that you just left Johan”. The user felt that he had done the right thing by taking the drunk guy to the bathroom, and therefore he felt that the message was unjustified.

12.1.4 Immersion

The test showed a few signs of immersion. While one user was on the dancefloor, he started to move slowly to the music for a second after which he laughed and said, “I totally forgot that you could see me” and instantly stopped moving. When asked about this afterwards he reported a feeling of being at the party and for moments forgot where he physically was.

Another user said that she got the feeling of being present in the virtual room, but that she did not feel engaged in the story, which played out around her. This indicates a lack of narrative immersion. It could be caused by her being a few years older than the intended target group.

This feeling of being present at the party is beneficial to the learning process. It enables the user to get a realistic firsthand experience with alcohol. By breaking the immersion, the user gets an opportunity to take a step back and analyze the situation, which is also critical in relation to experiential learning. Frasca (2006) argues that destroying immersion can “…be a positive feature because it can encourage the player’s critical thinking” (Frasca, 2006). He described this as outmersion. In VR PartyLab outmersion might happen when the BAC bar draws attention to itself by shaking and enlarging after the user drinks alcohol. This could make the user analyze her own behavior and for example come to the conclusion that she should wait to drink another beer as seen in the test.

13 Thoughts about the learning design inspired by experiential learning

In this section, we introduce ideas for developing didactics/learning design to support the learning goals. The VR Party application should in real life be a part of classroom teaching where the drinking topic and maybe group pressure theory is introduced before students are exposed to the VR Party.

Learning goals: The intended learning goal for the students using this simulation was to recognize and deal with peer pressure in a party situation. Additionally, the students would experience the consequences of saying yes and/or no to alcohol in the simulation. The goal was that the students developed their understanding of blood alcohol concentration (BAC), peer pressure, and competencies regarding choosing only to drink moderately based on their VR experiences.

Content and learning activities: In the simulation, the student attended a virtual party and created her own experience through a number of choices. The 360-degree simulation was experienced through VR glasses to provide an immersive and intense experience. One example was that the learner could choose: 1) whether to drink alcohol or not, 2) the type of alcohol and 3) drinking frequency. The user was also faced with non-alcohol related choices such as the opportunity to help an intoxicated man, starting a heated argument or flirting with other guests.

Learning aspects - Experiential Learning: In this experiment we used the Experiential Learning Theory as a basis of how to support students’ learning process, as students learn through experience in this VR-simulation. Kolb’s (1984) theory of Experiential Learning describes how learning happens as the learner reflects on concrete experiences.
In the first stage - *Concrete Experience*, the learner physically experiences the here-and-now (see figure 10). This experience forms the basis for reflection and the learner has the opportunity to consider what is taking place and decode it (reflective observation). Then they can compare this to their previous knowledge and try to work out and decide how to understand this and decide what worked well and what could be improved (abstract conceptualization). After this he or she can think about how to engage in an experiment based on what they learned to improve what they just experienced (active experimentation). Every new experiment is informed by previous experiences and reflections and forms a cyclical pattern that can be continued, until the learner reaches the goal they aims for in this learning experience.

In the *VR-Party* the learner experienced the here-and-now party situations such as peer pressure in the form of drinks offered by new potential friends (concrete experience). The learner then reflected on the drinking situations (reflective observation) and thought of how to interpret and evaluate what took place (abstract conceptualization). Then she made strategies on how to improve her next decisions and tried this out in the VR-experience (active experimentation), informing new cycles of experiences and reflections (active experimentation).

*Learning design reflections*: To optimize the students' learning process and harvest the gains from the VR experience, the teacher must plan the learning design carefully 'around' the use of the VR-experience, see the figure below.

---

**Figure 10**: The small learning loop - Experiential Learning Model (Kolb, 1984)

**Figure 11**: The large learning loop - Learning design around the VR application.

The usage of the VR-Party application in classroom teaching calls for an initial introduction to knowledge about blood alcohol concentration (BAC) levels and peer pressure. Retrospective reflections on the experiences after the VR experiences are also crucial to transform the experience into new knowledge about BAC, peer pressure, typical party situations, and drinking behavior. The concrete learning design will often be repeated if more
theory and new challenges in the VR application needs to be introduced, tested, and evaluated. In this case we have more than one learning loop.

To summarise Virtual Experiential Learning runs in two loops. The small loop is what the students experience and reflect on in the VR simulation. The larger loop focuses on the learning design, academic concepts and retrospective reflections. In the small loop the individual student experiences VR and the experience leads to tacit knowledge. In the larger loop, the teacher’s role is to support a process that transforms the tacit experience into explicit knowledge on BAC, group pressure and drinking patterns.

14 Summary and conclusion

The article has presented a practical example of how to co-design an immersive and interactive environment, where adolescents can acquire skills for recognizing and handling peer pressure in relation to alcohol though experience based learning. The design process began with exploration of key concepts and concept design in the development group, followed by design of the prototype involving development of flowcharts, writing of manuscript, filming and development in Unity. The application ended up consisting of 125 movie clips. The clips the user meets and in which order depends on the choices the user makes, but also gender and current BAC.

We learned that flowcharts are a great help, when filming a larger story with multiple paths. Without the flowcharts we would have lost track and we would not have been able to shoot all the clips in just one weekend. The flowcharts were also a big help when the clips were implemented in Unity.

The prototype has been through two usability tests. The tests showed that the application has potential for immersing users. The users felt presence, and some had a feeling of “being there” at the party, which is positive in relation to users getting realistic firsthand experiences with alcohol (concrete experience). Users reflected on their experiences (reflective observation) and interpreted them by analyzing the events and connecting them (abstract conceptualization). From this point new strategies in the VR experience were made and tested (active experimentation). The next step is to test the application on the target group. We will start by doing a pilot test and then the application will be tested in a randomized controlled trial to clarify the effect – will adolescents have more skills to resist peer pressure to drink after having used this application?

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References


Engaging Students in a Peer-Quizzing Game to Encourage Active Learning and Building a Student-Generated Question Bank

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Abstract: Games are a great source of entertainment and are used by people of all ages; they motivate and engage people and affect their behavior. Therefore, games have been widely studied in many non-game contexts. Education is one of those areas where gamified, and game-based learning strategies have been implemented and explored. To engage and motivate students to quiz each other, and as a side effect, build a question bank, as well as to study the gaming and learning behavior of students, we used a peer-quizzing game called “Tower of Questions” (ToQ). The game uses some themes and mechanics found in tower defense (TD) games. The students received points for posing and answering the questions in the game in the form of gems. Students played the game with pseudonyms for one academic term and were told not to disclose their identities to anyone. We conducted a 3-month long study for two consecutive years in the same first-year undergraduate computer science course. In this paper, we present the findings from our studies using ToQ, specifically findings related to the students’ self-monitoring and quizzing activities based on the game logs and two self-reported surveys from data collected in the second year of the study.

Keywords: gamification, game-based testing, peer-quizzing, incentives, engagement

1. Introduction

Computer games have become one of the favorite means of entertainment for people of all ages. Gamers spend countless hours trying to complete the challenges they encounter. Unlike physical games, computer games do not usually exhaust the players from prolonged play-sessions. The players keep engaged and motivated to play even when they fail to accomplish the challenges of the game, and in the process, acquire new skills. The challenges and the skills required to overcome the challenges in the game should be balanced because if the challenges are harder than the individuals’ skills, they may feel anxious. If it is more comfortable, they may get bored. Researchers and businesses have exploited this motivation/engagement effect of games by applying game mechanics and dynamics in non-game contexts (gamification) with mostly successful results. Computer-Based Learning is one of the fields that has adopted gamified and game-based solutions to engage and motivate the learners. Motivated students have a more positive attitude and engage better in the learning process (Bergin and Reilly 2005).

Gamification is the use of game elements (such as points, badges, rewards, and leaderboard) in non-game applications (Deterding et al. 2011; Hamari, Koivisto, and Sarsa 2014). Gamified learning tools are usually designed to allow learners to make choices and receive rewards for the right actions (Alsawaier 2018). On the other hand, game-based learning tools are primarily games that are designed to facilitate learning while playing. Some examples of game-based learning software are The Oregon Trail, Blue’s Birthday Adventure, Minecraft: Education Edition, and various typing tutors. While game elements add all the novelties to make learning enjoyable, the underlying educational methods are equally important. Game elements and instructional methods work in tandem with each other in educational games. Therefore, it is essential that these two components are balanced out so that the enjoyment does not overtake on learning. Educational games might be played by the students alone or cooperatively with other students, and the setup may or may not have competitive components.

Students learn things better when they get to explore and ask questions (Bonwell and Eison 1991). By asking questions, not only can a student learn new things but also demonstrate the ability to think and debate. A good question can open the door to gaining knowledge and discovery (Vogt, Brown, and Isaacs 2003). As a learning process, course instructors engage students in constructing questions and using those in the class (Yu 2011).
Peer-quizzing is an excellent way to engage students in a class, and since it is informal and does not put them under the pressure of making a mistake that would affect their grades. This also opens room for discussions and debates, similar to the Socratic method (Nelson 1980). In the Socratic method, an argument between individuals by asking and answering questions can lead to critical thinking and discovering knowledge. It is found that students prefer Socratic methods more than traditional class-lectures (Adib-Hajbaghery and Aghajani 2011). Finally, formulating a good question by itself is a skill that is essential in the “understanding” stage of learning (Bloom et al. 1956; Krathwohl 2002). In the “understanding” stage, learners can demonstrate their comprehension by classifying, explaining, summarizing, and comparing the things they learned.

The study presented in this paper is an extension of a previous work (Kiron et al. 2019). We used data collected from our online web-based collaborative peer-quizzing game called “Tower of Questions” (ToQ). The game uses some game elements found in tower defense (TD) games (such as points, building and attacking towers). In the game, students build virtual towers by posing questions, and other students try to attack and conquer the towers by answering the questions. They receive points for asking and answering questions in the form of gems to match TD-themes. The idea behind the game is to engage the students in constructing good quiz-questions and answering those, and in the process, building a crowdsourced question-bank. This approach is known as “contributing student pedagogy” (Hamer et al. 2008), where the students take part in constructing learning materials and provide feedback on each other’s work (Hamer et al. 2008; Denny 2013).

High-quality questions from the question bank can be used in class discussions and even in tests for future classes. The question bank also serves as a medium to allow the students to learn about things crowdsourced by their peers and may help them fill in knowledge gaps. Also, the game did not have a leaderboard and instead implemented two pages where the students can observe their progress and support their self-efficacy. The two pages, as shown in figures 1 and 2, respectively, show the questions the students have conquered. On one page, the conquered towers are presented in thumbnails, and the other page shows the conquered towers in tabular form. One of our objectives is to study which type of self-monitoring page is used the most by the students. Also if the students have any gaming strategies or preferences on attacking or building towers in ToQ.

We carried out two studies with ToQ with first-year computer science students. The first study (n=37) took place during one academic term (September to December 2018), and it was found that students who regularly posed quiz-questions also answered other students’ quizzes frequently. Also, students who were familiar with TD games tended to answer other students’ questions more than posing questions themselves. In this paper, we present the findings of our second study (n=49), which took place in the same class and term but in the year after (September to December 2019). The results show that students enjoyed learning their course materials playing the game and found it useful as a learning tool, which is in line with our previous study (Kiron et al. 2019). In the present study, the students liked answering questions more than asking, and they did not like viewing the questions as much as they liked posing and answering questions. Also, students who used the tabular-based self-monitoring page tended to build more towers than the students who used the thumbnail-based self-monitoring page. This paper is structured into six sections; section 2 discusses related works, and section 3 describes the game we developed and used in our study. In section 4, we discussed the methods, participants, data analysis, and the results of our research. Section 5 and 6 are general discussions and conclusions, respectively.

2. Literature review

Deterding et al. (Deterding et al. 2011) proposed the definition of gamification as “the use of game design elements in non-game contexts.” Gamification acts as an extrinsic motivator that is designed to influence intrinsic motivations. It is an excellent tool for motivating and engaging people (Kapp 2012; Tanaka et al. 2016). Gamification helps setting up goals (long or short term) and set the focus of the user to achieve that while being entertained (Nah et al. 2013). Two of the most common purpose of both gamified and game-based tools is to motivate and engage people to perform a particular behavior. While engagement is somewhat easier to achieve in a gamified or game-based tool because of its gameful nature, the outcomes of motivation are variable.

The use of gamification and its outcomes depends on how it is designed and used. Domínguez et al. (Domínguez et al. 2013) designed and developed a plugin for the Blackboard learning system to motivate and engage students. They found that the students who used their gamified system did better in practical assignments and had better overall scores than those who did not. However, those students did not do well on written
assignments, and their participation in class activities was less than the participation of those who did not use the system. Denny (Denny 2013) used a badge-based achievement system in their experiment to study its effect on students’ participation and contributions. It was found that students who did not use the badges were more active in answering and enjoyed using the system in general and suggested that some other factors motivate their participation.

Many studies reported improved participation by gamifying their systems (Barata et al. 2013; Knutas et al. 2014; Cheong, Cheong, and Filippou 2013). Knutas (Knutas et al. 2014) used an online asynchronous collaborative discussion system to encourage students to help each other and utilized gamification elements (such as points, badges, and leaderboard) to motivate them. Their study (n=249) reported an increase in student collaboration, course communication, and reduced response times. They also found that skilled students were more active and enjoyed using gamification elements.

In another study to see how gamification affects participation, Thom et al. removed the gamification elements from a social network service (SNS) [Thom, Millen, and DiMicco 2012]. They conducted the study on a gamified enterprise SNS that awarded points to the users who contributed by submitting contents (lists, photos, or comments) in the platform. At one point in their study, they removed all features related to points (profile badges, leaderboards, and total points display) from the SNS. They found that the removal of those features leads to a reduction of users’ contributions to the SNS.

Our objective in the present study is to engage the students in designing and posing quiz-questions as a “contributing student pedagogy” (Hamer et al. 2008) using an online peer-quizing game. The goal is to engage students in creating questions related to the material and challenging each other to answer these questions, thus exercising their understanding and knowledge of facts about the learning material. It also facilitates the creating of a question bank and allows the students to study the answered questions alongside their course materials (similar to an FAQ). The game is themed with elements found in tower defense games but without leaderboards to encourage the students to focus on self-efficacy and competition.

3. Tower of Questions – A Peer-quizzing Game

We have used a peer-quizing game called “Tower of Questions” (ToQ) to engage students in designing questions and answers as a class activity. The game uses styles, mechanics, and dynamics found in Tower Defense (TD) games. TD games are a sub-genre of strategy games; while there are many variations of this genre, the most common implementations involve building structures (usually in the form of towers, fortresses, and castles) and applying defensive mechanisms to prevent attacks by game-AI or by other players. Some popular TD games are Plants vs. Zombies series, Bloons TD series, Kingdom Rush series, and many more. Our ToQ version uses game mechanics such as points in the form of gems, quizzes, domains, and progress and dynamics such as collection, exploration, and community (Bunchball 2010).

ToQ is a web-based game that the students play asynchronously by logging in with their gamer IDs (pseudonyms) and passwords. The front-end implementation uses HTML, CSS, and JavaScript, and the back-end – PHP and MySQL database. Before the game begins, the administrator configures some aspects of the game. For example, creating accounts for the students with the pseudonyms, setting the total number of gems that can be earned from the game in a given period, e.g. by the middle of the term, or for the entire semester. The administrator also configures the number of gems rewarded for building and attacking towers, and the gem-penalties for not playing the game fairly. Only participating students and administrators can access the game, and the quiz questions and answers are based on the course material.

In the game, the students (Lords) build virtual towers by posing quiz questions. For each tower, the students can choose one of the three types of questions available in the game: true/false (TF), multiple-choice questions (MCQ), and short answer questions. Then they select a domain where they want to place their tower in. The domains are the topics taught in the class, but in our game, they represent a zone that the Lords intend to dominate or establish their towers on. When posing a question, the student must also provide the answer. The game has a gem-bank with a finite number of gems that the players can earn by building towers (posing quiz-questions and answers). Players can also earn gems by attacking other students’ towers, in which case the gems they earn come from a portion of the gems earned when the tower was built. For example, a student (Lord of the tower) is awarded ten gems for building a tower, and another student (Enemy Lord) attacks that tower (by
answering the question represented by the tower). The Enemy Lord will get six gems from the ten gems, and the Lord of the tower will keep the remaining four. In the case when a tower remains undefeated for seven days, it is made open for all students to view the question along with the correct answer, and the Lord of the tower keeps all the ten gems. The gem distribution is designed this way so that the students think before posing a question and find the reward more valuable because of its scarcity and making collecting points enjoyable (Dichev et al. 2014; Cialdini and Cialdini 1993). Since the number of gems that can be earned from the game is finite, the students can pose questions and answers as long as there are gems available in the bank. If there are no gems left in the bank, no new towers can be built. However, points can still be earned from attacking the open towers. A breakdown of the gem distribution is presented in table 1.

Table 1: Rewards distribution for actions in the game.

<table>
<thead>
<tr>
<th>Action</th>
<th>Gems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create a tower</td>
<td>10</td>
</tr>
<tr>
<td>Attack a tower</td>
<td>4-6</td>
</tr>
<tr>
<td>Flag a tower</td>
<td>0</td>
</tr>
<tr>
<td>Being flagged</td>
<td>An increment of -10 gems for each offense</td>
</tr>
</tbody>
</table>

Gems for the TF and MCQ type questions are awarded instantly, but gems for the short questions are awarded after the Lord of the tower has reviewed the answer. The Lord of the tower can mark it as fully or partially correct or incorrect. Since these types of questions are open-ended and sometimes subjective, it is possible that the answer provided by the Lord of the tower and the Enemy Lord may not match fully in arguments and may not address all the points. To address this issue, the game is designed to allow the Lord of the tower to mark an answer to be partially correct. However, to prevent Enemy Lords from guessing, attacks on towers can be marked “partially correct” only up to three times, after which the Lord of the tower can only choose between incorrect or correct.

After a tower is built, it is placed in the “Open Towers” page of the game and is open for attacks by other students. The Lord, who created the tower, cannot attack their tower. A tower can be attacked only once; if it is successfully attacked by one student providing the correct answer, it is closed for further attacks and is moved to another area in the game called “Conquered Towers” and becomes open for all other students to browse it. The “Conquered Towers” area is the question and answers bank and one of the most important parts of the game. All towers showcased in the “Conquered Towers” area shows the question, answers, and all the attempts made (in case of short questions) when browsed.

While using the game, we were aware that in crowdsourced platforms, the crowd’s effort and quantity of contribution might be affected if there are unfair means of earning incentives (Sun and Vassileva 2006; Zhao and Zhu 2014). It is vital to demotivate hyperactive students that attempt to game the system by creating many repeated or trivial questions (Cheng and Vassileva 2005; Mao, Vassileva, and Grassmann 2007). Hence, the total number of gems that can be earned in the game is finite, and the system has a flagging feature to report unfair activities to the administrators who can then take necessary actions to discourage these behaviors. Questions and answers can be flagged by the students when the respective towers are in open or conquered stage. If a question or answer gets flagged by more than 10% of the number of actively playing, it gets moderated. For violations, the first time the student is notified about their action, the gems associated with the incident are taken away from their account and put back to the bank. For subsequent violations, the number of gem-penalty is increased by ten gems plus the gems involved in the incident.

There is no leaderboard in the game because we did not want the students to engage in social comparisons (Hanus and Fox 2015), but instead, we wanted them to focus on the number of gems they can earn from the bank. Self-monitoring helps students to prioritize their learning activities and select the one they find more effective, and it also helps them to manage their time (Zimmerman and Paulsen 1995). Therefore, to allow self-monitoring of their activities and progress, two pages are implemented in the game. The first page, as shown in figure 1, is called “Towers That I Ruled.” On this page, all the towers attacked and conquered by the student are displayed in thumbnails with pictures of towers and the question. The second page, as shown in figure 2, is an attack log-book in a tabular form containing more details like the timestamp of the attack, outcome of the attack, and a link to the question.
Towers That I Ruled by Territory

<table>
<thead>
<tr>
<th>Algorithms</th>
<th>Abstraction</th>
<th>Introduction to Processing</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour In Processing</td>
<td>Interaction and Events</td>
<td>Variables and Expressions</td>
<td>Functions with Outputs</td>
</tr>
<tr>
<td>Libraries</td>
<td>Conditional Branching</td>
<td>Repetition</td>
<td>Nesting Programming Constructs</td>
</tr>
<tr>
<td>Lists</td>
<td>File I/O</td>
<td>Dictionaries</td>
<td>Advanced Problem Solving</td>
</tr>
</tbody>
</table>

![Diagram of towers with questions]

**Figure 1:** This page in the game shows the students the towers they have successfully attacked and conquered with thumbnails of the questions (towers)

Log Book

<table>
<thead>
<tr>
<th>#</th>
<th>Question</th>
<th>Attempt</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To write a dictionary you must use which brackets?</td>
<td>Success</td>
<td>2019-11-27 19:35:10</td>
</tr>
<tr>
<td>2</td>
<td>Lists can't be used as values for key-value pairs.</td>
<td>Success</td>
<td>2019-11-28 21:02:14</td>
</tr>
<tr>
<td>3</td>
<td>Can you have more than one dictionary pair with the same key name?</td>
<td>Failed</td>
<td>2019-11-26 21:00:20</td>
</tr>
<tr>
<td>4</td>
<td>What is the delimiter in the file line 1.2.3.4.5.6?</td>
<td>Success</td>
<td>2019-11-26 20:49:51</td>
</tr>
<tr>
<td>5</td>
<td>In tabular files, all data items on a line must be the same.</td>
<td>Success</td>
<td>2019-11-26 20:49:21</td>
</tr>
<tr>
<td>6</td>
<td>You can write different types of data (ex, strings, lists, etc) to files</td>
<td>Failed</td>
<td>2019-11-26 20:45:24</td>
</tr>
<tr>
<td>7</td>
<td>What number is associated with the first item in a list?</td>
<td>Closed</td>
<td>2019-11-26 20:45:11</td>
</tr>
<tr>
<td>8</td>
<td>Which of the following lines of code successfully open the file my file.txt for reading?</td>
<td>Closed</td>
<td>2019-11-26 20:45:00</td>
</tr>
<tr>
<td>9</td>
<td>$f = open(&quot;my\text{file}.txt&quot;,&quot;r&quot;)$</td>
<td>what does &quot;$r&quot; mean</td>
<td>Closed</td>
</tr>
</tbody>
</table>

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</tr>
<tr>
<td>7</td>
<td>What number is associated with the first item in a list?</td>
<td>Closed</td>
<td>2019-11-26 20:45:11</td>
</tr>
<tr>
<td>8</td>
<td>Which of the following lines of code successfully open the file my file.txt for reading?</td>
<td>Closed</td>
<td>2019-11-26 20:45:00</td>
</tr>
<tr>
<td>9</td>
<td>$f = open(&quot;my\text{file}.txt&quot;,&quot;r&quot;)$</td>
<td>what does &quot;$r&quot; mean</td>
<td>Closed</td>
</tr>
</tbody>
</table>

**Figure 2:** The attack log-book displays all the attacks and attempts in tabular form with timestamps

4. **Method**

We carried out an exploratory study aiming to answer two research questions:

1. What, if any, gaming strategies did the students deploy in ToQ?
2. What self-monitoring style preferences did the students have?

We collected their game-play data by logging the students’ actions and events in the game. We looked for patterns in the data that may reveal in their gaming strategy (build, attack, or view existing towers) that are used
the most and if it had any effect in their grades. We also looked at which of the two types of self-monitoring pages in the game they used the most and if it had any impact in their gem-collection?

4.1 Participants

We recruited 166 first-year undergraduate students taking an introductory computer science course at our University to play the game as a class activity in their introductory programming class in the fall term of 2019. Participation was voluntary, and the students who played the game actively received up to a 5% participation bonus mark. After consenting to participate in the study, the students had to complete a pre-study survey of twelve questions about their gender, preferred study hours, time spent studying, time spent gaming, familiarity with tower defense games, and preference to work alone or in a group. The students played the game for an entire academic term of four months (they played actively for approximately three months, September 4 to December 6, 2019). At the end of the term, the students were invited to respond to a short post-study survey of ten questions, which required them to reflect on their experiences playing the game. The participants were assigned a pseudonym when they signed up for the game and used it to play the game the whole term.

Thirty percent (30%) of the 166 students (n=49) who signed up for the game played it regularly until the end of the term and completed the surveys. Of the 49 students, there were 27 males, 21 females, and one student who identified as “other.”

4.2 Results

Together the 49 students created 424 towers (MCQ:171, True/False:172, and Short-Answer:81), of which 167 were built before the mid-term exam (MCQ:74, True/False:52, and Short-Answer:41) and 257 towers between the mid-term and the final exam (MCQ:97, True/False:120, and Short-Answer:40). Of the towers created before the mid-term exam, 159 out of 167 towers (95%) were conquered. The conquered towers of those created between the mid-term and the final exam are 232 out of 257 towers (90%). A summary of the demographics of the active participants in the game is shown in table 2.

Table 2: Description of participants (n=49)

<table>
<thead>
<tr>
<th>Description</th>
<th>Female</th>
<th>Male</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>21</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Times Towers Viewed</td>
<td>Before Midterm: 363</td>
<td>Before Final Exam: 209</td>
<td></td>
</tr>
<tr>
<td>(Viewed Solved Q&amp;A)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Before Midterm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Times Self-Monitoring Method Used</td>
<td>Thumbnail-based page: 129</td>
<td>Tabular-based page: 119</td>
<td></td>
</tr>
<tr>
<td>(Before Final term)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Before the game session began for the term, we configured the gem bank with 5000 gems. By the end of the term, 4340 gems were earned by the 49 students who played the game regularly. The students posed questions in all the 13 domains except “Advanced Problem Solving.” The possible reasons for this are that first, the three types of questions allowed in ToQ are better suited for quizzing facts, concepts, and definitions, as well as simple program tracing examples but do not fit well with solving advanced programming problems. Another reason might have been that this was the last chapter taught in the class, and right after that, the students had their final exam, so they were busy reviewing the entire class material, and they probably did not have time to play the game, even though the game’s question bank could have helped them to prepare.

A total of 424 towers were built (424 questions), and 391 of those towers were attacked successfully (391 questions were answered). The students used the thumbnail-based self-monitoring page 344 times (215 times before the midterm and 129 times before the final exam) and the tabular feature 370 times (251 times during midterm and 119 times during final term exam) during the whole game session. The students viewed for studying 572 towers (363 before the midterm and 209 before the final term exam) after they were conquered.

We carried out a correlation analysis between several variables (midterm exam grade, final exam grade, the final grade for the class, gems earned, towers built, towers conquered, and towers visited) to evaluate the strength of the relationships. In addition to that, we also analyzed the post-study survey to find out about their experience playing the game and using it as a learning tool.
4.3 Data Analysis

The analysis was carried out on the data generated by the 49 participants who played the game regularly and completed the pre- and post-study survey. We found a stronger correlation between towers conquered and gems earned, \( r (47) = 0.855, p < 0.05 \), compared to towers built and gems earned, \( r (47) = 0.331, p < 0.020 \). This may suggest that most of the students were more focused on earning points by attacking towers than building. Also, we found a strong correlation between towers visited (viewing solved questions) and points earned, \( r (47) = 0.610, p < 0.05 \). The correlation coefficient between towers visited and towers built is \( r (47) = 0.400, p < 0.004 \), and between towers visited and towers conquered, it was \( r (47) = 0.541, p < 0.05 \) respectively. This may indicate that students who visited the conquered towers page were more active in searching for new questions than making questions themselves.

**Table 3:** Correlation coefficients between midterm grade, final term grade, final grade, gems earned, towers built, towers conquered, towers visited, using thumbnail, or tabular self-monitoring page—correlations where \( p < 0.05 \) is marked with an asterisk (*).

<table>
<thead>
<tr>
<th></th>
<th>Midterm grade</th>
<th>Final term grade</th>
<th>Final grade</th>
<th>Gems earned</th>
<th>Towers built</th>
<th>Towers conquered</th>
<th>Towers visited</th>
<th>Used thumbnail</th>
<th>Used tabular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midterm grade</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final term grade</td>
<td>0.852*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final grade</td>
<td>0.855*</td>
<td>0.932*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gems earned</td>
<td>0.229</td>
<td>0.198</td>
<td>0.281</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Towers built</td>
<td>0.121</td>
<td>0.051</td>
<td>0.172</td>
<td>0.331*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Towers conquered</td>
<td>0.162</td>
<td>0.209</td>
<td>0.232-0.854*</td>
<td>-0.083</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Towers visited</td>
<td>0.086</td>
<td>0.139</td>
<td>0.203</td>
<td>0.610*</td>
<td>0.400*</td>
<td>0.541*</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Used thumbnail</td>
<td>0.049</td>
<td>0.125</td>
<td>0.138</td>
<td>0.043</td>
<td>0.292*</td>
<td>-0.128</td>
<td>0.015</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Used tabular</td>
<td>0.097</td>
<td>0.094</td>
<td>0.108</td>
<td>0.028</td>
<td>0.364*</td>
<td>-0.127</td>
<td>0.188</td>
<td>0.587*</td>
<td>1</td>
</tr>
</tbody>
</table>

When analyzing the correlation between the students’ usage of the thumbnail-based page and points earned, and between the tabular-based page and points earned, we found \( r (47) = 0.043, p > 0.05 \), and \( r (47) = 0.028, p > 0.05 \) respectively. The correlation between usage of thumbnail-based page and towers created, and between tabular-based pages and towers created is \( r (47) = 0.292, p < 0.041 \) and \( r (47) = 0.364, p < 0.009 \) respectively. It seems that tabular-based self-monitoring has slightly more influence in the building of towers.

We also calculated the correlation between the points earned and final grade, \( r (47) = 0.280, p > 0.05 \), towers conquered and final grade, \( r (47) = 0.232, p > 0.05 \), towers built and final grade, \( r (47) = 0.172, p > 0.05 \), and towers visited (viewing questions) and final grade, \( r (47) = 0.203, p > 0.05 \). The fact that none of the values are significant may mean that the students’ final grades are not influenced by playing the game.

4.4 Result from the Post-study Survey

The post-study survey was completed at the end of the term. It asked about the students’ experience using the game and the quality of the questions and answers.

When asked about the quality of questions posed by their classmates, 78.79% of the students said the questions were good. For 12.12% of the students, the questions were too easy, and for 9.09% - too challenging. When asked if they found it enjoyable to learn their course materials using the game, 75.76% responded “yes” and 24.24% – “no.” In response to the question if ToQ was useful as a learning tool, 78.79% said “yes” and 21.21% – “no.” Regarding which features in the game they liked the most from the multiple-choice options, the most (48.48%) chosen option was “Answering the questions,” and the least (12.12%) preferred option was “Reading from the question bank.” A graph of which features are liked the most by the students is presented in figure 3.
Figure 3: Post-study survey result of the multiple-choice question - Which features of the game the students liked most

When asked about which features they think need improvement, a lot of the responses were about not having enough questions to answer. Some of the feedback is highlighted below:

1. “There often were not open towers to attack. Sometimes the questions people posted were worded in a confusing way.”
2. “Pre-built question in case there’s no question available.”
3. “Not enough questions to go around.”

When asked if they have any other feedback for the game, one student wrote:

“I think this was a cool learning tool. It has room for improvement but I think if the Q/A are reliably accurate, it can be a good study tool as well. A little competition never hurt either, so maybe something like a daily or weekly bonus question for some reward would get people on it more often, and even more competitively if only a certain number of people could get the reward for answering. That sounds maybe a bit complex, but I’d participate in that on an ordinary non-terrible non-midterm week!”

Another student wrote:

“Moderation of the questions (answered questions don’t get updated quickly enough, and some people are bad at presenting questions) and making the UI easier to navigate (I couldn’t find where to ask/answer questions for the first week)”

From all the feedback, it appears that the students enjoyed collecting points, and they preferred to have ready-made questions in the bank for practicing. The quality of the crowdsourced questions seems to be concerning to the students. This may explain why reading the questions from the question bank consisting of the answered questions had the lowest votes in the post-study survey. Even though there was a flagging option that allowed students to mark spam or trivial questions in the game, it was not used by the students as much as expected. Results from the post-study survey, as shown in figure 3, show that answering the questions, collecting points, and creating towers are the three most liked features of the game.

5. Discussion

Gamification and game-based learning have a promising future. The design of the gamified and game-based applications plays an important role in its success. We explored how students play a peer-quizing game themed as a tower defense game and which actions (building, attacking, or visiting conquered towers) they prefer to take the most. Also, we wanted to find out which of the two self-monitoring pages (thumbnail with tower icon
and the text of the question or a tabular form with more details like attack success/fail, link to question and timestamp) was used the most as a reflection/self-monitoring tool, in the absence of a leaderboard. In addition to that, we also analyzed the post-study survey results to evaluate the experience of the students from playing the game.

Results from the correlation analysis suggest that the students gave more emphasis on earning gems by attacking towers, which is in line with the results from the self-reported post-study survey where answering the questions turned out to be the most liked part of the game. The students enjoyed collecting the gems and playing the game in general, as reported by researchers in previous studies about games in education (Denny 2013; Domínguez et al. 2013). In the process, we did manage to collect quiz-questions and answers and build a question bank by the students. However, we found from the data analysis that playing the game did not affect the students’ overall grades. This finding is in line with other studies, e.g., one conducted by Frost, Matta, and Macivor (Frost, Matta, and Macivor n.d.). The question bank can potentially be a useful learning resource in preparation for the final exam. However, most of the students did not find it an enjoyable activity to look through the question bank (as shown in figure 3). It is also possible that the quality of questions and answers was not perceived as sufficiently high to be used as a learning resource, as suggested by the answers of 22% of the students, stating that the questions were either too easy or too hard. Future work will evaluate the quality of the questions and answers collected in the game during this study.

Our study was limited in several ways. First, the game was used in a first-year programming language course that had lectures and lab classes. ToQ was designed to work with theoretical quiz-questions that are short and to the point. These questions did not address the practical part of programming language courses. Developing programming skills is an essential part of programming classes, and programming tasks have a higher weight in the evaluation of student performance.

Second, not all the students who signed up for the game played it evenly; some students were more active than others. In addition to that, the number of students who fulfilled all the requirements (completing the pre and post-study survey and playing the game) was significantly smaller (n=49) than the number of students who signed up for the study (n=166).

Third, because of the hybrid nature of gamified systems (neither a ‘pure’ functional software nor a “full-fledged” game), they are prone to cheating based on the game elements included in their design (Deterding et al. 2013). In ToQ, there was a possibility for students to collude to earn points by posing and answering questions even though they were told not to disclose their pseudonyms. Also, the surveys were self-reported; we did not use a standard tool or scale to measure their degree of enjoyment and engagement.

Other ways of gaming the system involved spamming/submitting trivial questions. We had envisaged that possibility and added the Flaggging feature that allowed students to report such poor-quality questions. Since the game entirely relied on crowdsourced actions, and we did not plan to interfere with the students, it was not possible to determine and filter out all the poor questions. We also did not use any measures to moderate the students’ gaming activity, such as obtaining questions from online repositories and power-gaming (Edery and Mollick 2008). The flagging feature was not used by the students as expected. We only received a few flags (15 before the midterm exam and 17 between the mid-term and final exam). Future work can explore awarding gems for policing the tower building process, i.e., creating rewards for players for moderating the quality of questions, using an adaptive rewards mechanics similar to the one in (Cheng and Vassileva 2005).

The game’s user interface was straightforward and aesthetically not so appealing; it would be good to provide a more aesthetically pleasing GUI. Finally, a redesign of the concept of towers and attacks can be carried out to make the game more suitable, especially for learning the use of a programming language for problem-solving. The design of the game, along with all the elements, will likely require a revision, e.g., using quests and collaborating teams of attackers to conquer a problem.

In the near future, we plan to repeat the study in a course more suitable for the game like an online university course with more factual and theoretical materials. We will be looking for more sophisticated ways to control the quality of the questions (e.g., applying lexical and semantic analysis). Last but not least, we also plan to add tools to the existing game to facilitate the submission of short coding quizzes, as seen on various online programming websites.
6. Conclusion

In this study, we used a peer-quizizing game to engage students in generating quiz-questions and building a question bank in the process. A total of 49 students played the game regularly over an entire term (3 months) and participated in both the pre- and post-study surveys. From our study, we found that generally, the students enjoyed learning their course materials in this way and found the game useful as a learning tool. The students enjoyed answering the quiz-questions and earning points.

The students used the two self-monitoring pages in the game almost with similar priorities. The tabular-based self-monitoring page has a stronger correlation with building new towers compared to the thumbnail-based self-monitoring page. In general, the two self-monitoring pages might have been used by the students to view their conquered questions mainly.

In the future, we would like to conduct the study in a different course, preferably a course with more theoretical content. Since the flagging option was not used by the students as expected and because they loved collecting gems, we would like to incentivize that to increase participation in moderations.

References


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Appendices

Appendix 1: Pre-study survey questions

1. Please enter your ID

2. Gender
   Male
   Female
   Other

3. Do you play video games in any platforms (PC, Mobile, Console etc.)?
   Yes
   No

4. How many hours do you spend playing games each week?
   0
   1-4
   5-10
   11-15
   15+

5. Are you familiar with Tower Defense Games?
   Yes
   No

6. If you answered YES in the previous question, name some Tower Defense games you have played.

7. Do you submit your assignments in time?
   Strongly agree
   Agree
   Neither agree nor disagree
   Disagree
   Strongly disagree

8. How many late assignment submissions do you have in the last 6 months?
   I am a freshman
   None
   1-2
   3-5
   6-8
   8+

9. Do you like to work alone or in a group?
   Alone
   Group

10. What’s your ideal group size?

11. What is your most preferred time for studying?
    8am-12pm
    12pm-4pm
    4pm-8pm
    8pm-12am
    12am-8am

12. How many hours do you study each week?
Appendix 2: Post-study survey questions

1. What is your ID?

2. How did you find the questions your classmates asked?
   Not challenging
   Too easy
   Good
   Too challenging

3. Do you think it was fun to learn your course materials in this way?
   Yes
   No

4. Do you think Tower of Questions was useful as a learning tool?
   Yes
   No

5. Which feature(s) did you like the most? (multiple items)
   Asking the questions (creating towers)
   Answering the questions (attacking towers)
   Reading from the question bank (viewing conquered towers)
   Collecting points
   Flagging towers

6. Do you want to try the system in other courses?
   Yes
   No

7. If you answered yes in the previous question, please tell us the name or code of those courses (separated by comma)?

8. Which feature(s) do you think needs improvement?

9. What is your overall experience with the game?
   5-star rating scale

10. Any other feedback you would like to give us.
Bridging the Gap: A Computer Science Pre-MOOC for First Semester Students

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Abstract: Knowledge in Computer Science (CS) is essential, and companies have increased their demands for CS professionals. Despite this, many jobs remain vacant. Furthermore, computational thinking (CT) skills are required in all contexts of problem solving. A further serious problem arises from the gender disparity in technology related fields. Even if tech companies want to hire women in technology, the number of women who enter these fields is remarkably low. In high schools with no technical focus, most teenagers acquire only low-level skills in CS. The consequences are misleading preconceptions about the fundamental ideas of CS and stereotype-based expectations. Consequently, many teenagers exclude computing from their career path. In this paper, two promising concepts to overcome these challenges are presented. In 2018, a voluntary gamified lecture “Design your own app”, held at the University of Graz for students of all degree programs, was introduced. The course attracted over 200 students and received positive evaluations. This led to the second concept. In January 2019, a MOOC (Massive Open Online Course) with the title “Get FIT in Computer Science” was designed and launched in August 2019 on the platform iMooX.at with the goal to provide a basic introduction to different concepts of CS, including programming and the application of game design strategies. The MOOC was accompanied by an offline lecture, following the principles of flipped classroom and inverse blended learning. For evaluation purposes, we collected data at three stages: 1) during the MOOC, 2) during the offline lecture, and 3) two months after the lecture. The results showed that the MOOC framework was a promising approach to support and motivate at least a certain group of first-semester students, especially those who had no prior knowledge in CS.

Keywords: computer science education, digital literacy, technology enhanced learning, MOOC, flipped classroom, Pocket Code

1. Introduction

IT specialists are needed worldwide in order for businesses to be competitive in science and technology. Thus, there is a growing demand for IT professionals (Cuff, 2015). On the one hand, the enrolment of students in Computer Science (CS) programs in European countries has slightly increased, according to Informatics Europe (2015). On the other hand, degree courses in CS have very high drop-out rates (European Commission, 2015). There are many reasons why students drop out of university, but this report points out that students who have no previous knowledge in CS are more likely to drop out in comparison to students who already have programming experience and a basic understanding of the important concepts of CS. In addition, data from European Statistics Eurostat (2019) confirm a low percentage of female students in studies related to CS. In Austria, the percentage is only about 14%, which is even lower than the EU average (17%), but higher than the share of women in ICT studies in Luxembourg (10%), Belgium (8%) and in the Netherlands (6%). Female students, who decide to enter the field of ICT or CS, are then confronted with various challenges and prejudices. In STEM (Science, Technology, Engineering and Math) subjects in Austria, all male and female students in bachelor programs have the same success rates of about one third (Binder et al., 2017). However, more men (16%) further enroll for a graduate study (master’s or doctoral program) than women (10%). Degree programs of non-STEM fields are more likely to be completed by women. Here, it is apparent that the higher the proportion of women in a subject, the more frequently women complete their studies compared to men (Dormayr and Winkler, 2016). With regard to success rates and gender, the only exception is the field of CS: Here, women have a 10%-points lower success rate than men. One explanation of this gender related success rate is the differences in school education. Overall, women in STEM studies more often have a degree from an upper secondary school providing

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a general education (women 66% vs. men 50%) and rarely completed their secondary education at a technical college (women 8% vs. men 37%).

The percentage of female students at Graz University of Technology (TU Graz) in Austria for the winter term 2017/2018 reaches just 23.87%. This percentage increases slightly every year, but it is mainly due to the high amount of female first semester students in architecture, biomedical engineering, and chemistry. A closer look at the percentage of women’s bachelor’s degrees in computer science shows a percentage of 12.55%, without significant changes over the last 20 years. The gender distribution at the TU Graz in the different levels continues to show inequality. With 76.13% male students, female students are in the clear minority.

**Figure 1:** Percentage of CS degree programs at TU Graz (winter term of 2003/04 to 2017/18)
https://online.tugraz.at/tugonline/ Studierendenstatistik.html

This situation is similar to other developed countries. Reasons why female teenagers decide not to choose CS as a major are diverse. Literature and researchers argue that existing stereotypes, preconceptions about the field of CS, gender inequality in education, the absence of female role models and mentors, and moreover, girls’ presumed deficits, like low tech affinity, interests, and experiences in tech, are all reasons that lead to that gender gap in ICT. These important gender differences especially in interest, self-efficacy or sense of belonging are part of the authors’ previous work (Spieler, Oates-Induchová, Slany, in press). These issues need to be considered when thinking of alternative approaches to increase female achievement in this field (Cheryan et al., 2013). In addition to this, there is a major lack of exposure to CS at schools all over Europe (CECE, 2017).

The aim of the paper is twofold: First, the development of a MOOC (Massive Open Online Course) and the implementation of a corresponding offline lecture at TU Graz, providing a general introduction to CS, are described. The MOOC and the lecture were designed to help all first semester students to gain knowledge in CS and programming. Second, the results of the online course and the offline lecture were compared with the answers of a post questionnaire, done by CS first semester students in December 2019 to see if the topics covered by the MOOC were helpful. For those who did not participate in MOOC, we wanted to know which topics would help them in their first semester courses. This paper investigates the following research question: How can a MOOC in the form of a preparatory course help students and especially women with different background knowledge in technology to acquire CS and programming skills?

This paper is organized as follows: First, relevant concepts, methods and arguments for the design of the pre-MOOC are presented from a theoretical point of view. Based on the theoretical framework, the authors describe the research method, followed by a discussion of the final results related to the MOOC, the offline lecture and additional questionnaires. The last section concludes this paper and describes the author's future work.
2. Related Literature

A New York Times article by Singer (2019) stated that a growing number of students with no experiences in CS feel motivated to learn about coding but are not willing to study CS as a major. Offering courses at the university level that focus on a general introduction to CS and, more precisely, on computational thinking skills instead of digital literacy, may lead to better career prospects and a better understanding of the importance of CS in nearly all domains. In this section, related literature referring to the content, format, didactics and pedagogics of a CS introduction course is presented.

3. Digital Literacy versus Computer Science

A critical approach to new technologies requires a general understanding of the logical and technical aspects behind them. However, European school systems are mostly concerned with Digital Literacy and Information and Communication Technology (ICT) as a supporting context-free medium/technology to enhance learning.” (CECE, 2017). CS is more than just using the computer as a tool but a “distinct scientific discipline” that plays an insignificant and insufficient role in the school curricula of most European school systems (ibid.). Consequently, CS remains a great unknown for many pupils worldwide. Computational Thinking (CT) is considered an essential skill in the 21st century. According to J. Wing, it “represents a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use.” (Wing, 2006). Under certain conditions, coding activities are one way to train CT. Many countries around the world, including Austria and Germany, organize an annual Bebras contest that usually takes place in November (Brebras Challenge UK: http://www.bebras.uk/). The aim of this contest is to help pupils of different age groups to develop computational thinking skills and to boost interest in CS without the actual use of a computer. Furthermore, CS unplugged activities are a way to teach fundamental principles of CS playfully by using paper, strings, crayons, and movement (Brackmann et al., 2017).

4. Technology Enhanced Learning and Massive Open Online Courses (MOOCs)

E-Learning concepts, online courses, or MOOCs, in particular, are a perfect way to support distance education or lifelong learning. The rise of MOOCs can be dated back to the so-called “year of the MOOCs” in 2012 (Pappana, 2012). Since then, more and more higher education institutions began to produce so-called xMOOCs (Carson and Schmid, 2012), by using large MOOC platforms like Udacity, edX, or Coursera to publish their video-based courses or lectures. It has become apparent that those MOOCs helped to reach a broad public and to introduce new didactic approaches (Ebner and Schöns, 2019). However, the most well-known problems of MOOCs are the high drop-out rate (Khalil and Ebner, 2014) and the difficulty in certifying courses in the context of a higher education institution (Kopp and Ebner, 2017). In 2014, TU Graz and the University of Graz founded the first and currently only MOOC-platform in Austria, called iMooX (Khalil and Ebner, 2016). Following the idea of open education, each single learning object within a course on iMooX is published with an open license and can be identified as an Open Educational Resource (OER). In recent years, more than 60 MOOCs have been offered on iMooX.at, addressing people from different educational sectors with different interests. In the context of this research work, one of the most relevant courses was the so-called “Mathe-FIT-MOOC” (Get-FIT-In-Math-MOOC). This MOOC is combined with an offline lecture and aims to act as a preparatory course to bridge the knowledge gap in Math between school and university level.

5. The Pre-MOOC Principle: From Flipping the Classroom to Inverse Blended Learning

Following the research study and the design principles of Ebner et al. (2020) there are seven learning and teaching scenarios to use MOOCs in higher education - from a very traditional, pure online form to a mix between face-to-face and online education. The MOOC “Get-FIT-In-Math” follows the concept of a pre-MOOC, meaning that the MOOC starts and ends before the face-to-face education (Ebner et. al, 2020, p. 79). This type of MOOC is used when students (or other learners) need to have some prior knowledge or if there are simply some other restrictions in time or place.

The underlying didactical design is a mix between the well-known flipped or inverted classroom and the concept of Inverse Blended Learning. Flipping the classroom is the idea that students can study the content of a lecture at home (mostly by watching videos of the instructions of the lecturers) and do their “homework” or exercises in class (Li et al., 2015). Inverse Blended Learning (IBL) is following the idea that education and therefore learning is a social process which must be done by the learners themselves - people interacting with people; the teacher interacting with the learners; learners interacting with the teacher and just as important, the learner interacting
with other learners (Price and Lapham, 2003). With other words, we have to ensure and foster interaction to strengthen the learning process instead of rather consuming content. MOOCs traditionally lack interaction, which leads to a high drop-out rates in those courses (Khall and Ebner, 2014). IBL aims to bring the pure online course back to face-to-face education. For example, different forms of learning meetings, in parallel to the MOOC, can be arranged to ensure discussions between learners or give them the possibility to exchange with instructors in case of any questions. Both, the principles of flipped classroom as well as IBL increase the retention rate in MOOCs (Ebner et al., 2017).

6. Game Development Based Learning (GBL) Challenges and Tools

Game Development Based Learning (GBL) challenges are popular in introductory programming courses at all educational levels and a popular strategy to motivate and engage students in CS topics (Wu and Wang, 2012). The active involvement as designers and producers of their own games promotes creativity, problem-solving, and critical thinking skills (Vos, van der Meijsen and Denessen, 2011; Ya-Ting et al., 2013). Relevant knowledge in CS should help (young) people to consider new career paths that can ultimately lead to a fast employment and well-paid jobs (European Commission, 2016). New technologies and tools formed the ways of learning and teaching in the 21st century. For example, web-based technologies like HTML5, as well as an increase in the number of modern smartphones and tablets, opened up new ways for innovative coding concepts (Kahn, 2017). Game Development-based approaches could be easily applied with block-based visual oriented programming tools, like Scratch (https://scratch.mit.edu/) and support novices in their first programming steps (Tumlin, 2017). In 2010, the Catrobat team (https://catrobat.org) at TU Graz developed an educational app that allows the creation of games, stories, animations, and many types of other apps directly on smartphones or tablets, see Figure 2.

![Figure 2: Pocket Code's User Interface. Free on Google Play and iTunes.](image)

7. Diversity in Computer Science

The introduction section stated the problem: The percentages of female university students in ICT fields in Austria currently varies between 4% to 20% and the drop-out rate is much higher among female students than among male students (Binder et al., 2017). This leads to a small number of female professionals in CS and consequently to missing role models and male-dominated development teams.

Many researchers conclude that there is no need to “fix the women”, but to fix the system (e.g., Master, Sapna, and Meltzoff, 2016; Alvarado, Cao, and Minnes, 2017). Predominant stereotypes, and missing role models (Young et al., 2013), as well as other social and cultural factors (e.g., gender role socialization, peer groups), expose technology as male-dominated field. Girls’ lower sense of belonging corresponds with the feeling of “Lack of Fit” or “the Sense of Not Fitting In” with CS stereotypes. This occurs when female CS students feel that they do not receive help, question their ability in CS, or feel intimidated by others. If the profession does not fit the “traditional gender model”, one is not as likely to pursue or feel discriminated against by someone who does. To be socially connected and respected is a strong internal motivator (Walton and Cohen, 2007): It can “create a sense of belonging that can reinforce students’ self-efficacy and connections to community that support student perceptions of their ability within the field” (Veilleux et al., 2013, p. 64). This is important in students’ decision to pursue IT and helps to identify with the field (Beyer, 2016). Since the stereotype in IT is more associated with a male role, female teenagers are less likely to feel a sense of belonging with these stereotypes (Cheryan, 2012;
Master, Sapna and Meltzoff, 2016). All of these factors make young women question whether their abilities and interests are harmonious with their selected field.

8. Methods

To explore the MOOC concept as a supportive tool for female first semester students to gain knowledge in CS and programming, we developed a new CS pre-MOOC. This MOOC, with the title “Get FIT in Computer Science”, is based on the experiences and feedback gained from the obligatory lecture “Design your own App” and followed the principle of the “Get FIT in Math” MOOC. “Get FIT in CS” was launched on August 5th, 2019 on the iMooX-platform and was offered in combination with an offline lecture at TU Graz.

9. Research Design

The voluntary lecture “Design your own App” was introduced in the summer terms of 2018 and 2019 for all students at the University of Graz. A total of 202 students from diverse degree programs attended the first lecture. A majority of students (43.82%) came from three degree programs: 17.98% from teacher training studies (e.g., studying a language, maths, geography, physics), 15.73% from Business Management and Economics, and 10.11% from CS. A percentage of 56.18% came from 120 different degree programs, including psychology, legal sciences, molecular biology, sociology, history, chemistry, or philosophy. This variety of students was impressive. The goal of the lecture was to 1) stimulate computational thinking skills, by using logical puzzles (e.g., Beaver challenges), and 2) foster participation and creative thinking via the game-making and coding tool Pocket Code.

The newly designed MOOC “Get FIT in CS” consists of seven lectures, which are presented in Figure 3. It is still possible to register for the course by following the link: https://imoox.at/mooc/go/Info-Fit19. The MOOC provides a general introduction to the field of CS and programming. Besides videos, the MOOC includes interactive exercises (e.g., gap text, timelines) and programming tasks. Students who participated in the MOOC were supposed to apply game design strategies by using Pocket Code and while learning the basics of programming with Python and Java. Every lecture included exercises (e.g. to write pseudocode, execute assembler commands, solve tasks of the “Bebras challenges”), and self-assessment questions are presented in a multiple-choice format. Furthermore, students were encouraged to post and discuss their results in the corresponding online forums and received feedback from the course leaders and/or the other participants. Participants who completed all seven lectures had to fill out a final survey and receive a certificate.

![Figure 3: The MOOC “Get FIT in CS” consists of seven lectures. The content of each lecture is represented by a central question.](image)

This MOOC was offered in combination with an offline lecture at TU Graz. The identically named lecture took place on five consecutive days, between the 18th and the 25th of September 2019, and lasted two hours per day. The lecture followed the structure of the MOOC and aimed to repeat the main topics of the MOOC, practice computational thinking, and prepare students for upcoming challenges in their degree program at the university. For most of the students this lecture was their first lecture at TU Graz. Thus, the lecturer also focuses on organizational details (e.g. WLAN access, learning management system). Students received a grade and 1.5 ECTS
if they completed the MOOC by the 25th of September, attended 80% of the offline lecture, submitted homework tasks (e.g., a Python program), and submitted and peer reviewed a Pocket Code game. During the lecture, exercises were discussed with the students in an interactive way, ranging from a CS-unplugged human binary counter to a demonstrative explanation of the bubble sort algorithm and tasks of the “Bebras” initiative (see Section 2.1).

To attract more female students, we tried to counteract stereotypes and clarify expectations. First of all, nearly all videos in the MOOC show a female speaker (the lecturers). Secondly, in lecture one, a video was created to portray famous female (computer) scientists. The organizers also decided to use a game design approach to highlight how programming is a highly creative process. Completed games could be presented on a voluntary basis on the last day of the lecture. During the offline lecture, both female lecturers used gender-sensitive language and talked about female achievements, which received many positive reactions. In order to elaborate the process of asking questions during the lecture, an audience response system (ARS) was used.

10. Data Collection Process

Data was collected in three phases: 1) online questionnaires after students completed the MOOC, 2) during the lecture with the help of audience response systems (ARS), lecture evaluations, and submitted games, and 3) a questionnaire two months after the lecture during the first semester course “Foundation of CS”. At TU Graz, students of CS need to pass the course “Foundations of CS” as part of the orientation period (STEOP). Therefore, students of the course were asked to fill out a questionnaire concerning their experiences and impressions of the last three months. Table 1 provides an overview of the data collection process at the different times.

Table 1: Chronological overview of the data collection process

<table>
<thead>
<tr>
<th></th>
<th>MOOC</th>
<th>Offline Lecture</th>
<th>Lecture “Foundation of Computer Science”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
<td>05.08. – 30.09.2019 (7 week online course + 1 week offline lecture)</td>
<td>18.09. – 25.09.2019</td>
<td>December 2019</td>
</tr>
<tr>
<td>Participants</td>
<td>In total 643, finished: 76</td>
<td>In total 102, finished: 76</td>
<td>62</td>
</tr>
<tr>
<td>Data collected</td>
<td>Course engagement Final online survey*</td>
<td>ARS feedbackr responses, Pocket Code programs Lecture evaluation**</td>
<td>Post-questionnaire with LimeSurvey***</td>
</tr>
</tbody>
</table>

* This survey is part of every MOOC on iMooX.
** During the lecture, the ARS “feedbackr” (https://www.feedbackr.io/) was used to allow students to ask questions and to give suggestions about the content and organisation of the course in an anonymous way. Feedbackr is a web application, which allows students to access a survey by entering a defined session code, available via (mobile) devices.
*** The questionnaire was generated with LimeSurvey (https://www.limesurvey.org/), an open source online survey tool which allows the creation of secure and anonymous surveys.

11. Data Analysis

With the help of questionnaires, we collected quantitative and qualitative data. Quantitative measures were used to evaluate the MOOC itself, while qualitative measures were used to ask open questions about improvements and enhancements, thus exploring the concept of a pre-MOOC more broadly. For evaluation, two kinds of 5-point Likert Scales were used (Sullivan and Artino, 2013). The first asked for agreement/disagreement (1: strongly agree, 2: agree, 3: partly, 3: disagree, and 4: strongly disagree), and the second used a grading system (1: highest to 5: lowest).

For the game analysis, one final game will serve as an example and will be described in more detail. First students had to generate a storyboard to define the genre, theme, and goal of their game (Spieler and Slany, 2018). These game design strategies and decisions were part of the MOOC lecture 6. Second, they created small games which should have fulfilled the following requirements: stick to a concise structure (title, introduction, end screen), use different Mechanics, Dynamics, and Aesthetics (MDA) (min. 3, e.g., points, levels, narrative), and set the level of control. MDAs are defined as key components required for building games (Hunicke et al., 2004). The level of control requires students to integrate different concepts for moving objects such as animations or touch-actions (simple), device sensors or buttons (advanced), or clones or physics bricks (expert).
12. Results and Discussion

Based on the data collection and analysis, the following section presents the main results and findings of the MOOC, the offline lecture and the post questionnaire, shows different engagement levels, and proves that the pre-MOOC “Get Fit in CS” acts as a successful example of a preparatory course for entering the field of CS.

13. MOOC

Participants: At the end of September 2019, a group of 643 participants signed up for the MOOC. In total, 237 participants completed the first lecture, 181 the second, 131 the third, 104 the fourth, 93 the fifth, 81 the sixth, and 76 completed the seventh and last lecture. Hence, 12% of the participants completed the MOOC. The average age of the participants was 27.01 years, while 60.61% were male and 39.39% were female. Most of the participants were from Austria (82.83%), and 14.14% from other German speaking countries. Figure 4 illustrates the answers of the online questionnaire. Participants who have completed all lectures of the MOOC are required to fill out this questionnaire to receive a certificate of participation. Answers are displayed with the average values.

![Image](image.png)

**Figure 3: MOOC survey evaluation. a) students’ motivational aspects, b) skills required for the MOOC, and c) students' evaluation of the MOOC. Answers are displayed with the average values**

Motivation (Figure 4a, in orange): Questions about motivational aspects show mixed results: On the one side, participants strongly agreed or agreed that they are interested in the course topic (1.35) and that the topic complements their study (2.09). This shows a high self-motivation of students to complete the course. On the other side, they strongly disagreed or disagreed that they completed the course because their friends also participated in the MOOC (3.53), that they are looking for a new profession (3.56). Since the majority of the participants were students (67%), these results are not surprising. Examples for open answers were “I want to prepare myself for the study of CS” or “to refresh my skills”.

Skills (Figure 4b, in blue): Most agreed answers on skills required by the MOOC were willingness to learn (1.91), self-organisation (1.92), and autonomous learning (1.77). It can be argued that prospective students have already been encouraged to apply skills that are essential for a study.

Content Design and Organization (Figure 4c, in green): The students were asked to grade the MOOC on a scale from 1 to 5 (in school grades). Positive ratings were given for design elements, such as graphical/textual representation (~1.85), and the learning goals, content, and workload (~1.93). Content or navigation received the best rating (~1.73). The overall concept of the MOOC received an average grade of 1.53.
Finally, they rated their engagement with 2.01 on average. 60% stated that they never read or left a post, and 27% used the forum up to five times. Many exercises had to be submitted within a forum, and in total 341 forum entries were made. Some students appreciated the possibility to see code from others and get direct feedback, and some disliked the forum submissions (this was also mentioned in the evaluation of the lecture as well as in the personal feedback given during the lecture). Most of the students dealt with the course topics one to three hours a week (48%) and a percentage of 81% stated that the online course fostered their interest for this topic. Open questions to likes/dislikes showed that participants liked the videos, using the Pocket Code app, Python programming, the examples, quizzes, forum discussions, and the general structure of the MOOC. On the one hand, students mentioned that the Java examples were too difficult for beginners, on the other hand they asked for more examples with textual programming languages like Python instead of using Pocket Code. This is in line with the feedback during the lecture and shows the need to specify the target group of the MOOC more clearly (i.e., beginners). 72% of the participants said that they would like to participate in other MOOCs like this, and 94% stated that they would recommend this MOOC. In conclusion, it can be assumed that for those who completed the MOOC, the concept was very satisfactory.

**Discussion:** The concept of a pre-MOOC for CS was seen as a welcome offer that was gladly accepted by a certain group of first-year students. Differences in perceived usefulness could be detected between students who already had knowledge in CS and those who were beginners. The MOOC was advertised in newsletters, during registration at the university, at the student service office, and via social media platforms. However, many students already had some or a lot of knowledge in CS and only wanted to gain 1.5 ECTS. These students said that the MOOC was too easy and wished to have more textual programming languages. In the future, the target group (students with no background knowledge in CS) must be communicated more clearly.

Furthermore, the 40% female participation rate in the MOOC provides evidence that gender-sensitive education is a key factor for engagement and collaboration. Female students in particular recognize the absence of female role models in technology with whom they can personally identify (Lockwood, 2006). Female lecturers in MOOCs and at university in CS can break down the stereotyped expectations. The literature suggests that if female students are exposed to strong female role models, they rarely express stereotypical thoughts. Steady contact with successful women (e.g., female professors) leads to higher career ambitions and stronger implicit self-images (Asgari et al., 2010).

### 14. Offline lecture

**Participants:** Initially, 102 students signed up for the offline lecture. 76 students actually received a final grade (23 females, 53 males). A total of 59 students were first semester students from different degree programs such as computer science, electrical engineering, software engineering, or psychology.

**Audience Response:** Students were encouraged to ask and answer questions via the ARS feedbackcr and 75 students did so. The students’ answers can be categorized in questions regarding the organisation of the course (e.g. “Is there an exam in the end”, “Which smartphone is required to use the app Pocket Code”), general comments about the content (“I find it cool that you point out the role of women in the technological progress”), and specific questions regarding the content of the course (“Can you explain the Java program again?”, “Can you explain why the symbols i, j, temp, ++ are used in the program?”). The ARS was also used to ask the students about the type of school they came from and their choice of study to better understand the students’ motivation and concerns. More than half of the students, who participated in the survey, said that they came from a college/upper secondary school providing a general education. This information led to the assumption that more than half of the students had little to no programming experience.

**Lecture Evaluation:** At TU Graz students are able to evaluate lectures anonymously and 27 students have used this possibility. Most of them rated the workload as adequate (55.6%) or high (25.9%). The level of difficulty of the course was mostly considered adequate (66.7%) and the majority was satisfied with the course (62.6%). Students enjoyed working independently, designing their own games with Pocket Code, feedback, the flipped classroom scenario, the helpful and friendly lecturers, and the opportunity to meet new people before the university classes started. But students saw also room for improvement: the order of the lectures of the MOOC should be changed slightly, a greater emphasis should be put on Python programming basics instead of Pocket Code and Java (in the MOOC as well as in the offline lecture), and attendance should not be mandatory.
Pocket Code Projects: Altogether a total of 113 Pocket Code games were submitted (some students attended the lecture without grading). After the first submission, students received a peer review and a remix from another student and were allowed to revise and resubmit their game to receive extra points. For this paper, a game by a 19-year-old female student is analysed in more detail, see Figure 5. This game has the name “Das große Meeresquiz” (“The big ocean quiz”) and is considered an action game with an underwater theme. The goal is to solve different mini-games (e.g.: catch/avoid, shoot). The characters are controlled by the tilt sensor, and physical attributes such as gravity are used for the automotive objects. The game has all screens integrated (title, introduction, end), uses different MDAs (four levels, points, a high score, countdowns, visual and sound feedback). The peer review suggests improvements for navigation (an additional start button) and describes bugs in the high score. For the remix program the first level was extended (more obstacles, different scores). For the bonus task, a narrative storyline was added.

Figure 5: The example game “The big ocean quiz” a) title screen, b) story line, c) catch/avoid items, d) shoot sharks with ink, and e) a pinball game with a blowfish.

Discussion: The results indicate that a safe environment was created in which students were encouraged to actively participate through challenges, activities, questions, and discussion. In general, many students feel uncomfortable asking questions in lectures with big groups (Margolds, Fisher, and Miller, 2014). Particularly in CS degree programs, students have different background knowledge as the integration and intensity of CS topics into high school curricula varies between schools and countries. Years of literature show that female learners in particular tend to be less comfortable than their male colleagues when asking questions, and thus are left with lingering doubts regarding the material (Frieze and Quehenberry, 2015). The MOOC and the ARS-tool allow students to study the content of a lecture at home can build self-confidence in women.

With interactive exercises, the learners wanted to foster feelings of enjoyment, which have a positive effect on students’ motivation and outcome (Filsecker and Kerres, 2014). Additionally, the peer review and the presentation of the individual Pocket Code projects in front of peers, engages the learners, cultivates their sense of ownership, and gives them the opportunity for sharing different artefacts (i.e., via the Catrobat Community, Papert, 1993).

15. Post-Questionnaire

Participants: The online questionnaire was conducted in December 2019, with students from the lecture “Foundation of CS”. A total of 62 students (16 females, 46 males) completed the online questionnaire.

Answers of students, who completed the MOOC: A total of 11 students stated that they completed the MOOC “Get FIT in CS”. Of these, five students agreed that the topics that were covered in the MOOC were supportive for the mandatory lectures “Design your Own App” and “Foundations of CS”. Three students said they were “not sure” if the MOOC contributed to a better understanding of the lecture(s) and three other students rated the MOOC as not supportive. One of these students argued: “It is better to learn Python and C instead of Java and Pocket Code, because these programming languages have no relevance for CS studies at TU Graz.”
Answers of other students: The students, who did not complete or participate (in) the MOOC, were asked, which topics or applications should be discussed in a pre-course. The answers included “basis concepts of programming”, “Python for beginners”, “more Python, less Scratch and Pocket Code”, “introduction to the programming language C”, “binary/hexadecimal number system”, “sentential logic”, “Linux”, “Git” (version-control system), or “relevant software for CS students”. Except for the programming language C, Linux and specific software solutions, all other topics were covered in the MOOC, respectively. 33 of these students said that they had experienced some lack of knowledge, which related to not having CS lessons at school. Of these, 24 students stated that they had graduated from a college/upper secondary school which provided only a general education or from a vocational school with no technical specialization. This result supports the claim that many (Austrian) schools do not provide an in-depth view of CS.

Discussion: The purpose of the MOOC was to introduce different concepts of programming (loops, conditions, variables, etc.) by using a block-based and a textual programming language. The focus was not on a particular programming language, but to apply these basic programming concepts and to get a feeling for syntactical and semantical issues. Some students were not happy with the blocked-based programming approach and asked for more “relevant” software and programming languages. In a systematic literature review, Noone and Mooney (2018) tried to answer the questions whether there are “any benefits of learning a visual programming language over a traditional text-based language” and whether “the choice of first programming language” makes a difference. Noone and Mooney (2018) conclude, that “the actual choice of what tools to use does not matter, within reason.” It is about the conjunction with effective pedagogical and didactic actions. Anyway, Python and Java are characterized as “good” first programming languages. The use of visual programming languages in the first step is announced as “clearly beneficial” as it helps to increase student’s learning motivation, interest, and self-efficacy (Weintrop and Wilensky, 2015; Tsai, 2018).

16. Conclusion

In this paper we present the design and evaluation process of the pre-MOOC “Get fit in CS” and the corresponding offline lecture. We put a special emphasis on the students’ different background knowledge in CS and female students. The results show that students of various degree programs were attracted by the overall concept (the MOOC and in lecture). This indicates the growing importance of basic CS skills in all fields of studies. In general, students have to understand that it is very likely that a general understanding of the main concepts of CS is required or at least beneficial for their future career paths. Thus, it was important that the MOOC foster students’ sense-of belonging by showing a broader picture of CS, the use of a gamified approach, and by providing a low entry point.

The major weaknesses reported by the students were 1) the order of the topics/lectures (in terms of difficulty), 2) organisational aspects in regard to the offline lecture (compulsory attendance, grading), and 3) the frequent use of the visual coding tool Pocket Code instead of textual programming languages. At this point, it can be argued that visual coding concepts may be of “limited benefit to high self-efficacy students with programming background during the initial phase” (Tsai, 2018). In this case, Weintrop and Wilensky (2015) suggest to use a hybrid or dual-modality programming environment to address the needs of learners with a different level of prior experiences in programming.

To sum up, the results led to a better understanding of the way in which students engage with the content of the MOOC. We were able to answer our pre-defined research questions by examining the learners’ experiences on a broader level and providing insights into their level of engagement. Furthermore, the evaluation illustrates the need to promote gender-sensitivity and equality in lectures in aiding students’ digital inclusion. This was reflected in the positive comments via feedback and in the results of the lecture evaluation. However, the analysis also demonstrates the difficulty of motivating students with different background knowledge in programming equally and to design a MOOC for different target groups. Consequently, it is necessary to communicate the target group of the MOOC (=programming beginners) more clearly. It can be argued that such courses are important to create equal conditions right at the beginning of their study and especially in CS where students have different knowledge levels depending on their secondary education. To conclude, this MOOC serves as an applicable example for a pre-preparatory course for CS and the findings act as a basis for further improvements.
17. Outlook

The MOOC and the lecture will be held again in the winter term of 2020. The results suggest opportunities for improvements. For example, this time it will be mandatory to complete the entire MOOC and its exercises before the offline lecture begins. In this way, all students will start with the same basic knowledge in CS and the lecture can focus more on sparking discussions and offering examples instead of repeating content. The forum has received positive and negative evaluations. However, following the Constructionism theory of Seymour Papert (1993) we will stick to this concept of sharing results. In order to improve organisational aspects, the MOOC must follow the structure of the "Mathe-FIT-MOOC". Here attendance is not compulsory and students do not receive any grades. As a result, in the "Fit in CS"-MOOC students were confused by the different regulations and feared that they would receive a bad grade.

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What’s the math in Minecraft? A Design-Based Study of Students’ Perspectives and Mathematical Experiences Across game and School Domains

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Abstract: This paper presents empirical findings from a qualitative study on Minecraft as a mathematical tool and learning environment. Even though Minecraft has been used for several years in classrooms around the world, there is a lack of detailed empirical studies of how students learn subject-related content by working with the game. This study is based on a design experiment with an inquiry-based teaching unit for fifth graders, which focused on using the coordinate system embedded in Minecraft, as a means to navigate and explore the game in order to solve mathematical problems. Based on student interviews, we explore how the students experienced and switched to new perspectives on mathematical knowledge through their participation in the teaching unit. Using thematic analysis, we explore data from six group interviews. The theoretical framework is based on domain theory, dialogical theory and notions of students’ mathematical agency. The key analytical findings regard the students’ experience of the coordinate system as part of both the academic domain of mathematics and their everyday domain of playing Minecraft, how they actively use the coordinate system to improve in Minecraft and how they experience new ways of participating in mathematics. The article concludes by offering design principles for the future use of computer games in mathematics education.

Keywords: Minecraft, game-based learning, mathematics education, domain theory, coordinate system

1. Introduction

Games have long existed as part of mathematics education and have been investigated for several years (Bright, 1983; Oldfield, 1991). According to one review, games are used more frequently for teaching mathematics than for any other subject (Haine et al., 2016). Thus, there is a widespread belief that games have tremendous potential in mathematics education. Although some scholars have pointed to video games as an ideal medium for teaching mathematics in middle school (Devlin, 2011), two recent meta-analyses showed only small and marginally significant positive learning effects from using games in mathematics education (Byun and Joung, 2018; Tokac, Novak and Thompson, 2019). This indicates that there is only limited research evidence to support the assumed potential of game use in mathematics learning.

A prevailing problem for mathematics education is that many students do not come to see mathematics as a constructive endeavor (Boaler, 2015). Similarly, student interest in mathematics is reported to be one of the most significant predictors in determining mathematical performance and perseverance (Hannula et al., 2016). However, the use of games in mathematics education is often based on game elements serving as rewards or aspects of extrinsic motivation, which do not support learning as much as games, where the learning activities are driven by students’ inner motivation (Habgood and Ainsworth, 2011). Cobb (2007) argues that classroom activities being worthy of student engagement in its own right is an important part of the cultivation of students’ interest in mathematics and should be considered an important goal for mathematics educators. As such, the aim of the current study is to explore these two research questions:

- How can Minecraft be used in a teaching unit to engage students in mathematics education by enabling different forms of participation?
- How do students experience new perspectives on mathematical knowledge across in-school and out-of-school domains?

2. Learning mathematics with Minecraft

Minecraft is one of the most played video games in the world, and it appeals widely to both boys and girls, especially around the ages of 9–11 (Mavoa, Carter and Gibbs, 2018). At the same time, Minecraft is also increasingly being used as an educational tool in classrooms (Kipnis, 2018), and research has been conducted on its use in promoting learning within a wide variety of school subjects (Nebel, Schneider and Rey, 2016). Several

studies have explored the envisioned potential for using Minecraft as a component of mathematics education (Tromba, 2013; Bos et al., 2014; Ellison and Evans, 2016; Winter, Love and Corritore, 2016). For example, Kim and Park (2018) explored how preservice teachers identify potential mathematics learning benefits when using Minecraft as a learning tool. Other studies have described how Minecraft can model different mathematical concepts (Short, 2012) or how player behavior can be considered mathematical (Kipnis, 2018), with some proposing teaching material that employ elements from Minecraft as a context for mathematical exploration (Moore, 2018). However, these studies share a general lack of empirical evidence to support their claims about student learning, as the focus is primarily speculative explorations of possible learning potentials. Other studies have reported on local teaching experiments using Minecraft in mathematical contexts (Al-Washmi et al., 2014; Foerster, 2017; Freina et al., 2017) but provide limited descriptions of students’ mathematical outcomes. Another study found no significant correlations between students’ Minecraft habits and their perceived abilities to solve mathematical problems (Griffin and Griffin, 2018). None of these studies provide detailed descriptions of students’ learning in relation to Minecraft. An exception, however, is the ethnomathematical qualitative study by Kehrsen and Misfeldt (2015), focusing on mathematical activity in Minecraft in an after-school programme. This study used empirical evidence with children, combined with a theoretically founded approach to understanding learning.

Overall, the studies point to learning potentials, promising teaching designs and innovative approaches regarding the use of Minecraft in mathematics education. However, most studies are based on anecdotal evidence, and very few articles focus empirically on students’ learning or use a theoretically grounded approach to mathematical learning. This article seeks to address this research gap by presenting an empirical qualitative study of how Minecraft can help students learn mathematics.

3. Case: Teaching unit with Minecraft

The current study is based on a design experiment with a teaching unit using a Minecraft map in a fifth grade class comprising 22 students. Minecraft worlds are randomly generated, so a key element in the game is the exploration of the specific virtual world in which you are playing (Lane et al., 2017). However, it can be difficult to successfully navigate Minecraft and locate specific objects or other players. This can result in problems for players – e.g. getting lost on the map after building a structure and being unable to locate the structure again. The idea of the intervention originated from the fact that the mathematical concept of Cartesian coordinates used in the mathematics educational curriculum was accessible in the Minecraft user interface and that three-dimensional (3D) navigation is a key challenge in the game. More specifically, the player can access the x, y and z coordinates of his avatar in the game. The x-axis indicates the position on an east–west axis, the z-axis shows the position on a south–north axis, and the y-axis indicates elevation (see figure 1 below). One whole number on the axis is equal to the length/height of one block in the game, which is equal to one meter in the real world.
Figure 1: Screendump from the game map and an illustration of the x, y and z coordinates

When the players move their avatar in the virtual world, the values of the axes change according to the position. Moving directly up or down will affect the y-axis and moving directly towards the east will increase the value of the x-axis. Looking at figure 2, we see a player avatar standing on the first, second and third steps of a staircase in Minecraft. For each picture, the avatar coordinates are in the upper-right corner.

<table>
<thead>
<tr>
<th>First step</th>
<th>Second step</th>
<th>Third step</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="First step" /></td>
<td><img src="image2" alt="Second step" /></td>
<td><img src="image3" alt="Third step" /></td>
</tr>
</tbody>
</table>

Figure 2: Change in coordinates

Following the avatar going up the stairs, the y-axis changes from 68 to 69 to 70. The x-axis also changes because the avatar is also moving west as it climbs the stairs. The change in the numbers after the decimal point indicates that the avatar can be placed on different locations within one square block.

The accessibility of such an underlying mathematical dynamic is not commonplace in commercial games, where the mathematical rules are often hidden from players, as they may disturb the players’ immediate experience of the game (Löwrie and Jorgensen, 2015). Our hypothesis or humble theory (Prediger, 2019) for the design experiment was that the mathematical concept of Cartesian coordinates could be introduced as a means to solving the real player problem of locating objects in Minecraft in order to help students master and influence their understanding of the game. Therefore, instead of using the game as an instrumental tool for teaching mathematics, our starting point was to understand how we could design a teaching unit that created meaningful links between in-game challenges and the mathematical aspects of the game. Thus, the coordinate system in Minecraft should optimally serve as a useful resource for learning mathematics in order to master the navigation in the game and for playing the game in order to explore the mathematical concept of coordinates.

The teaching unit with the game map consisted of 15 lessons distributed over five days in one week. One of the researchers held meetings with the teacher, who contributed with feedback and ideas for improving the unit. The students’ activities were mainly inquiry-based and framed around open questions. The initial task for the students was to understand what the numbers at x, y; and z: indicated. The staircase shown in figure 2 was used by the students to examine how the coordinate numbers changed when their avatar moved up and down the stairs. This was not explained directly to the students in the way we have done above. Instead, the students
were asked to build a staircase and reason about how the coordinate numbers changed. This would help them identify y: as an indication of their height level. In another activity, the students were asked to move in a way so that either the x or z coordinate remained constant while they moved. This was challenging for them, as it required them to move directly towards east, west, north or south. One solution was to build a wall and move in parallel with it. These assignments helped the students to reason about what the coordinate numbers indicated. Later in the unit, the students had to use their knowledge of the coordinate system to solve tasks. One task was to build a railway of exactly 100 blocks long, in pairs, starting from opposite ends and meeting in the middle. Another similar task was to build a tunnel through a mountain from each side. Finally, the students used the coordinate system to create treasure hunts, with new coordinates written on each post. In one instance, a student-created treasure hunt was played by the entire class in pairs. One student in each pair would control the avatar, while the other student would act as the navigator, looking at the coordinate numbers and guiding the controlling student.

4. Theoretical framework

Our research question was explored by analyzing student interviews through a theoretical framework consisting of two complementary theories. The first theory was scenario-based domain theory (Hanghøj et al., 2018), which was used to map the interplay of different practices in the game-based teaching unit, with a particular emphasis on students’ mathematical obligations (Cobb, Gresalfi and Hodge, 2009). The second theory assumed that students would explore the game-based teaching unit through different voices and perspectives in relation to the dialogic space created in and around the game scenario (Wegerif, 2006). By combining these perspectives in our exploration of Minecraft in mathematics, we described the students’ perspectives on mathematical learning across in-school and out-of-school domains. We shall now outline the two complementary theories.

4.1 Domain theory

When the students played Minecraft in the mathematics classroom, they took part in a specific educational scenario (Hanghøj et al., 2018), which required them to imagine and perform domain-specific game practices, such as navigating the 3D game space, finding locations, hiding items from other players or building structures. In order to overcome in-game challenges, the students had to develop and use their knowledge of the coordinate system as a mathematical concept. As fifth graders, most of them were quite familiar with the game, having played it at home. In this way they participated in an open-ended inquiry process, which involved an interplay of practices across in-school and out-of-school domains.

A practice involves recognizable ways of doing things for shared social purposes, such as being able to navigate the game world of Minecraft or solving a mathematical task in the classroom (Hanghøj et al., 2018). Domains represent clusters or families of different practices and involve different validity criteria for what counts as legitimate knowledge and what does not. As such, students’ exploration of Minecraft in mathematics involves a transformation of experiences and practices across four domains: the domain of everyday life, the pedagogical domain of schooling, the disciplinary domain of mathematics and the scenario-based domain of overcoming challenges in Minecraft. We shall now unpack these domains.

The domain of everyday life concerns students’ lifeworlds, such as their life at home with family or friends. In this study, we were particularly interested in how the students were able to link the teaching unit with their out-of-school experience of playing Minecraft and their experience of using mathematics in their everyday life.

The second domain involved the pedagogical domain of schooling, which relates to the asymmetrical relationship between the teacher and student and the norms and expectations of what it means to participate in classroom teaching. These institutional and communicative practices are “school only”, as they only occur in school contexts, but are always locally defined at the classroom level. In this study, we looked at how the game-based teaching unit, which differed from their regular teaching, allowed the students to collaborate and change their relationships.

Third, the disciplinary domain of mathematics concerned how the students participated in and experience mathematics as a school subject. In order to describe this aspect, we used concepts from the interpretive framework of Cobb, Gresalfi and Hodge (2009) for understanding students’ mathematical identities. The authors argue that being a doer of mathematics implies a normative identity with certain obligations that define and constitutes the role of a good mathematical student in a specific classroom. These obligations concern three
aspects. The first concerns the ways in which students legitimately express agency, which relates to both their use of established mathematical solution methods (disciplinary agency) and their ability to choose mathematical methods and develop meanings and relations between concepts and principles (conceptual agency). The second aspect relates to the distribution of authority, i.e. to whom the students are accountable when working with mathematics. The third aspect encompasses specific mathematical obligations that the students are accountable for, that is, what counts as competence in terms of mathematical reasoning and argumentation. Drawing on these concepts, we were able to show how the students, in working with Minecraft, expressed different forms of agency, authority and competence in the disciplinary domain of mathematics compared to their experience of normal classroom practices.

Finally, the fourth domain was the scenario-based domain of Minecraft, that is, the students’ exploration of the specific game map used in the teaching unit. We took a closer look at the students’ different interests in the game and how these influenced their experience of playing the game in a formal educational setting. Even though nearly all the students had tried Minecraft prior to the teaching unit, there were important differences in their experience and competence with playing the game.

The dynamic relationship amongst the knowledge practices of the four domains involved in the students’ game activities is illustrated in Figure 3:

![Diagram of interplay of practices across domains](image)

**Figure 3:** Interplay of practices across domains

By describing this interplay of knowledge practices across the in-school and out-of-school domains, it became possible to explore what counts as valid knowledge and the valid ways of doing math when playing Minecraft in the mathematics classroom.

### 4.2 Dialogic perspectives on Minecraft and mathematics education

The scenario-based domain theory is a generic theoretical framework, which can be used to describe the interplay of domains in a range of educational contexts. In order to provide a more detailed understanding of the bridging of practices and student experiences across the four domains, we found inspiration in the theory on dialogic education (Wegerif, 2006), which has been further developed in relation to mathematics education (Kazak, Wegerif and Fujita, 2015) and game-based teaching (Arnseth, Hanghøj and Silseth, 2018). Dialogues may be recorded as talk and interaction in external space and time. However, according to Wegerif (2006), dialogues are not simply external phenomena; they also involve an internal aspect, which invokes different times and spaces and a range of voices that reflect the participants’ perspectives. The term voice, originally developed by Bakhtin (1981), refers to a first person perspective in a dialogue. In this sense, a dialogic space “is the space that emerges between voices, but that is also a shared space within which voices relate to each other” (Kazak, Wegerif and Fujita, 2015, p. 107).
Playing games at school with others may create dialogic spaces in which participants can explore and exchange a range of voices and perspectives (Arnseth, Hanghøj and Silseth, 2018). In our study, the students explored the use of Minecraft in mathematics through different voices, reflecting an interplay of experiences across the four domains. As we shall see in the analysis, some students related the Minecraft teaching unit to their everyday experience with the game outside of school or their everyday experience of “doing math class”. Some students focused on the mathematical aspects of the game, while others emphasized how the teaching unit allowed them to collaborate and learn from their peers. It can thus be argued that the educational use of Minecraft opens up a multi-voiced dialogic space, where students are able to explore several interests and experiences across in-school and out-of-school domains.

According to Kazak, Wegerif and Fujita (2015), participation in a dialogic space enables students to switch between different perspectives, which is valuable in terms of extending and developing their understanding of a given problem or concept. However, switching between perspectives is not a mechanical process and requires an active choice, where students are willing and able to step back from their own point of view in order to explore different perspectives within a dialogue. The current study is based on group interviews with the students following the completion of the teaching unit with Minecraft. Through the interviews, we aimed to explore how the students experienced perspectives on mathematical knowledge in relation to the Minecraft teaching unit. We were not interested in documenting specific learning outcomes or how the students’ learning processes took place during the teaching unit. Rather, we were interested in describing how the students’ exploration of Minecraft allowed the emergence of new perspectives on mathematical concepts.

5. Methodological approach

This pilot study is part of an on-going design-based investigation (Barab and Squire, 2004) of how commercial games can be linked to curriculum aims. The data were collected in an urban public school with a large percentage of bi-lingual students in a socially and economically challenged area in Copenhagen. The school had participated in a previous project using commercial games (Hanghøj, Lieberoth and Misfeldt, 2018), where several of the teachers had developed a positive interest in using Minecraft for mathematics teaching. Based on this interest, teachers at the school decided to allow two fifth-grade classes – not part of the previous project – to participate in a game-based teaching unit for mathematics. One of the authors of this study conducted video observations and took field notes in one of the classes, where he had on-going dialogue with the teacher about how to facilitate the teaching unit. After the teaching unit was completed, six semi-structured group interviews (Brinkmann and Kvale, 2015) were completed with two fifth-grade students in each group. These interview data formed the empirical focus for this study.

Six student groups of two students each were selected prior to the intervention and in dialogue with the teacher in order to represent a broad spectrum of mathematical performance with students who demonstrated high-, low- and medium-level mathematical skills. The groups were mixed gender, with three male-only groups, two male–female groups and one female-only group. There were mainly male students in the class, which was reflected in the division of gender. The teachers described the class as disruptive and difficult to manage, with an overall low performance in mathematics and only a few mathematically skilled students. In order to ensure a contextual link with the gameplay activities, the students were interviewed once after the teaching unit, in the same pairs described above. The interview guide involved questions regarding their everyday experiences of math class and the mathematics the students used during the intervention with Minecraft. Each interview lasted between 45 and 60 minutes. Thereafter, all the collected interview data were subjected to a thematic analysis (Braun and Clarke, 2006), which involved transcription and coding using open categories, which were used to establish themes relating to the students’ experiences of learning mathematics and participation in the mathematical activities. Following this, we identified overall analytical themes by linking the categories with concepts from domain theory and the students’ mathematical agency (Cobb, Gresalfi and Hodge, 2009).

6. Analysis

In this section, we unfold how Minecraft can be used in a teaching unit to engage students in mathematics education through different forms of participation and how the students experienced new perspectives on mathematical knowledge across in-school and out-of-school domains.

Based on the analysis of the six interviews, we identified four analytical themes on different student perspectives on mathematical knowledge construction. The first concerned the students’ experience of what it meant to
participate as a student in regular math class. The second described how the students experienced learning mathematics through *Minecraft*. The third theme involved students’ experiences about using mathematics to learn how to become better players. Finally, the fourth theme had to do with how the students experienced collaborative work in mathematics in relation to *Minecraft*. The four themes show a wide range of connections of student experiences across the different domains, all illustrating how the game-based intervention changed the students’ experience of learning mathematics. We describe below the students’ perspectives of mathematical learning. To illustrate how the use of *Minecraft* generated experiences that differed from those of the students’ everyday math class, we describe the students’ perspectives on math class with and without *Minecraft*.

### 6.1 Participation as a student in “math class”

This theme explored the *students’ perspectives on their everyday participation in “math class”* before the intervention. We intentionally used the term math class to underline that this theme did not reflect the students’ perspectives on mathematics as such but, instead, how they perceived participation in the local pedagogical context of their everyday mathematics classroom. Hence, this theme focuses less on exploring *Minecraft* and more on the students’ established perspective on what it means to participate in math class.

One of the categories that emerged around this theme was the students’ perception that it was important to calculate quickly. This finding relates back to the notion by Cobb et al. (2009) of disciplinary agency, i.e. being able to follow established methods in order to be considered mathematically competent. For instance, when Melanie was asked what it meant to be a good mathematics student, she replied:

> *When I know something, or if I have listened and understood it, then I can be fast and answer quickly.*

Other students also linked being a good math student to the speed at which answers are provided, knowing something or being able to understand the teacher’s explanation. In Henrik’s words: “You have to be good at calculating fast.” Henrik further explained that, sometimes, it is best to know new concepts and answers before they are introduced by the teacher, as this gives an advantage in terms of answering quickly and correctly.

Another category indicated that the students rarely experienced links between the domain-specific activities and concepts from math class with experiences from their everyday domain. In reflecting on his experience of the intervention, Mads replied:

> *I didn’t know that you could use the coordinate system in games or in Mine... [craft] or in reality.... No, I just thought it was a... a thing you had to learn.*

Earlier in the interview, Mads recalled that he had worked with the coordinate system before the Minecraft intervention. However, as the quote shows, he had not considered whether this mathematical concept had any relevance outside of the subject domain. From his perspective, what you do in mathematics is not necessarily useful in “reality”. Rather, the coordinate system is just “a thing you had to learn”, which suggests that the students did not see the purpose of what they had to learn. Thus, Mads did not anticipate that the content in math class was of relevance to his everyday life.

Summing up, the students’ general perspective on mathematical classroom activities was that “math class” was an isolated domain and that the legitimate exercise of agency in everyday math class was disciplinary. The students experienced that in order to participate competently, they had to listen closely to what the teacher was saying and answer quickly, indicating that authority in the classroom was largely distributed to the teacher.

### 6.2 Learning mathematics through *Minecraft*

The second analytical theme concerned the *students’ perspectives on learning mathematics through *Minecraft*.* The interviews involved several examples of students reflecting on how the *Minecraft* teaching unit created new perspectives on what constitutes mathematical knowledge. One example was Henrik’s reflections on the intervention:

> *Henrik: It was the first, almost.
Interviewer: It was the first?*
> *Henrik: Mm... approximately.*
Interviewer: Uh... I’m just trying here to understand. The first what?
Henrik: I could use, in all subjects, from mathematics.
Interviewer: Ahh. It was the first [time] you have experienced in mathematics...
Henrik: That you can use in all subjects. Yes.

Henrik’s experience of using the coordinate system in the intervention was a first in terms of understanding that mathematical concepts can be used in subjects other than mathematics. This indicates that he experienced that what he learnt in mathematics could have connections to the world. The use of the word “first” also suggests that he expected more connections to be made. The word “almost” indicates that such an experience might have been present, though not to any lasting degree, or that he, in some way, thought that mathematics should be related to the world but that he had not experienced it before. Henrik further reflected on how he switched his perspectives on mathematics in relation to the Minecraft teaching unit. He was asked whether he used mathematics in the teaching unit, and he replied that he did not see it as mathematics at first. The interviewer asked him to elaborate. He replied as follows:

Look... in the beginning, I thought the coordinate system was entirely mathematics, just something like, that you can just do in mathematics. But no, you can use it in all subjects. You can also use it in physical education and in unmn... and arts class because there is a coordinate system on a picture, there and in the upper left and the upper right and all sorts of different things.

Here, Henrik described how he switched his perspective from seeing the coordinate system as exclusively linked with math class to seeing possibilities for applying it in other subjects, thereby creating connections from the mathematics subject domain to a more general school setting. Henrik expressed conceptual agency by developing the meaning of the concept of the coordinate system, explaining that it is “where you can be”, which refers to the notation of placement. Additionally, he made connections between the coordinate system and new possible areas of use, which is also a way of expressing conceptual agency across different domains.

Similarly, other students created new connections between using the coordinate system in Minecraft and the everyday domain in a more general sense. This can be illustrated in Maja’s description of how she perceived the coordinate system:

it was new and you could... you could use it to find places. Like a compass but, where it says... a place... uhm. You can kind of call it an address of some sort.

This quote shows that Maja was able to exercise conceptual agency in two ways. First, she described how the coordinate system could be meaningfully used to find places. Moreover, she used her own words to explain the meaning of coordinates in a system by creating connections to similar phenomena such as “compass” and “address”. Both the description of what the coordinate system can be used for and the comparison with other concepts are indicative of conceptual agency. The connection made by Maya is not limited to the subject domain of mathematics; it is linked to the scenario of the teaching unit, which required the students to locate specific coordinates in order to create or overcome in-game challenges. In this way, she made linkages between using the coordinate system to find places in Minecraft and its use in the everyday domain by comparing coordinates to an address.

As the examples suggest, the students generally experienced a higher degree of conceptual agency when engaging with the mathematics in Minecraft than in their everyday math class. Moreover, they experienced several connections across the in-school and out-of-school domains, which they did not mention in relation to regular math class.

However, the realization that the coordinate system could be of relevance across several domains did not occur to all the students. One student, Melanie, did not think that the coordinate system was taught in normal math class at all and described math class as being only about numbers and calculations. Melanie reasoned that the teaching unit concerned mathematics primarily because it was taught by her mathematics teacher. As such, Melanie failed to make a connection between the game domain and the mathematical subject domain. Moreover, Melanie created a dichotomy between the domains by explaining that mathematics is about calculations, in contrast to Minecraft, which is a game. These examples show that making connections between
the subject domain and other domains relied heavily on the students being able to alter their perception of mathematics as an already established subject domain.

6.3 How Minecraft is given new meaning through mathematics

During the analysis, it became clear that the teaching unit not only gave the students opportunities to develop new perspectives on mathematics. some of the students also valued the teaching unit for providing perspectives that gave new meaning to playing Minecraft as a game, as shown in the following example:

Interviewer: Have you learned anything new about the coordinate system that you didn’t know before. Or can you do something now that you couldn’t do before?
Hasan: Yes. Well, I didn’t know, even though I have been playing Minecraft a lot, I didn’t know where the coordinate system was. Even though I pressed F3 and it [the coordinates] then it appeared, but I didn’t know, I didn’t know what it was. When I moved, it just changed a lot, and I turned it off again, and I didn’t know what it was. But now, now I know what it is. Now I use it often in Minecraft.
Interviewer: Okay, so you have used it afterwards after the course?
Hasan: Yes, because if I have to find something that I have forgotten but I have the coordinates to, then I can just, then I can just go over to them.

Hasan knew from playing the game at home that he could press F3 and prompt new and changeable information but was unable to translate the information into something meaningful. After learning what the numbers meant, he now frequently used them to locate objects in the game. In terms of domains, Hasan referenced his everyday activities in Minecraft (the game domain) to explain the usefulness of the coordinate system from the mathematical domain. As such, he created a strong connection between the different domains. His use of the coordinate system in Minecraft became a new way to interact with the game. If we expand the notion of agency in math class to understand the changes in how Hasan now played the game, then his statements validates the use of the coordinate system as a legitimate way of expressing what we could call player agency in Minecraft because it can be used to address the actual challenge in the game of how to locate objects by keeping track of their placement via coordinates.

The position of being a mathematical Minecraft player refers to the students’ experiences of using the coordinate system to remember and find places in Minecraft. When the students experience that they can use the coordinate system in the game to solve the mathematical task given by their teacher in math class, they establish new connections between the two already established, though initially separated, domains, that is, mathematics and the everyday domain, which in turn transform both domains.

6.4 Collaborating around Minecraft in math class

The fourth and final analytical theme concerned the students’ perspectives on collaboration in math class in relation to Minecraft. In addition to affecting the students’ view of mathematics as a subject and their ability to navigate within Minecraft, the teaching unit also changed the students’ perception of participating in math class. To exemplify, we shall focus on two students, Mads and Adam, who the teacher regarded as the highest-performing students in math class. Here, Mads explained that always being the first to finish tasks in regular math classes often put the two friends in an awkward position in relation to their classmates.

Mads: And then they [the other students] always get angry and say, you shouldn’t always say “we are finished, we are finished”... But we understand why they say it
Interviewer: Okay
Mads: Because it is only... Most of the time, we are the only ones who finish first. It may never... they can’t look forward to finishing faster than us.

As the first theme showed, being mathematically competent in this classroom was highly dependent on speedy task-solving. However, when the same students repeatedly finished first, their peers found themselves in a situation where it was difficult for them to be regarded as mathematically competent. According to Mads and Adam, the other students felt like they had no chance of ever finishing first. Because of this, Mads and Adam experienced the other students’ frustration and anger towards them.

These two students had little prior knowledge of Minecraft before the teaching unit. However, they had a very positive experience of the teaching unit because it had freed them from their original positions in math class as
the fastest to solve tasks. Moreover, they were also able to learn about the game from their classmates, indicating a greater distribution of authority in the classroom. This is exemplified in the following excerpt:

Adam: But when we are working in pairs and we are together, then (Mads: Then they all get mad) sometimes. Because we are very fast and they have to keep up, but are slower, but in this [Minecraft unit], it was just fantastic.
Interviewer: Yes, and how can it be that this was fantastic?
Adam: Because. it. We usually don’t play Minecraft, but the others know how to play. The others, who need some time to understand mathematics, they have played Minecraft, so they can react faster and know everything you have to do and everything you can build. We had to learn that from them.
Interviewer: You had to learn from them?
Adam: Yes, and then we could see how it is when we do math quickly and they have to keep up with us.
Mads: But with this, with this Minecraft, then we were all equal (Adam: yes); nobody was better or worse.
Interviewer: at playing Minecraft?
Mads: At everything.

Mads and Adam’s positive experience of having to learn from the other students can be seen as a renegotiation of the authority in the classroom towards a more distributed model of teaching and learning than they would normally experience. Drawing on the other students’ expertise with Minecraft, the game opens up a space for exercising conceptual agency, where Mads and Adam became the novices and had to learn from their classmates. Thus, the game created new connections for knowledge construction across the pedagogical and game domains.

Moreover, the two students concluded that the reversal of student authority and switch of perspectives proved beneficial to everyone. Valuable knowledge was not tied simply to the first to finish a mathematical task but to how all the students could collaborate about integrating knowledge across the various domains. This challenged Mads and Adam to understand knowledge about Minecraft, which became a valid and valuable aspect of competency in the intervention. The students who were skilled at mathematics were not necessarily the same students who were skilled at Minecraft, which means that the students’ competences were redistributed across different domains. Mads and Adam’s experience of being more on the same level as the other students released them from the normal classroom obligation of finishing tasks quickly. What they addressed with this change was not, however, that they were losing an opportunity to display mathematical competence towards the teacher; rather, to be free from this obligation was “fantastic” and was a shift toward positive identification. This underlines the fact that the focus on being the first to finish creates very narrow opportunities for students to live up to their classroom obligations.

Collaboration was far from the norm in the students’ experience of everyday math class, where most work was done individually. They described that it was best “to keep to themselves” and only check results with the teacher, not with other students, which was regarded as cheating. Even though Mads and Adam had tried to play other learning games in mathematics, such as the mini-games in the Matfessor learning portal, their experience of game-based intervention was highly different. As Adam put it: “in Matfessor, there is no need to talk to each other at all”, whereas working with Minecraft requires “a lot about collaboration”, where they “talk to each other all the time”. In summary, this final theme emphasizes how collaboration opens up to various ways of participation relating to the different ways of working with mathematical activities and helping each other navigate and build things in the game.

7. Discussion

The analysis showed how the intervention allowed the students to experience new perspectives as they transformed mathematical knowledge across the different domains of the school subject, the game map and their everyday game experiences. Table 1 presents a summary of our findings in the four analytical themes.
Table 1: Summary of analytical findings

<table>
<thead>
<tr>
<th>Theme</th>
<th>Focus</th>
<th>Domain crossings</th>
<th>Findings</th>
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<tbody>
<tr>
<td>Participation as a student in “math class”</td>
<td>Students’ experience of participating in their regular mathematical lessons</td>
<td>Links between the disciplinary domain and the pedagogical domain</td>
<td>The students stress the importance of being able to calculate and answer quickly and listening closely to the teacher. Mathematical knowledge is disconnected from the everyday domain. Experience of mathematics as following established procedures (disciplinary agency)</td>
</tr>
<tr>
<td>Learning mathematics through Minecraft</td>
<td>Students’ experience of a changed perspective on mathematics as a subject</td>
<td>Links between the disciplinary domain, the everyday domain and the scenario-based domain (game map)</td>
<td>The students describe how the coordinate system in and beyond the game represents (or does not represent) mathematical knowledge Different experiences of the coordinate system as a mathematical concept (conceptual agency)</td>
</tr>
<tr>
<td>Minecraft is given new meaning through mathematics</td>
<td>Students’ experience of a changed perspective on Minecraft</td>
<td>Links between the scenario-based game domain and the disciplinary domain</td>
<td>The students are able to use their knowledge of the coordinate system as a new way to play Minecraft Experience of how the coordinate system is meaningfully linked to in-game actions (conceptual agency)</td>
</tr>
<tr>
<td>Collaboration in math class in relation to Minecraft</td>
<td>Students’ experience of a changed perspective on participation in math class</td>
<td>Links between the pedagogical domain, the disciplinary domain and the scenario-based game domain</td>
<td>The students experience broader possibilities for participation, which involve more ways of being considered competent as well as more distributed authority between the teacher and students Working collaboratively opens up for the emergence of different understandings between the students of the coordinate system (conceptual agency)</td>
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Generally, the findings show how, compared with everyday math class, the students experienced a higher degree of freedom as they explored and solved tasks in the *Minecraft* map. This involved a broad distribution of authority, with several ways of seeking and getting help from other students. The game-based learning environment allowed new ways of participation and expression of agency, which, for some students, evened out the hierarchical playing field in their math class. The results also indicate shifts in what counts as legitimate mathematical agency in the classroom, as the intervention created new perspectives on how the mathematical concept of the coordinate system could be used in *Minecraft* and beyond. Thus, the students experienced several ways of being competent – i.e. within the domain of mathematics education, learning to navigate in the game domain and making connections relating to how mathematical knowledge could be relevant in other domains.

As mentioned earlier, much of the research on games in mathematics education is focused on using single-player learning games as somewhat instrumental tools for increasing student motivation and narrowly defined learning outcomes. Using the concepts of Cobb and colleagues (2009), learning games are often used in mathematics education to enforce disciplinary agency through skill and drill exercises, with lesser emphasis on students’ conceptual agency. However, the findings of our study suggest that there are good reasons for exploring the use of open game worlds and inquiry-based teaching with games in the mathematics classroom – e.g. to develop students’ conceptual understanding of the coordinate system. Based on our design-based approach and findings, we suggest three design principles that could inform future research on games in mathematics education.

The first design principle relates to how the students created meaningful experiences across in-school and out-of-school domains by collaboratively solving tasks in the *Minecraft* map. Based on these findings and borrowing
from scenario-based domain theory (Hanghøj et al., 2018), we propose that the educational use of games in mathematics could benefit from designing and teaching with game worlds, where students are given opportunities for meaningful agency through problem-solving, which relate to domains that go beyond the disciplinary domain of mathematics as a school subject. Here, we assume that commercial games can be used to create valuable learning experiences in mathematics education, which relate to the students’ everyday lifeworlds and challenge the current training paradigm for learning games.

The second design principle concerns the choice and use of specific commercial games for mathematics education. Computer games are, by definition, built on algorithms and an extensive use of mathematical concepts. However, the mathematical aspects are often hidden from the player in order to ensure immersion in the game (Llowrie and Jorgensen, 2015). Based on the results from this study and our other attempts at using commercial games in mathematics education (Hanghøj et al., 2018), we find it highly important to select and teach with games that provide direct access to specific mathematical aspects that are relevant to the mathematics curriculum. Access to recognizable mathematical activities in a game allows students and teachers to create their own experimental conditions for inquiry-based teaching. In this study, the students’ inquiry of the coordinate system in a Minecraft map allowed them to explore a somewhat familiar game world from new perspectives and develop meaning that was valid across various domains. Consequently, the freedom to access and explore underlying mathematical game features is a key precondition for repositioning students from disciplinary agency towards conceptual agency.

The third and final design principle concerns the complex relationship between game-related mathematical tasks and the actual experience of playing a game. One of the core in-game challenges when playing Minecraft is navigating the game world in order to find specific locations and avoid being lost. Our findings suggest that the students could use the game not only to learn about the coordinate system but also to understand the concept of coordinates by exploring in-game goals, such as building railroads or finding each other. This enabled the students to value not only the ability to learn mathematics by exploring Minecraft but also to improve their navigational skills in the game. Several of the students were able to engage in what they deemed a significant game practice from their everyday domain in a mathematically substantial way. Based on these findings, our third proposed design principle is that educators using commercial games in mathematics education should be able to facilitate teaching that links mathematical aspects in a game to in-game challenges that are meaningful to the players. This recommendation is in line with the study of Habgood and Ainsworth (2011), which documented the increased value of using games for learning mathematics that are intrinsically motivating in contrast to games, which are mostly based on external rewards.

In summary, the intervention created several positive findings regarding the students’ newfound perspectives on and transformation of mathematical experiences, which may inform the future use of games in mathematics education. However, there were also several limitations to our study, one of which was that the analysis was based on interview data and did not incorporate a detailed analysis of actual gameplay. It can be argued that the students’ switching to new conceptual perspectives mainly emerged in the interviews as reflective responses to the interviewer and that they would not have realized these conceptualizations without the interview. In this way, the validity of the findings would have benefitted from comparing the interview data more closely with observational data from the students’ classroom dialogues in situ. Another limitation is that our analysis did not focus on the role of the teacher in the game-based teaching unit, which is often emphasized as crucial to students’ learning experiences in terms of facilitating dialogue before, during and after gameplay (Arneth, Hanghøj and Silseth, 2018). As our findings show, the students valued relatively different mathematical aspects of the intervention – i.e. the ability to use mathematical concepts in a meaningful way, to improve navigation skills in the game or to collaborate and reposition the social hierarchy of the math class. Arguably, these aspects are all valuable in terms of facilitating engagement and improving learning outcomes. However, the wide range of experiences among the students also suggest that it may be highly demanding for teachers to identify students’ individual experiences and provide relevant feedback through dialogue. As we mentioned in the analysis, not all the students were able to clearly identify the mathematical aspects of the teaching unit. Thus, the current study could have benefitted from a closer analysis of the dialogue between the teacher and students as well as between the teacher and us, as researchers, about the perceived possibilities and challenges of using Minecraft in mathematics education.

On a final note, we wish to suggest directions for future research methodologies for studying how games can be used to learn mathematics. Despite few convincing results, most researchers working within this field have
mainly been interested in quantitative approaches, which measure whether students become more motivated or learn more with games than with other tools or instructional approaches. However, the diversity of student perspectives and experiences in our qualitative data analysis shows that there are good reasons to be critical of instrumental approaches to games and learning, which is currently the dominant research paradigm. Our study underlines the importance of moving away from narrow measurements and asking questions such as how and, in particular, what are students learning differently when they use games in education. There is a need for researchers to explore the ways in which mathematical concepts become meaningful to students in relation to game-based learning. One future focus for in-depth studies of mathematical learning processes with games could be how dialogical reasoning occurs in students’ interaction with games. As we have shown, Minecraft can potentially be used to positively affect students’ perception of mathematical activities and development of mathematical interest. Moreover, had the game been an instrumental learning tool, it would have been impossible for the students to engage with the learning scenario in a variety of ways or for each of them to represent different meaningful ways of participation. Therefore, researchers working with games and learning should not only focus on students’ ability to achieve mathematical standards or future demands. Instead, we should also pay more attention to how students’ everyday experiences with games may relate to mathematical concepts and create multiple gateways for participating in and understanding mathematics education as a meaningful practice.

8. Conclusion

The objective of the study was to investigate how Minecraft could be used in a teaching unit to engage students in mathematics education through different forms of participation and how students experience new perspectives on mathematical knowledge across in-school and out-of-school domains. The study showed that the Minecraft intervention created new perspectives in the students’ experience of mathematical knowledge, which they related to different in-school and out-of-school domains. The teaching unit clearly marked a change from the students’ everyday experience of “doing mathematics”, which they mainly described as the speedy solving of procedural tasks. Our analysis suggests that one of the main reasons for this successful recontextualization of knowledge between the game and school domains was that the students were actually able to use their knowledge of the coordinate system inside Minecraft as part of the teaching unit in terms of navigating the game space and overcoming meaningful challenges. Moreover, the analysis shows how the intervention motivated shifts in social relations, conceptual agency and perceptions of competence. As the findings indicate, the students were offered several possibilities for participation, which were sometimes related to understanding mathematics and other times to mastering the game. These findings stand in sharp contrast to the students’ everyday experience of complying with classroom norms, e.g. listening to the teacher, following closely what happens on the blackboard and providing answers quickly. We should be careful with generalizing these findings based only on one classroom intervention. Nevertheless, we still believe that these findings call for more in-depth studies of the use of commercial games in mathematics education, where students can use mathematical knowledge to overcome meaningful challenges.

References


