The impact of a mathematics game programming project on student motivation in grade 8

Eline Westerhout, Paul Drijvers and Arthur Bakker

Utrecht University, Freudenthal Institute, Utrecht, The Netherlands; e.n.westerhout@uu.nl, p.drijvers@uu.nl, a.bakker4@uu.nl

In this paper, we describe the impact of a mathematics game programming project on the intrinsic motivation of eighth grade students (n = 8). We investigate which aspects of the project contributed to student motivation based on a taxonomy that distinguishes individual (e.g., challenge) and interpersonal motivation aspects (e.g., recognition). We also employ these aspects to compare the programming project to regular mathematics education. The findings reveal that students appreciated the project because it was challenging and they had freedom of choice. All group members had a positive attitude towards learning. In regular mathematics classes, they experienced a lack of challenge while the freedom of choice was minimal.

Keywords: Intrinsic motivation, autonomy, mathematics education, programming.

Introduction

To foster intrinsic motivation, a learning environment needs to respond to students' needs for autonomy, feeling of competence, and social belonging (Ryan & Deci, 2000). A key question in secondary mathematics education is: what can teachers and educators do to create such an environment? As the motivation[1] for mathematics decreases during secondary school (OECD, 2013), we need to find ways to make educational practice more motivating.

The need for autonomy is especially complicated to promote in a formal learning context. Autonomy can be supported by anticipating students' intrinsic values and interests and by creating a context in which they feel at the root of their own learning behavior. This is diametrically opposed to the situation in mathematics education in many countries including our own, where educational practice is strongly guided by textbooks and national examinations.

The research question addressed in this paper is: how can aspects of a formal learning environment in which students' autonomy is supported contribute to an increase of the intrinsic motivation of students with a positive attitude towards learning? We describe the results of an intervention in which such an environment has been developed in the form of a mathematics game programming project for eighth graders. The learning goal was two-fold: while the main goal was to learn programming, as a secondary goal the project also aimed to extend students' mathematical knowledge. Since joining the project was on a voluntary basis, the eight participants were all motivated at the beginning of the project. Following them for a period of nine months and interviewing them at the end of this period gave us the opportunity to analyze what kept them motivated. The results of this study provide insights into the potential of giving (supervised) autonomy and a challenging task to students that are willing to learn.

[1] In the remainder of this paper, when we speak of 'motivation', we mean 'intrinsic motivation'

Theoretical framework

Research has delivered opposite findings with respect to the possible gain of playing computer games in education. Whereas several researchers measured a positive impact on problem solving capacities, no consensus has been reached with respect to the influence on motivation and attitudes towards mathematics (Kebritchi, Hirumi, & Bai, 2010; Perrotta, Featherstone, Aston, & Houghton, 2013; Wouters, Van Nimwegen, Van Oostendorp, & Van der Spek, 2013; Wouters, & Van Oostendorp, 2017). Wouters et al. (2013) came up with three reasons for the lack of improvement of students' motivation: they had limited autonomy, the connection between game design (focus on entertainment) and instructional design (focus on learning) is not natural, and the instruments used to measure motivation may not be appropriate.

Although research has been conducted on the potential of playing computer games in education (student as consumer), the potential of letting students develop and create such games (student as producer) has been explored insufficiently. Ke (2014) concluded after a six-week experiment using the *Scratch* programming environment that developing games stimulated the process of mathematical thinking and gave students a more positive attitude towards mathematics. He did not investigate why students' attitudes improved.

Intrinsic motivation is a multi-faceted concept that can be investigated from different perspectives. Self-determination theory (SDT) takes the learners' needs as a starting point and states that a motivational environment supports the needs for autonomy, feeling of competence, and social belonging (Ryan & Deci, 2000). The ARCS model of motivational design distinguishes four steps of promoting and sustaining motivation in the learning process: attention, relevance, confidence, and satisfaction (Keller, 2009). According to Malone and Lepper's (1987) model based on what makes gaming fun, motivation can be supported at the individual level (challenge, curiosity, control, and fantasy) and at the interpersonal level (cooperation, competition, and recognition). Elements that threaten to reduce students' intrinsic motivation are tangible rewards, threats of punishment, time pressure, and overly close surveillance (Ryan & Deci, 2009). The exploratory study described in this paper focuses on the impact of creating mathematical games on student motivation on the basis of Malone and Lepper's model and contrasts the programming project with regular mathematics education. The project was based on a constructionist approach to education (Papert & Harel, 1991): students learned through creative making processes and discovered the necessary knowledge themselves instead of receiving it passively.

Methods

The design of the programming project was driven by students' need for autonomy. During the first phase, they learned the basics of the *Processing* programming language, and all had to do the same assignments. This phase ended with the design and creation of a simple computer game. The second phase started with an advanced programming course. As the students' skills developed, their level of autonomy increased, which also meant that they got more freedom. In the final assignment, they designed and created their second computer game, with the only requirement that their game included a mathematical element (in the topic and/or in the code).

This assignment required many skills from students: they had to be creative (mathematical topic, design, rules, goals), to estimate their level of competence, to acquire new skills (mathematical and programming), and to manage their own process. The mathematical knowledge they acquired differed depending on their game.

Eight students (aged 13–14, grade 8) took part in the programming project, which was organized as an extracurricular activity open for all eighth graders in the school pursuing junior university preparatory education (VWO, 171 students) or junior general secondary education (HAVO, 94 students). Twelve students started in the project, but four of them withdrew after completing the introductory course due to health problems (1), a lack of interest (1), or school results (2). This paper focuses on the eight remaining students, who all pursued junior university preparatory education. They had in common that they were all motivated to learn programming, while they differed in intelligence, diligence with respect to schoolwork and math interests. Three of them had been diagnosed as gifted students of various types (Neihart & Betts, 2010): type 1 (opts for safe route), type 5 (demonstrates inconsistent work), and type 6 (autonomous learner). For the statistical analysis, the students who dropped out have been included in the test group.

Since the programming project was a long-term, extracurricular project, random selection of participants was not possible. As a consequence, we were not able to compose a control group that was similar to the test group. To position the participants within their cohort of eighth graders ('comparison group', $n = 171$), they all completed the *Attitude towards Math Inventory* (ATMI) questionnaire before and after the project, which consists of 40 five-point Likert-scale items on attitudes towards mathematics related to self-confidence, value, enjoyment, and motivation (Tapia & Marsh, 2004). For this research, the motivation scale (5 items; $\alpha = .793$ (pre-test), $\alpha = .803$ (post-test)) is especially relevant. The scores on mathematics tests in grade 8 have been collected for all students from the test and comparison groups as well.

Before joining the project, students were asked to write a motivation letter. At the end of the project, they completed a questionnaire covering several themes: (1) their motivation for programming, (2) the learning outcomes, (3) the transfer from programming to mathematics, (4) a comparison between the programming project and regular classes, and (5) the supervision during the project. Their answers to the questions were the starting point for semi-structured individual video-recorded interviews. We analyzed the motivation letters and interviews to identify students' reasons for joining the programming project and the factors of the learning environment within the project that contributed to the students' motivation using the categories distinguished by Malone and Lepper (1987) as a frame of reference: challenge, curiosity, control, cooperation and recognition. Fantasy and competition have been left out, since these were not relevant in this intervention. In addition, the interviews were analyzed to find out what lessons can be learned from the project for traditional mathematics class in grade 8.

Results

Preliminary analysis

As could be expected on the basis of students' voluntary participation and preference for STEM subjects, the score on the ATMI motivation scale was significantly higher in the programming

(*M* = 3.58, *SD* = 0.48) than in the non-programming (*M* = 2.66, *SD* = 0.71) group ($t(159) = 4.05$, $p < .001$, effect size Hedges' $g = 1.32$). This was still the case after the project ended ($t(155) = 3.16$, $p = .002$, $g = 0.99$).

Students' intentions

The students' reasons for joining the project as described in the motivation letters can be summarized into four types, all of them related to cognitive curiosity. The first and most common reason concerned preparation for their future. They had a preference for STEM subjects in school and considered a programming job in the future as a likely option. As a second reason, students liked the challenge of learning something completely new. Third, some students who had already been introduced to programming wanted to deepen their skills. They did not manage to learn programming on their own, either because the learning materials were not suitable or because they missed support and guidance. As a last reason, one of the students wanted to learn programming, because the possibilities with respect to programs that can be coded are limitless. In the interviews, the eight students indicated that the project lived up to their expectations: it was more challenging, the assignments were more open, and they learned more than expected. The results are described in more detail below on the basis of Malone and Lepper's (1987) motivation taxonomy.

Individual motivation

Challenge

Providing an optimal level of difficulty for learners is important for motivation (Malone & Lepper, 1987). During the project, it went too fast or was too complicated for some students at the beginning of the introductory course and at the beginning of the advanced course. Despite the level of difficulty being too high during these moments, the eight participants did not withdraw. Their reasons to persevere were diverse: practical ("waste to stop after investing so much time"), social ("nice group"), and personal ("want to be proud of own accomplishment").

At the end of both phases, in which students designed and built their own games, the difficulty level was adapted to the skills of the student in a natural way, which made it challenging for everyone. The outcome was uncertain, as they did not know in advance whether they would manage to implement all their plans. They were creating something completely new that had not been created in the same way by others before. The students challenged themselves to make the best games possible and acquired additional skills when needed, both at the programming and at the mathematical level (e.g., gravity, radians). Both the weaker and stronger programmers appreciated that they were able to work at their own pace and difficulty level.

A challenging learning environment provides learners with structure in the form of short-term and long-term goals. This was the case in the programming project as well. During the learning phases, weekly short-time goals had to be accomplished. The final assignment (creating a math game) was split into some smaller short-term goals as well. For example, the students were not allowed to start programming before tutors approved their idea on paper. Although the students got frustrated when they did not get the green light directly, they were aware that the detailed plan helped them during the rest of the development process. In this phase, the students also had to set their own goals, because all of the games where different and required their own planning.

Performance feedback helps to keep students motivated (Malone & Lepper, 1987). An advantage of programming is that some basic feedback is provided directly by the computer: does the game do what I want it to do? However, when a program does *not* work properly, it is often difficult to understand what is going wrong, and therefore human feedback is useful as well. The small group size, the weekly sessions, and the availability of the WhatsApp group enabled prompt performance feedback. The feedback was always constructive and if an explanation was not immediately clear, students kept asking until their problem was solved. Tutors and peers promoted the self-esteem of the students during class as well as during group presentations.

Whereas the programming project was challenging for all students, this was not the case with their mathematics classes. When it comes to giving feedback, programming was considered superior to mathematics as well. The direct feedback provided ‘for free’ in programming (e.g., error messages, output on the screen, behavior of the game) is not available when making mathematics homework where it requires effort from students to receive feedback.

Curiosity

Cognitive curiosity was one of the motives for students to participate in the project. Some of them had basic programming knowledge and wanted to learn more while others had no experience at all. When such curiosity and eagerness to learn something new is not present at the start, it will be more complicated to get students involved. Despite the absence of formative tests, students stayed actively involved and were willing to invest time and effort to achieve their learning goals because of their cognitive curiosity. According to one of the students, cognitive curiosity is not always stimulated properly in math class. Their teachers explain everything instead of promoting inquiry-based learning.

Control

According to Malone and Lepper (1987), having influence on your own learning process is a prerequisite for being motivated. All students appreciated the fact that they had the opportunity to follow their own paths in the introductory and the final assignment. Only one of the students indicated that the assignments could have been even more open (not restricted to games). The final assignment, where the students got several months to create their own math game, especially promoted their feelings of autonomy. It gave them a sense of power to be able to create their own game:

> *I really liked programming. It was problem solving, which took a great deal of time and when I then succeeded, it made me happy: “Yes, I finally did it”.*

The final assignment created a highly responsive learning environment, where students and tutors were continuously interacting on how to proceed. Even during holidays and weekends, questions were being asked and answered in the project WhatsApp group.

In the video-interviews and on the questionnaire all students (strongly) agreed that they got enough freedom to work on their own plans. One of them explained why he enjoyed the level of freedom in the project over the common practice at school: in the programming project he could use his own imagination and creativity instead of “following a cookbook recipe”.

Interpersonal motivation

Cooperation

Although programming is partly a lonely activity, the programming project incorporated cooperation between students at several levels as well. The first way in which cooperation was ensured was the level of instruction. Instead of a teacher being in charge, peers who were only three years older (‘tutors’) gave the lessons and guided the students’ projects. This peer-to-peer structure made the setting more informal and lowered the threshold for students, especially when they needed help outside of the classroom. As a second way of promoting cooperation, there were no classroom rules with respect to seating, walking around or talking. Throughout the project, the students got to know each other and they got more and more involved in each other’s games. They also started to help each other and shared ideas. The third cooperation mechanism was the WhatsApp group, where students shared their questions with their peers. Students who asked more questions during class were also more active in the app group, both in asking and answering questions. The tutors did not always provide ready-to-use solutions, but asked questions and gave suggestions to stimulate students to come up with their own solutions.

Cooperating on school tasks was not common for these students during class. The reasons given for their difference in behavior between the programming project and regular classes are the lack of challenge and social pressure in their regular classes.

Recognition

The students developed real games that could be played by others and their efforts were clearly appreciated by their surroundings. They were given the chance to present both their games once they were (almost) finished. The first presentation marked the transition of the introductory course to the advanced course. Their parents and siblings were invited at school for this presentation, where the students also received a certificate. They presented their games, but there was also time to try and play all games. The second presentation was given at the end of the project. The students sometimes showed their games to their friends and got recognition from them as well for their efforts.

Discussion and conclusions

The question to be answered was how aspects of a formal learning environment in which students’ autonomy is supported contributed to an increase of the intrinsic motivation of students that have a positive attitude towards learning. Malone and Lepper’s (1987) taxonomy provided an appropriate framework for understanding what happened during the intervention. Although the number of participants was small and the outcomes could not be compared with a control group, we have reasons to believe that providing autonomy indeed had positive consequences for many motivational aspects, both at the individual (challenge, curiosity, and control) and the interpersonal (cooperation, recognition) level. Most importantly, compared to traditional mathematics classes, the learning process became more challenging, because students were allowed to set their own goals and could make their games as complicated as they wanted. Focusing on the need for autonomy directly affected the needs for feeling competent and social belonging as well (Ryan & Deci, 2010). Integrating autonomy with guidance and support increased students' feelings of competence and thus the motivation potential. In addition, the autonomy to choose their own level of difficulty allowed all students to feel competent. The need for social belonging was unintentionally met: the eight students coming from five different classes developed a pleasant working atmosphere together, which increased their motivation to proceed and persevere even when they found it difficult.

As a follow-up of this project, it would be interesting to implement the motivational aspects from the programming project in a regular class, including students with less positive attitudes towards learning. Another question for future research is whether focusing on the need for autonomy in regular mathematics classes could also strengthen students' feelings of competence and social belonging. The current attention for problem solving in mathematics education in the Netherlands (Doorman et al., 2007) is a promising step in this direction, because this provides opportunities for responding to students' need for autonomy. Lessons learned from our intervention are that it is important to make problems as open as possible allowing students to use their own creativity and to make them understand why problem-solving skills are relevant.

The focus of the current study was on the impact of autonomy on motivation. Another aspect that could be analyzed would be the influence of such a programming project on the students' creative thinking skills and their mathematical knowledge. The students indicated in the interviews that the programming project was more challenging and more interesting than their mathematics classes. Although the participants' motivation for mathematics was higher in the current study, they did not outperform their peers with respect to mathematics test scores before the project started. The learning outcomes with respect to mathematics have not been analyzed in detail in this study.

The way in which the programming project was organized shares characteristics with the Maker Movement, a community of hobbyists, engineers, hackers, and artists that builds on each person's ability to create things (Martin, 2015). The movement did not start in education, but educators are becoming interested in adopting the *making* activity into secondary education to enhance opportunities for students to engage in STEM practices. The Maker Movement makes learning more tangible and less abstract. The programming project has shown that this motivates students and that it makes them proud if they manage to create something they designed themselves. As a follow-up of the programming project, the eight project participants decided to participate in a national competition in which they are going to program a robot (the micro:bit).

References

Doorman, M., Drijvers, P., Dekker, T., Van den Heuvel-Panhuizen, M., De Lange, J., & Wijers, M. (2007). Problem solving as a challenge for mathematics education in the Netherlands. *ZDM – Mathematics Education, 39*(5-6), 405–418.

Ke, F. (2014). An implementation of design-based learning through creating educational computer games: A case study on mathematics learning during design and computing. *Computers & Education, 73*, 26–39.

Kebritchi, M., Hirumi, A., & Bai, H. (2010). The effects of modern mathematics computer games on mathematics achievement and class motivation. *Computers & Education, 55*(2), 427–443.

Keller, J. M. (2009). *Motivational design for learning and performance: The ARCS model approach*. New York: Springer.

Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning. In R. E. Snow, & M. J. Farr (Eds.), *Aptitude, learning and instruction* (pp. 223–253). Hillsdale, NJ: Lawrence Erlbaum Associates.

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research (J-PEER), 5*(1), 30–39.

Neihart, M., & Betts, G. (2010). Revised profiles of the gifted and talented. Paper presented at the *11th Asia Pacific Conference on Gifted, Sydney, Australia*.

OECD (2013). *PISA 2012 results: Ready to learn. Students' engagement, drive and self-beliefs. Volume III*. Paris: OECD.

Papert, S., & Harel, I. (1991). Situating constructionism. *Constructionism, 36*(2), 1–11.

Perrotta, C., Featherstone, G., Aston, H., & Houghton, E. (2013). Game-based learning: Latest evidence and future directions. *Slough: NFER*.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist, 55*(1), 68–78.

Ryan, R. M., & Deci, E. L. (2009). Promoting self-determined school engagement: Motivation, learning, and well-being. In K. R. Wentzel, & D. B. Miele (Eds.), *Handbook of motivation at school* (pp. 171–195). New York: Routledge.

Tapia, M., & Marsh, G. E. (2004). An instrument to measure mathematics attitudes. *Academic Exchange Quarterly, 8*(2), 16–22.

Wouters, P., Van Nimwegen, C., Van Oostendorp, H., & Van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology, 105*(2), 249–265.

Wouters, P., & Van Oostendorp, H. (2017). Overview of instructional techniques to facilitate learning and motivation of serious games. In P. Wouters, & H. van Oostendorp (Eds.), *Instructional techniques to facilitate learning and motivation of serious games* (pp. 1–16). Cham, Switzerland: Springer.