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Published in:
Proceedings of the 13th International Conference on Game Based Learning, ECGBL 2019

DOI (link to publication from Publisher):
10.34190/GBL.19.087

Publication date:
2019

Document Version
Early version, also known as pre-print

Citation for published version (APA):
Jensen, E. O., & Hanghøj, T. (2019). Math in Minecraft: Changes in Students' Mathematical Identities When Overcoming In-Game Challenges. In L. Elbaek, G. Majgaard, A. Valente, & S. Khalid (Eds.), *Proceedings of the 13th International Conference on Game Based Learning, ECGBL 2019* (pp. 355-362). Academic Conferences and Publishing International. https://doi.org/10.34190/GBL.19.087

Math in Minecraft: Changes in Students' Mathematical Identities When Overcoming In-game Challenges

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Abstract: This paper presents empirical findings from a qualitative study that uses *Minecraft* as a mathematical tool and learning environment. Even though *Minecraft* has been used for several years in classrooms all over the world, there is a lack of detailed empirical studies of what subject-related content students can learn by working with the game. The study is based on a teaching unit for 5th grade, which focused on using the coordinate system already embedded in *Minecraft* as a means of navigating and exploring the game in order to solve mathematical problems. Based on a design experiment with the teaching unit, we explore the following research question: How do 5th grade students experience a change in their mathematical identities when they participate in an inquiry-based teaching unit with *Minecraft*? A thematic analysis explore data from six group interviews. The theoretical perspectives used in the coding of data were based on domain theory and an interpretive framework for understanding students' mathematical identity. The key analytical findings regard the students' experience of the coordinate system as part of both the academic domain of mathematics and as a part of their everyday domain playing *Minecraft*, how students actively use the coordinate system to improve play in *Minecraft*, and how students experience new ways of participating in mathematics.

Keywords: *Minecraft*, mathematics education, student identity, domain theory, coordinate system

1. Introduction

Games have existed as a part of mathematical education for a long time 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 other subjects (Hainey, Connolly, Boyle, Wilson, & Razak, 2016). Thus, there is a widespread belief that games have a great potential in mathematics education.

Some scholars point to video games as an ideal medium for teaching mathematics in middle school (Devlin, 2011). Yet, recent meta-analysis show only small and marginally significant positive learning effects of using games in mathematics education (Byun & Joung, 2018; Tokac, Novak, & Thompson, 2019). The proposed potential for games are yet to be fulfilled. One issue raised in the reviews was that the researchers trying to understand learning of mathematics with games are often specialized in other fields than mathematics education. Most being from educational technology, computer science and engineering with only 5 of 71 researchers having a mathematics education profile (Byun & Joung, 2018). In this way, there is need for more research on using games for mathematical purposes, which relate closer to the research field of mathematics education.

One of the main reasons for teaching with games is to increase motivation. Student interest in mathematics is reported to be one of the most significant predictors when determining mathematical performance and perseverance (Hannula et al, 2016). Moreover, a prevailing problem for mathematics education is that many students do not come to see mathematics as a constructive endeavour (Boaler, 2015). Cobb (2007) argues that classroom activities being worthy of student engagement in its own right, from a student perspective, is an important part of the cultivation of students interest in mathematics and should be considered an important goal for mathematics educators. Thus, we want to address the use of games in math class by using the theoretical construct of sociomathematical norms (Cobb, Gresalfi & Hodge, 2008) to understand how students' mathematical identities are affected. This leads us to the research question: How do 5th grade students experience a change in their mathematical identities when they participate in an inquiry-based teaching unit with *Minecraft*?

2. Learning mathematics in *Minecraft*

Minecraft is an educational tool used in classrooms worldwide. Similarly, there has been conducted research on the use of *Minecraft* to promote learning for several years, spanning a wide variety of subjects (Nebel, Schneider & Rey, 2016). A number of studies have explored teaching activities with *Minecraft* in mathematics educational settings. Some highlight envisioned potentials for the use of *Minecraft* for learning mathematics and relate the use of the game to desirable mathematics education standards (Bos et al, 2014; Floyd, 2016; Tromba, 2013). However, the explored potentials in these studies are based on rather limited empirical examples. Other studies on *Minecraft* originate from the fields of computer science and educational technology and report on class experiments (Al Washmi et al, 2014; Foerster, 2017; Freina et al, 2017) or propose a study (Nguyen, & Rank, 2016) with *Minecraft* in a mathematics education setting. However, none of the above articles use mathematical educational theories to understand student learning or analyze data. One exception is the study by Kørhsen & Misfeldt (2015), which takes an ethnomathematical approach to understanding mathematical activity in *Minecraft* in an after-school programme through Bishops six fundamental categories (Bishop, 1991). Kørhsen & Misfeldt (2015) present evidence of player activity related to each of the categories (Counting, Measuring, Locating, Designing, Explaining and Playing). They find that the activities are influenced by the design of *Minecraft*, which challenges the students to visualize and systematise constructions following the social and cultural conditions in the after-school programme. The children collaborate and learn from each other and develop game narratives that requires demanding constructions. In summary, the studies indicate potentials and promising teaching designs and approaches for using *Minecraft* in mathematics education. However, there are few articles, which focus empirically on the players' mathematical activities. In this way, there is a need for more detailed studies of how *Minecraft* can help students learn mathematics.

3. Case: Teaching unit with *Minecraft*

The current study is based on a teaching unit with *Minecraft* in a 5th grade class (22 students), which involved 15 lessons distributed over five days in one week. One of the researchers conducted prior meetings with the teacher, who contributed with input to the design of the unit. The initial idea for the intervention, originated from the fact that a the mathematical concept of Cartesian coordinates from the mathematics educational curriculum was accessible in *Minecraft* and that 3D navigation is a key challenge in the game. The accessibility of such an underlying mathematical dynamic is not commonplace in commercial games, where the mathematical rules are often hidden from the players (Lowrie & Jorgensen, 2015). Our initial hypothesis or humble theory (Prediger, 2019) was that the mathematical concept of Cartesian coordinates could be introduced as a means to solve the real player problem of locating objects in the *Minecraft* in order to help the students master the game and also affect their understanding of the game. *Minecraft* worlds are randomly generated so a key element in the game is the exploration of the specific virtual world you are playing in. But it can be difficult to navigate *Minecraft* successfully and locate specific objects or other players can experience problems such as having built a structure and not being able to return to that structure because you got lost.

3.1 Navigation with Cartesian coordinates

In *Minecraft* the player can access the avatars x, y and z coordinates in the game. The x-axis indicate position on an east-west axis, the z-axis on a south-north axis, while the y-axis indicate elevation. See figure 1. One whole number on the axis is equal to the length/height of one block in the game, which in turn is equals one meter in the real world.

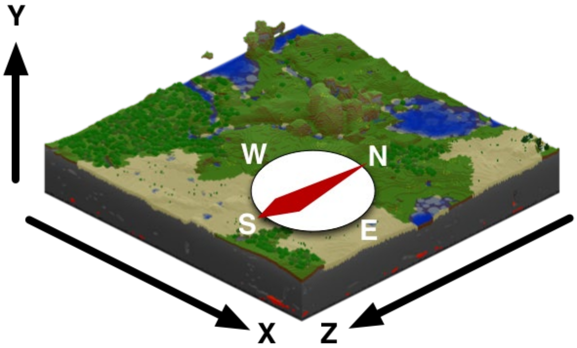

Figure 1: The x, y and z coordinates in Minecraft

When the players move their avatar in the virtual world, the values of the axis' chance according to the position. So 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 step of a staircase in *Minecraft*. For each picture the avatars coordinates is in the upper right corner.

Figure 2: Change in coordinates

Following the avatar through 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 when going up 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.

4. Theoretical perspectives

Our research question is explored through two complementary theoretical perspectives: a domain theory of educational gaming and an interpretive framework for analysing students' mathematical identities.

4.1 Domain theory

Using commercial games in mathematics education involve an interplay of different in- and out-of-school domains and knowledge practices, which raises a number of questions that must be addressed and negotiated - i.e. what counts as valid knowledge and valid ways of doing math when playing games in the mathematics classroom? Following the domain theory of educational gaming developed by Hanghøj et al (2018), the use of *Minecraft* in the classroom is understood as an interplay of three domains illustrated in fig 3.:

1. The school-based domain of mathematics education. This involve particular forms of teacher-student authority as well as validity criteria for determining mathematical knowledge.

2. The game domain of *Minecraft*. This both refers to the existing (if any) knowledge of *Minecraft* and their experience of playing the game in the classroom, and
3. The everyday domain of the students. This relates to their lifeworld and everyday experiences beyond having mathematics and playing *Minecraft*.

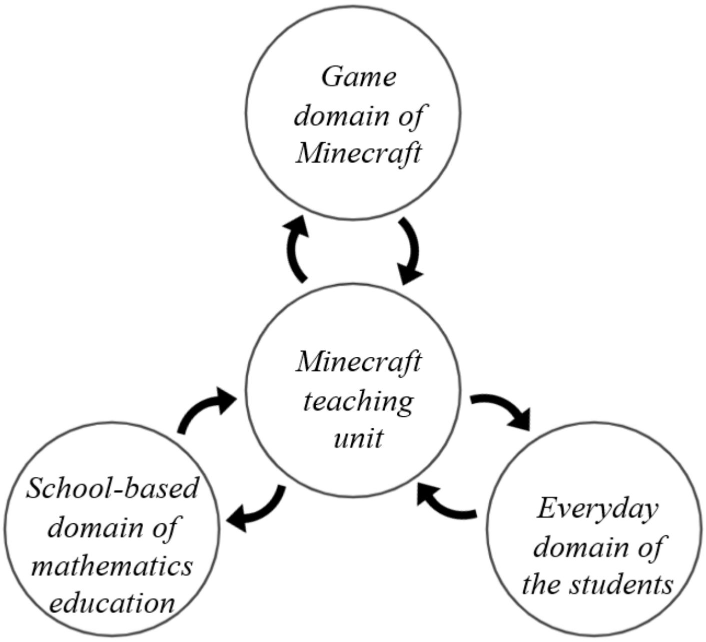

Fig 3

4.2 Mathematical identities

To understand how the use of *Minecraft* may affect students' participation in mathematics education, we use the notion of mathematical identity. According to Cobb, Gresalfi and Hodge (2008), normative identity describes the obligations that define and constitutes the role of a good mathematical student in a specific classroom. There are three different aspects of the classrooms obligations. Authority refers to whom the students are accountable to, and how authority is distributed in varying degrees between students and teacher. Agency address how the students are able to act legitimately in the classroom. There are two basic forms: Disciplinary agency concerns students' use of established solution methods, whereas conceptual agency is about choosing methods, develop meaning and relations between concepts. The third aspect is mathematical competence, which refers to what the student is responsible for in terms of mathematical reasoning and argumentation. Finally, Cobb, Gresalfi & Hodge (2008) also introduce the notion of students' personal identity, which refers to how the students relate to these obligations and see value in mathematics as it is realised in the classroom. There are three typical ways of doing this: the students identify with the obligations, they simply cooperate with the teacher, or they resist engaging in classroom activities. These concepts allow us to explore how students experience their relation to mathematics and whether they see value in mathematics as it is realized through the intervention.

5. Methodological approach

This pilot study is part of an on-going design-based investigation (Barab & Squire, 2004) of how commercial games can be linked to curricular aims. The collected data is based on six semi-structured group interviews (Kvale & Brinkmann, 2009) with two 5th grade students in each group. The interviews were conducted after the enacting of the teaching unit. There were a majority of boys and of bilingual students in the class. The teachers described the class as being disruptive and difficult to manage with a generally low performance in mathematics with a few mathematically skilled students. The student groups were selected prior to the intervention to represent a broad spectrum of mathematical achievement in class as defined by the teacher.

6. Analysis

The analysis is based on a thematic analysis (Braun & Clarke, 2006) of the data and is structured around four overall themes relating to the students' mathematical identities and their experience of the different domains. The analysis will show a number of new connections between the different domains and how the normative identity as a doer of mathematics in the intervention was different from their regular math class. The analysis describes these existing and new possible ways of identifying with math class as available students positions.

6.1 Being a math student

This section explores the students' experience of the obligations in everyday math teaching as they experience it through regular math class. One theme is that doing calculations quickly is important to be considered mathematically competent. Here Melanie is asked when she experience, that she is a good math student.

Melanie: When I know something. Or if I have listened and understood it. Then I can be fast and answer quickly.

For Melanie being a good math students is connected to how fast answers are produced, knowing something or being able to understand the teachers explanation. Henrik also uses speed to describe what it means to be a good student:

Henrik: … You have to be good at calculating, fast.

The examples shows that the quality of an answer and the experience of being a mathematically competent student, is dependant on how fast answers can be produced. Henrik further explains that sometimes it is simply best to know new concepts and answers before they are introduced by the teacher, because this gives you an advantage in terms of answering quickly and correctly.

Another aspect is that the students rarely experience that activities and concepts from the mathematical subject domain has connections with activities and concepts from their everyday domain. This can be seen through Henrik reflections on the intervention:

Henrik: It was the first, almost.
Interviewer: It was the first?
Henrik: mm. approximately.
Interviewer: uhm. I'm just trying have to understand. The first what?
Henrik: I could use in all subjects, from mathematics.
Interviewer: Ahh. It was the first you have experienced in mathematics…
Henrik: That you can use in all subjects. Yes.

Henriks experience of the concept of the coordinate system in the intervention becomes a first in terms of concepts that can be used outside of math class. The realisation of mathematics being connected to the everyday domain is something he has very seldom experienced. But it also indicate that he might have experienced it, or that he is aware that what he learns in math class can have connections to the world. The use of the word "first" also seem to indicate that he expects more connections made. However, the subject domain of mathematics as it is experienced through normal math class is characterized by being disconnected from other domains.

The above examples and the other themes regarding regular math class, shows that the normative identity are about listening and paying attention, especially when the teacher presents on the whiteboard. Disciplinary agency is the primary way students legitimately can express agency. Talking with other students about a task is often regarded as cheating and students are mainly accountable to the teacher with little distribution of authority to the class. In the following sections, we will describe how new positions emerged in the class, when the students were given opportunity to connect mathematical concepts to specific situations outside of math.

6.2 Being a mathematical *Minecraft* player

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, but initially separated domains; mathematics and the everyday domain, which in turn transform both domains:

Interviewer: … have you learned anything new about the coordinate system that you didn't know before. (Hasan: yes) 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, 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 (Hasan: Yes) 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 that he could press F3 and prompt a series of information but could not translate the information into something meaningful. After learning what the numbers mean, he uses them often to locate objects. In terms of knowledge domains, Hasan uses activities in *Minecraft* (the game domain) to explain why the coordinate system from the mathematical domain is useful. In this way, he creates a strong connection between the different domains. His use of the coordinate system in *Minecraft* becomes a new way of interacting with the game. If we expand the notion of agency in math class to understand the changes in how Hasan play 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 actual challenges in the game.

6.3 Being repositioned as math students

The previous example showed how the intervention created student positions in terms of being a mathematical *Minecraft* player. However, the intervention also affected the students' personal identity towards mathematics. As an example, we will focus on two students Mads and Adam, who the teacher deemed the best math students in the class. Here Mads explains how always being the first to finish tasks, would put them in an awkward position.

Mads: And then they 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.

When mathematical competence is dependent on the speed of solutions and the same students often finish the tasks first, the other students find themselves in a situation where it is difficult for them to be regarded as mathematical competent. It seems that the other students feel they do not have a chance to be the first to finish. Because of this they direct frustration and anger towards Mads and Adam. They had little knowledge of *Minecraft*, but as we will see, they clearly identified with the mathematical content of the teaching unit. This could be connected to the fact that the everyday classroom obligations presented a problem for Mads and Adam, because the other students would get upset when they were not able to complete a task that Mads and Adam would complete quickly:

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, 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 they can? do? The others that 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 form 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: to play Minecraft?
Mads: To everything

As the intervention uses *Minecraft*, it draws on knowledge from both mathematics and the game domain concerning *Minecraft*. Mads and Adam's description of having to learn from the other students, can be seen as a renegotiation of the authority in the classroom towards more distributed model of teaching and learning than they normally experience. As the teacher is not the *Minecraft* expert, the game opens up a space for agency to be expressed in more conceptual ways in a crosslinks between the domains. Valuable knowledge is not just tied to who is the first to finish a mathematical task, but who can integrate knowledge between the domains. This challenges Mads and Adam to understand knowledge about *Minecraft*, which becomes a valid and valuable part of being competent in the intervention. The students who are skilled at mathematics are not necessarily the students, who are skilled *Minecraft* players, which means that the students' competences are redistributed across different domains. Mads and Adam experience being more on the same level as the other students, which releases Mads and Adam from the normal classroom obligations of finishing quickly. What they address with this change is not however that they are losing an opportunity to display mathematical competence towards the teacher. Rather, the release from this obligation is "fantastic" and is a shift toward positive identification. It underlines the fact that the focus on being the first to finish creates very narrow opportunities for the students to identify with the classroom obligations.

7. Discussion

The study shows how the intervention created an identity shift towards understanding mathematics as part of the students' lifeworld and being useful as a resource in *Minecraft*. This clearly marked a change from the students' everyday experience of "doing mathematics". We suggest that the reason for this successful transfer of knowledge between game and school domains is that the students can actually use the coordinate system in *Minecraft* to overcome meaningful challenges, which are relevant for them.

As we have showed, using a game like *Minecraft* for translating experiences across domains offers a number of affordances. We suggest that one of the key elements for this to succeed is that the game must offer a possibility to access an underlying mathematical aspect of the game, e.g. the coordinate system, enabling the students to work with it. Another key element is that the activities in the intervention was aimed at qualifying the way the students played *Minecraft* giving them new opportunities to navigate in the game world enabling them to engage in what the students deem a significant practise from the everyday domain but in a mathematically substantial way. This points to a need for more detailed analysis of how particular mathematical concepts are parts of specific games and how students can use these concepts to improve their interaction with the games.

In terms of the students' experience of obligations in math class, the intervention motivates shifts in both authority, agency and perception of competence. These shifts are partly due to the learning goals of the interventions are in the intersection between domains and not exclusive to the subject domain. This creates a more diverse way of being competent when participating in the intervention because knowledge of *Minecraft* becomes essential. This is in opposition to the normal way of complying with the classroom norms, by providing answers quickly. Which for one students is interpreted to an extent, where already knowing the new concepts being introduced, and therefore being able to answer quickly and correctly, is a way of explaining what it means to be a good student. It highlights the problematic nature of a focus on speed. It depends of course on the teacher's intent with the introduction of new concepts. If it is to help the students understand these concepts, it seems counterintuitive that some students feel that their best possibility of engaging in the activity in a mathematically competent way, is to already know the new concepts being introduced.

The intervention also shifts the authority from being primarily teacher-centered to more student-centered, because some students have knowledge about *Minecraft*, which not even the teacher has. This means there are both several different ways of being competent and also several ways of getting help from both the teacher and other students. There is also a shift in what counts as legitimate agency, because there are more ways of participating conceptually, assessing if mathematical concepts can be used in *Minecraft*. Different ways of being recognized and expressing agency affects possible student positions in the classroom. For some students this evens the playing field giving rise to new ways of participating positively.

For Cobb (2007), an important consideration when formulating curriculum goals for student learning in mathematics education, should be to describe central mathematical ideas in particular mathematical domains and that a justification of these goals should be in the terms of activities that students will gain future access to. Our data shows that Cobb's (2007) two statements regarding future access and activities worthy of engagement can be connected in such a way that the access is moved to the present. In summary: instead of students gaining a perceived future access to a domain through mathematics, they experience the access themselves in the present.

The idea that students should gain access to significant practices in the future seems a very justifiable end-goal for mathematics education. However, several examples in our data suggest that the way mathematics is being taught does not help the students sufficiently to make connections between the subject domain and their everyday domain experiences. One implication of this could be that students lose interest in mathematics long before they realise that mathematics can be useful outside of math class, making Cobb's (2007) proposed end goal seem unattainable. The analysis shows that students can experience that mathematical concepts enable them to participate in significant practices in substantial ways. Not significant in terms of democratic or critical end-goal for mathematics education, but significant practices and substantial ways in a more humble sense, viewed from the students' perspective and everyday domain. And that this experience seems a catalyst for the perspective that math actually have something to do with the students everyday domain.

8. Conclusion

The study shows that *Minecraft* used in an inquiry-based approach in math class can change students' identification with mathematics, create new ways of participation and "doing mathematics". The intervention thus enables the students to participate in what the students experience as significant practices outside of mathematics education (Cobb, 2007). The point here is not that playing *Minecraft* is a significant practice for mathematics educations in itself, but when the game is used to create significant mathematical practices, the intervention gives access to new ways of participating in that practice. This can open up to new ways of identifying with mathematics bridging a gap between the students' everyday life experiences and the subject domain.

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