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Exploring critical aspects of students' mathematics learning in technology-enhanced and student-led flipped learning environments

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Although teaching according to a flipped classroom approach is being increasingly used in schools, it is still the case that this type of education is often teacher-driven, and that teachers play a dominant role in terms of determining learning objectives and materials. Recently, the definition of flipped classrooms is being changed, accordingly the approach is becoming more student-driven and teachers mostly start to play supportive roles. Thus, this new approach is currently referred to as the flipped learning approach. The aim of our research is to identify central elements for students when learning mathematics in flipped learning environments. Therefore, teaching scenarios were developed, applied at a higher secondary level and written feedback from pupils were obtained. The grounded theory based analysis of feedback suggests that it is crucial for students to work together, jointly generate knowledge, become active in determining learning paths and selecting materials.

Keywords: Flipped classroom, Flipped learning, Mathematics education, Student centred learning.

Introduction

Flipped Classroom Approaches (FCA) have been gaining popularity in education and in most cases, digital technologies are used to facilitate creating a flipped environment. Digital technologies include mathematics specific software products such as GeoGebra as well as communication and collaboration platforms such as Moodle or Mahara. In general, modern technologies have been becoming increasingly important in mathematics education. Nevertheless, using technologies should always improve students' learning process, and not simply appease them (Klein, 2002). Even though many scientists and practitioners describe education according to an FCA as progressive, there is already a development of this approach – the flipped learning approach (FLA). However, the terms Flipped Classroom and Flipped Learning are used synonymously in some scientific articles (e.g. González-Gómez et al., 2016; J. Lee, Lim, & Kim, 2017). But the approaches differ regarding their definitions and characteristics. The fact that the two approaches are still used synonymously may indicate that education according to an FLA has not been fully integrated into research and teaching. This can also be observed in the STEM education field, since recent publications use the approaches interchangeably and without differentiation (e.g. Gnaur & Hüttel, 2014; Ponikwer & Patel, 2018).

The first section will discuss the differences between an FCA and an FLA. Here, a special focus is placed on students learning mathematics and how these approaches are linked to social constructivism. Then, we will focus on our actual research question: Which components of an FLA are crucial for both students' well-being in such environments and students' motivation to participate in mathematics education? In order to achieve the research aim, data were collected and

evaluated according to a grounded theory approach and action research. Finally, the thesis will discuss the results of the research and, from this, draw conclusions.

Theoretical Background

This section defines the singularities and differences between FCA and FLA. Additionally, relations of these approaches to mathematics education and to the theory of social constructivism are described.

Defining flipped classroom approaches

Even though FCA has been dealt with often at an academic level in recent years this form of education can be found in many classrooms, there is still no uniform definition of this educational approach (Enfield, 2016; Wasserman et al., 2015). But most FCA descriptions have common elements. The fact that direct instructions and passive learning activities take place outside classrooms characterizes many definitions of an FCA. The classroom time is then used for student-centred and active learning activities. This means that in pre-class phases of an FCA, mainly simple learning objectives are pursued and in in-class phases learners and a teacher try to achieve higher learning objectives (Wasserman et al., 2015).

In mathematics education it is quite common utilizing videos in pre-class phases and lessons are used for active, group-based or problem-solving activities. Recently, more and more research projects (e.g. Esperanza, Fabian & Toto, 2016) demonstrate that flipped classroom education can improve students' achievement in learning mathematics.

Defining flipped learning approaches

Many assume that *flipped classroom* and *flipped learning* are similar terms used to describe more or less the same approach. To counter misconceptions, the Flipped Learning Network (FLN) (2014) composed a formal definition of the term "flipped learning", as follows: "Flipped Learning is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter" (FLN, 2014). According to the FLN, an FCA does not necessarily lead to flipped learning. However, FLA can be considered as a development of FCA.

Implementing FLA into mathematics education should lead to flexible learning environments in which students could achieve higher cognitive goals, for instance by tackling real-world problems. Moreover, for the construction of different mathematical meanings, learners can be given the opportunity to make their own experiences and feel the need for an introduction of concepts or terms.

Although many studies have already explored implementing an FCA in mathematics teaching, there is a lack of research investigating flipped learning in mathematics education. In a few mathematics education research studies some elements of an FLA can be found (e.g. Weidlich & Spannagel, 2014). However, these learning environments are often not described according to an FLA.

Social constructivism's influence on flipped learning environments

Social constructivism (SC) (Vygotsky, 1978) is a student-centred learning theory that emphasises importance of the social environments in which learners generate their knowledge themselves. According to SC, students are becoming more active to determine their learn path and teachers' role change from knowledge providers to supporters of the learning environments. FLA has already incorporated SC in its initial development as in flipped learning environments learning is self-directed and seen as an active process. Moreover, students are also encouraged to learn through social interactions within their groups (Green, 2015).

Research design

This section outlines the participants, the mathematical content and the procedures of our flipped learning experiments.

Framework of our flipped learning educational experiment

The educational experiment was conducted with four classes (students aged from 14 to 16 years) at two different schools in Vienna – an urban college of business administration and a humanistic high school with a focus on classical languages. All four classes were already taught in a traditional flipped classroom setting. The educational experiment lasted between 6 to 7 teaching units and more than 110 students took part in it in total. The centre of education was formed by square functions and their applications. Since students from different types of schools were involved, the experiment was carried out according to the respective curricula of the 9th and 10th grade.

Proceedings of our flipped learning educational experiment

At the beginning of the learning sequences, all students were informed about the tasks to be performed, the goals to be achieved and the deadline. In the college of business administration, students had to solve different tasks, which were made available via an online learning platform. There were also short interactive videos with integrated questions provided to check students' comprehension. Therefore, watching a video became an active process. In the high school, students had to research Leonardo bridges, build such a bridge themselves, and finally mathematically examine this self-built bridge. Students were able to use tablets (college of business administration), their own notebooks (high school) and other learning materials according to their preferences.

In all settings it was essential that learners were given tasks and objectives. However, the availability of time and technological tools enabled the students to self-determine the learning path. This availability should make it easier for learners to individualise learning processes themselves. The provision of modern technologies, as well as databases and communities on these technologies, should enable students to tackle higher mathematics.

Since experimental conditions in education in general, and in a flipped setting in particular, are difficult to produce (Reinmann, 2005) and our research interest focuses on exploring crucial aspects for students when learning mathematics in flipped learning scenarios, we decided on qualitative oriented research methods. Thus, approaches and methods of action research and grounded theory were used to collect and evaluate data.

Research aim and research methods

Exploring which components are significant for students when learning mathematics according to an FLA is the aim of our research. In order to develop these new hypotheses and theories concerning FLA mathematics education, our research is designed according to qualitative research approaches.

The education sequences described above were planned and carried out by us, the authors. We had to assume both the role of a teacher and the role of a researcher. This should help to ensure that both practical and academic knowledge could be gained through the research process. For the action research McKernan's iterative model (McKernan, 1991) was chosen. This model is based on Lewin's four original action research phases: plan, act, observe and reflect (Lewin, 1946).

Additionally, a grounded theory approach (GTA) was applied to develop an FLA mathematics education theory. This theory is based on teaching records and on student feedback forms. Both data collection and evaluation follow GTA principles according to Strauss and Corbin (1990, 1997). Since both perspectives of researchers and the educational environment are of central importance, many elements of a constructive GTA according to Charmaz (2006) can also be found in the present research design. After the last lesson of this sequence, learners were asked to provide open written feedback on the FLA mathematics education experiment. The learners were asked to evaluate the positive and negative experiences and aspects. The feedback guidance was formulated openly and broadly, as on the one hand new hypotheses and theories were to be developed based on feedback forms. On the other hand, precise guiding questions were omitted in order to reduce the risk of students answering as they think teachers would like them to. We were able to achieve a complete survey of all students, which provided 110 feedback forms. First, feedback forms were fully transcribed and openly coded. This led to 30 codes. The comparison of the codes and corresponding transcript passages led to four new codes with an added level of abstraction. The new codes were then mutually examined, axially coded and a synthesis of findings was produced. This led to two central concepts described below according to our research interests.

Results

In the following paragraphs, the two central concepts mentioned above are explained in more detail. The inserted quotations of the learners were translated by us, the authors.

Working together and in groups

The feedback from students shows that they found it positive when learning products were created together and when different tasks could be solved as a group. Learners also appreciated that mathematical knowledge was created collaboratively and that they could support each other in this creative process. Here, certain students also took on the role of coaches, which reduced the time taken to receive help, and was emphasized positively by the learners.

Student: I found it a very good and useful opportunity to teach and support other students. It was all positive. When there was a question, immediate help was given.

Student: It was good to work on topics together and to discuss and debate these topics together.

It was also noted that working with friends was always fun and enjoyable. Moreover, this had a positive effect on the motivation of the learners and led to the mathematics class turning into a more positive place compared to teacher-centred lessons.

Student: By creating the mind map [on the blackboard, concerning a catenary] together, the lesson became funnier and the math was treated in more detail.

In this context, it was important for the students to be involved in the formation process of the groups and to be able to decide which students would form a group. Furthermore, the learners emphasized that it is just as important to be able to work individually (temporarily) in such a setting.

Student: I liked it because we could also work alone.

Active and self-directed learning process

Feedback from learners demonstrates that it was positively received that students themselves could choose the approach and how to tackle a problem. They highlighted that it was exciting to be able to work out a problem and that the answer is not immediately given.

Student: I think it was a good exercise, because you learn to work independently and try to find a solution on your own.

Furthermore, data from the feedback forms show that students liked the speed and intensity of learning as well as the focus of the learning process being chosen by the students themselves. This also means that the learners liked that some of the places of learning could be chosen by them and that the lessons could therefore be better adapted to their needs.

Student: [...] that we actually built the bridge was great and that we had lessons in roof rooms was also great.

Student: [...] I liked it [flipped learning], because everyone could work at their own pace.

In their feedback on the teaching sequence the learners commented that it was perceived as helpful that they themselves could switch between the real world with real problems and mathematical concepts. In line with student feedback, this made it possible to improve the idea of mathematical concepts and to make the significance of mathematics easier to grasp.

Student: It wasn't just numbers, we built the bridge ourselves and the real meaning behind the calculations was better understood this way.

Discussion and further considerations

This section will discuss the findings and contributions and attempt to establish a connection to current literature as well as to school practice. According to sub-codes, further considerations are made in the conclusion, not only regarding isolated and/or non-cumulative feedbacks from learners, but also missing feedback on certain topics.

Working and learning in groups

Since an FLA is characterised by students working in groups and thus exploring the subject matter, it is not surprising that this classroom mode was preferred by students. But it is still rare that mathematics lessons are taught in groups. This applies both to academic discourse and to everyday school practice. Only a few authors (e.g. Bell & Pape, 2012 or Lee & Johnston-Wilder, 2013) have dealt with group work in mathematics lessons. Future research on mathematics education, especially on linking mathematics education and an FLA, should also look at how group work can be integrated into this synthesis and which framework is important here. In this context, on the one hand, it would be important to investigate how mathematics can be learned in a flipped scenario, and, on the other hand, how learning outcomes achieved in FLA mathematics education can be both secured by students and assessed by teachers. This is because it could be shown that learning actions which are not graded are considered meaningless by pupils and their parents (Häcker, 2011).

Nevertheless, some feedback from learners and literature (e.g. Harkness & Stallworth, 2013) demonstrates that there are students who (also) prefer to work on their own. When group work is integrated into flipped mathematics, it is of paramount importance that these learners are not forgotten. Hence, it would be necessary to expand the students' learning space and options.

Active and self-directed learning process

The feedback data show that students perceived it positively that active learning was possible and that a learning path could be co-determined by them. Already Leonard et al. (2014) demonstrated in this context that different learners have different interests. If the interests of pupils are at the centre of the learning process, it increases the probability that active and sustainable learning takes place and that the pupils strive to plan their own learning path. For the purpose of creating a learning environment in which the interests of the students dominate and are therefore often self-directed, some basic conditions must be provided. One possibility is that the teacher offers a wide range of tasks from which students themselves can choose. Another possibility would be for tasks to be designed in such a way that they can be modified by learners. The fact that these tasks are present in a self-directed learning process is therefore important, since only then can one count on the fact that learners seriously attempt to solve a problem. This puzzling is necessary to achieve sustainable learning and consequently a better understanding of mathematics among students.

In contrast, the feedback data also revealed that there are students who struggle with taking control of their learning process. With regard to this, the learners mentioned that they missed structure in the teaching units and that a lack of structure hindered their learning process. As a result, a balance between freely selectable tasks as well as a given structure will have to be struck so that the majority of students can benefit from a pupil-active and self-directed learning environment.

Further considerations and conspicuous features

Although modern technologies were of central importance in our teaching experiments and learners made intensive use of them, working with technologies was rarely addressed in the feedback forms. On the one hand, this could be a consequence of the fact that it is not new for students that

technologies are used in the learning process. On the other hand, it is very probable that modern technologies are an integral part of the everyday lives of young people in the 21st century and it is therefore not worth mentioning to learners that these technologies are also used in school contexts.

With relations to the desire for a possibility of individual work, some students also addressed discipline and collegiality in the teaching experiment. For this purpose, future research should identify relationships between freedom and discipline that is conducive to the well-being of most learners.

For some students, time management in the teaching experiment was as challenging as its structure. It can be concluded that some students have a high need for such meta-competencies. Future research will also need to examine how learners can be supported in a flipped learning setting so that these skills can be acquired.

Conclusions and further research

The research data indicate that for students it is more important how mathematics is learned according to an FLA than which tools are used and how complex the learning content is in such a setting. From this we conclude that it might be most critical for students to be able to determine their learning paths as well as goals, and to set their own priorities in education. It was surprising to us that neither technology-enhanced learning environments nor tackled content, which was sometimes challenging for students, were stressed. This is particularly true of the content, because certain mathematical concepts are not covered in the curriculum until later (limiting value and complex numbers) or are not included in the secondary curriculum (catenary and hyperbolic cosine).

For learning mathematics according to an FLA, our research has drawn that the amount of direct instruction could be reduced in the individual learning space. Instructions could either be offered just in time, or students could acquire new learning content in a constructivist way. Here, it could be significant, both in an individual and in a group learning space, that a teacher is available to pupils as a guide if pupils learn mathematics in a self-determined way according to an FLA.

Since the research corpus for learning mathematics following an FLA is still weak and undifferentiated from an FCA, this paper could help to initiate further research in this direction. Here, it would be important that characteristics of an FLA (FLN, 2014) are taken into account and that further mathematics education FLA research is clearly distinguished from respective FCA research.

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