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Thesis of the PhD dissertation

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Developing students' knowledge using a novel approach in a mathematics course's program, from an adult education aspect

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1 Introduction

„In the field of education, everything seems to work."
(Hattie, 2008, p. 1)

The provocative statement above by John Hattie, the world-famous New Zealand researcher of education, seemingly questions the sense of researching the efficiency of education. Among others, his research showed that almost any interference or innovation in education may have a positive effect on students' learning outcomes. His research also extended to finding the variables that generate the biggest change, and which may receive a lot of research attention, but objectively have a less significant effect. In his book "Visible Learning" (2008) he performed a meta-analysis on 800 meta-analyses, based on a total of 50,000 studies, collectively involving more than 80 million students.

We talk about "*visible learning* and *teaching*" when the explicit goal is learning; if it poses the right challenges; if both the teacher and student are interested in whether they reached their goal and to what extent; if teacher and student respectively provide feedback to one another; if those participating in education are active and committed participants in the process (Hattie, 2008; 2012). To what extend does this apply to students learning mathematics in higher education, and their teachers?

My research was aimed at establishing how Hattie's "*visible learning and teaching*" concept is carried out at Széchenyi István University, considering that higher education involves teaching adult students. I am making an effort to put the findings of this study into practice during my work at the University.

Achieving and identifying "visible learning" is not difficult in the case of the most talented students. For less talented ones, however, learning is often not an optimal challenge, but rather an unattainable goal, which may lead to a decline in the commitment towards, and active participation in, learning. Bringing a positive change in this attitude is a basic goal for every committed teacher. The famous saying by the Izraeli teacher of mathematics didactics Michal Yerushalmy (Ambrus, 2003), namely

„I am a teacher of the 90%!"

indicates that talented students constitute a small slice (approx. 10%) of the student body, which leaves a lot of work to be done to achieve "visible learning". In line with Yerushalmy's credo, the purpose of my research is to learn about the learning qualities of engineering students in higher education as related to mathematics education, with a special focus on weaker students in danger of dropping out.

Many of the above mentioned 90% of engineering students in higher education are in danger of dropping out, and dropout rates may ultimately reach as much as 35 to 50% of all students. Even though, as higher education became more masslike, dropping out became common as far back as the 1960's, to this day it poses a challenge both for higher education institutions, and for teachers trying to cope "in the trenches". Dropping out is a multi-causal phenomenon, and the many reasons behind it have to do with the individual features, social background (socio-cultural and socio-economic factors) of students on the one hand, and institutional elements on the other. According to Prensky (2001), we should not deal with fact of the lowered quality of education, but the underlying reasons. It seems that students have changed radically, and there are socialisation differences behind their changing preferences. At present, public education involves Generations Z and Alfa, while higher education exclusively deals with Generation Z. They are digital natives, and they expect education to handle their needs accordingly.

I used the list of factors influencing the effectiveness of education by Hattie to determine the course of my research. Since, as stated above, there are many factors influencing the successful completion of mathematics classes, I involved several factors in the study, using a multi-perspective approach, which resulted in four focal areas of research: 1) self-efficacy and self-assessment; 2) learning approaches; 3) mathematical visualisation; and 4) achieving active learning in the course. Although these choices may seem arbitrary and restrictive, based on experiences from nearly 10 years of teaching and research at the Széchenyi István University, professional discourse with my colleagues and limitations on the scope of the research, I consider these factors most critical for the efficient learning of mathematics as well as the successful completion of courses, i.e. preventing drop-out.

Thus, in my research, I examined the variables mentioned above affecting the efficiency and drop-out rates in the context of mass education at the Széchenyi István University, as a function of the characteristics of the students in a mathematics course, taking into account the learning preferences of the adult Generation Z. I have been looking for innovative solutions in my teaching in order to mitigate dropout. I was focusing firstly on innovative educational thinking based on social constructivist epistemology, and secondly on innovative teaching methods (Fazekas et al., 2021; Zhu et al., 2013). I interpret learning mathematics as a transformation of personality, the basis of which may be detected in transformative epistemology founded on social constructivism. Building on this, as well as the learning outcome based approach introduced in higher education, I used the phases of the “hero’s journey” as defined by Joseph Campbell (1993), to design a narrative-based mathematics course, which is a completely new approach in Hungary. The process of “becoming a hero” is inseparable from learning methods that require active participation, whose investigation was also part of the research. In addition to active learning, putting an emphasis on visual learning methods, involving digital technologies in the learning process, taking intrapersonal learning into account, and frequent evaluation and feedback received special attention amongst the learning preferences of Generation Z.

2 The international and domestic context of the topic

With the explosion of technology inventions in the 21st century, we are in the fourth generation of industrial revolutions, which would not be possible without a significant investment into human knowledge. Education systems that support the human resources development necessary for the industrial revolutions, themselves go through revolutions, too, albeit at a slower pace. At present, smart tools and internet capabilities provide the basis for “Education 3.0”, leading the way into the fourth educational revolution, which will involve individualised learning based on human-computer interaction. Evolution is also ongoing in higher education, the pinnacle of the education system. Currently, Hungary is moving away from the Humboldt-type University Model towards entrepreneurial universities (University 3.0). Due to the economic and social changes brought about by technological innovation, the population’s general level of education is increasing, and more and more people participate in formal education. This brought changes especially in higher education and lifelong learning.

Transforming higher education into mass instruction posed new challenges for the operation, administration, maintenance, curriculum regulations, student opportunities, motivation, and the instruction process in higher education. Along with mass education, significant dropout rates also appeared in higher education. Many approaches emerged for the determination and operationalisation of the term dropout. There is no consistent practice, and thus research results are often incomparable. The fact that the medium term education policy published in 2016, titled "Fokozatváltás a felsőoktatásban" (Changing gears in higher education) specifically addresses this topic shows the significance of the problem. Statistical data shows that dropout rates are 36-38%, 14-17%, and around 50% in bachelor's, master and PhD level education, respectively (Derényi, 2015; Pusztai, 2018). This rate very much depends on the type of academic program, and especially high in case of agricultural, technical, IT and medical fields. When looking at dropout intensity against year of education, it seems that it is highest in the freshmen year (Miskolczi et al., 2018; Brunsden et al., 2000), and it occurs more frequently in even numbered semesters (Stéger, 2015).

For my research it is relevant if failure to pass the mathematics course may be a factor in freshmen-year dropout. The Study and Examination Regulations (SER) of the Széchenyi István University lists the cases for the termination of student status. There are 16 cases in the regulation related to dropout. I have performed secondary research (document analysis) on the data stored in the Higher Education Information System for full-time BSc students admitted to the university in the regular entrance procedure in the last five years. I examined student status termination cases recorded in the SER that may be related to mathematics studies. Data show that in the vast majority of cases, dropout is caused by bachelor's students not collecting at least 30 credit points by the end of the second active semester of their studies. Due to curriculum changes starting from the academic year 2017/2018, completing Mathematics 1 and Mathematics 2 is worth 5 credits each, rather than 4 points earlier. This increased the importance of completing these courses in the first two semesters, as well as the danger of dropping out. Data shows that only 10% of students who did not obtain the required minimum of 30 credits completed at least one of the mathematics courses, while 50% of students who did not acquire the requisite 60 credits by the end of the second semester did not complete any mathematics courses in the first two years. *All of this data confirms the significant role of Mathematics 1 in dropout intensity, which motivates me to innovate in order to decrease dropout rates.*

3 Transformative learning in higher education

Another potential cause for dropout may be the pedagogical-andragogical methodological competence of teachers (OECD, 2012; Bocsi et al., 2018; Bocsi et al., 2019). These should be continuously adapted to the learning characteristics of the generation that is in higher education. Since a new generation of different values, thinking, needs, technical, cultural and socio-cultural backgrounds replaces the old one approx. every 10 to 20 years, each educator will teach at least three, drastically different generations, and knowledge of the features of these generation should be the basis of his or her professional renewal. Right now, Generation Z is present in higher education, and taking their learning preferences into account is indispensable for teachers. These preferences include the following:

1. Preference for visual learning methods,
2. Classes tailored to short attention span,
3. Involving online learning and digital technologies in the learning process,
4. Taking intrapersonal learning into account,
5. Facilitating networking, providing instantly applicable knowledge,
6. The integration of active learning and problem-based learning
7. Frequent evaluation and feedback,
8. Personal communication.

Young people level up into higher education while they transition from youth to adulthood. This time is characterised by intensive mental, spiritual, and physical transition in their lives. The transformative learning model (Feketéné Szakos, 2014; Mezirow, 2000; Somogyiné Petik, 2010) provides a conceptual framework for these processes. Transformative learning, being an internal process, cannot be taught directly. The educator may facilitate it through optimizing the learning environment, learning situations and processes as well as the content and the instruction method (Illeris, 2015). It may be supported by teaching methods that promote group discussion, the critical analysis and utilisation of others' experiences, as well as forming individual opinions. Thus, learning is not limited to accepting objective reality, but a meaning attribution process that is not passive, but requires active participation. Through all of these, the transformative learning model interlaces with active learning and social constructivist epistemology, and supports the realization of "visible learning".

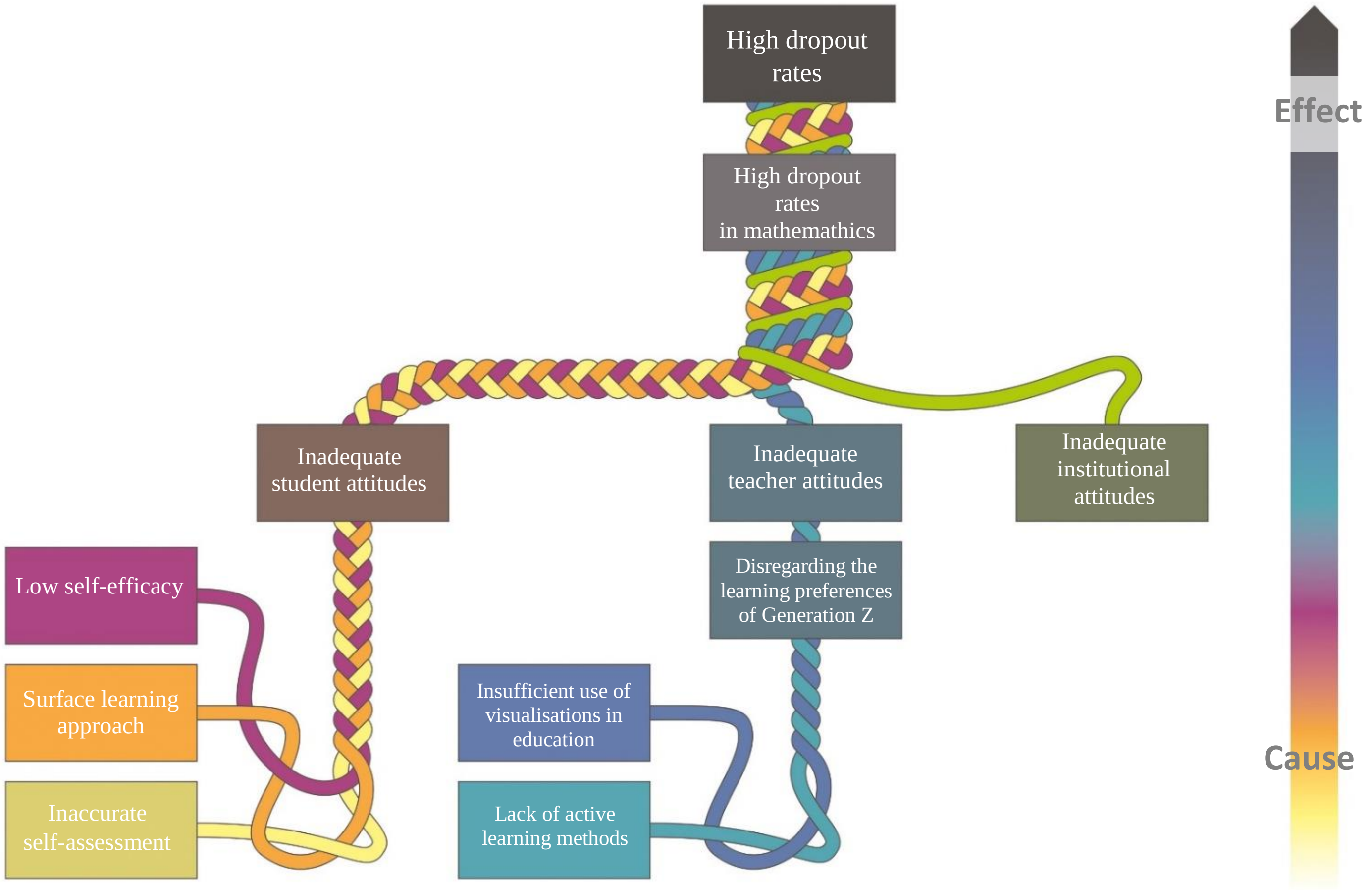
The higher education revolution generated by technological innovation, the appearance of new generations in higher education, and the transversal skills required by the industry necessitate the rethinking of quality criteria in higher education. Defining course outcome requirements in terms of well-defined learning outcome categories improves the quality of training programs and the efficacy of learning and teaching. The *learning outcome based course description* that I developed for *Mathematics 1* provides a general framework, which also offers a high degree of freedom for the educator in terms of training methods. To achieve the goals defined in this course description, I designed the course so that the research is based on using a narrative approach that goes back to the "hero's journey", the monomyth of Joseph Campbell (1993) and Christopher Vogler (1998). The "hero's journey" has a 12-stage structure where the hero, starting from the everyday world, goes through a special realm to get back to the mundane (meeting allies and a mentor along the way, going through a series of tests, and participating in a final trial to "return with the elixir"). The way is strewn with many obstacles that produce physical, spiritual and mental transformation. All of this matches the transformative learning approach of the social constructivist epistemology mentioned before (Jarvis, 2006; Mezirow, 2000). Using the narrative approach of the "hero's journey", Farmer (2019) created a 12-step framework for designing college courses, where the 12 stages of the course is modelled after the 12 steps of the hero's journey. I designed the student-oriented, active learning-based list of course activities to be used in teaching Mathematics 1 with regard to the *hero's journey based course design* methodology created by Farmer (2019), as a supplement to the course description. In this, I experimented with a method hitherto unknown in Hungary, but likely to be attractive to young engineering student who grew up watching action movies.

Higher education curricula, learning outcome based course descriptions and courses based on the "hero's journey" may reach their goal only if their application allows flexible changes and adaptation to changing circumstances. Recent events emphasized the importance of this, as the appearance of the COVID-19 pandemic resulted in the inevitable rethinking of the world's education systems. Although the primary goals of my research were not aimed at investigating the education under the pandemic, as a researcher I cannot ignore the new situation. While keeping the original focus, I placed my research in a new context, to reflect on the new state of affairs. Thus, part of my dissertation will be one of the documents created during COVID-19 regarding the higher education in the pandemic, thereby answering UNESCO's (2020) call for the intensive documentation of the pandemic situation.

4 Key factors in the mathematics course affecting dropout – research problem tree

From a learning point of view, the high dropout rate in engineering programs may be examined in terms of course accomplishment. In my research, I looked at the students' performance within a mathematics class's program. High failure rate is a general tendency of basic mathematics classes at the university, which is related to unsatisfactory attitudes by students, teachers and institutions. Of these aspects, I focused on human factors, i.e. student and teacher issues. In my experience, low performance in mathematics is probably related to low self-esteem and using surface learning approach by the students, and education methods that ignore the learning preferences of Generation Z on the teachers' side. The problem tree that served as the basis of my research shows the cause-and-effect relationships of these problems (Figure 1).

Figure 1: Research problem tree



Looking at the institutional steps taken at Széchenyi István University for dropout reduction (Benyák, 2021; Benyák and Fehér, 2019; Horváth, 2019) two important variables are clearly missing from the strategy created for change: the person of the student and that of the teacher in the context of learning. It appears that there is no consideration given to

- what happens in the classroom, what is the interaction between student and teacher?
- What previous experience and knowledge do *students* possess?
- How do they regard themselves as students?
- Do they consider themselves capable to reach a given learning goal?
- Where does their motivation come from?
- How do they evaluate their own performance?
- What efforts do they expand in order to learn?
- What learning approach do they employ?

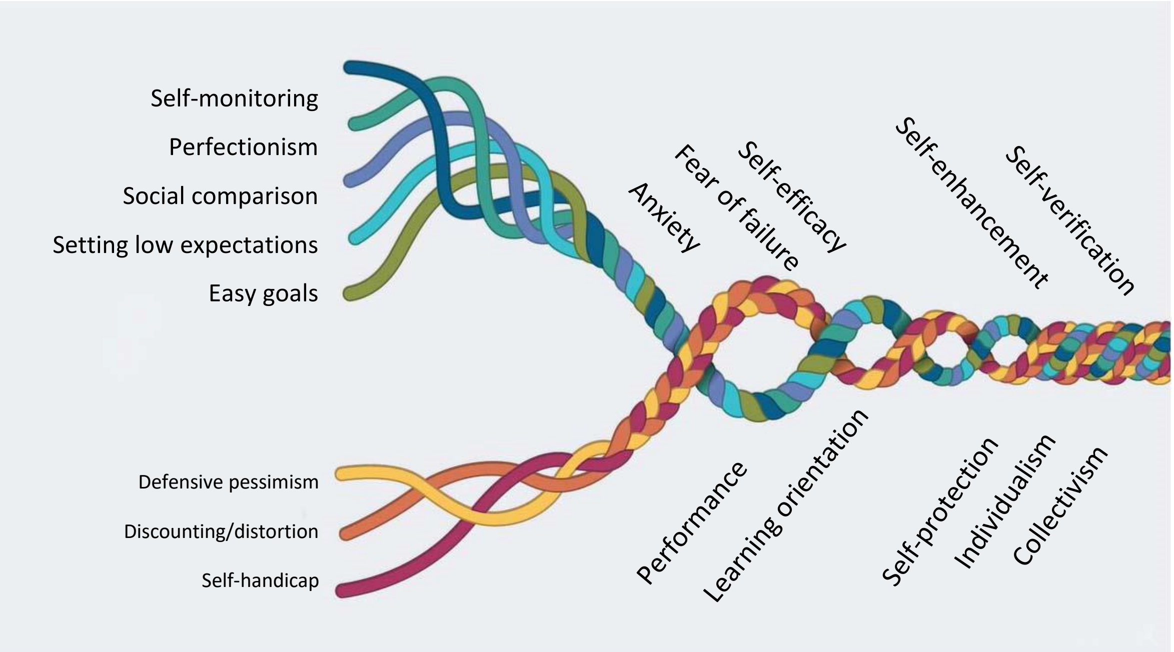
- What pedagogical attitudes do *teachers* employ during education?
- In what way do they organise classes, what methods do they use to build knowledge in students?
- What measurement and evaluation tools do they employ to assess the knowledge, skills and attitudes in students?
- What learning support tools do they create and use?
- In what way do they try to learn and understand the features of the given age group (generation), their learning preferences, and how do they incorporate these during their everyday work?

My research attempted to answer some of these questions, to supplement the steps taken to reduce dropout at the Széchenyi István University. As Hattie (2012, p. 159) puts it, as teachers, *„We are change agents"*. Since dropout is best handled using a multidimensional approach, this is how my research was structured. Using a comprehensive approach, I am investigating the micro level (individual) and macro level (teacher and institution) causes behind dropout simultaneously.

4.1 The role of self-concept and self-efficacy

Many theories have been created to define self-concept. Most of these agree that it is a system made up of several representations. In most of the models, there is a hierarchy of the various elements, but Hattie (2004) created a horizontal model, the rope model of self-concept. The primary threads of self-concept work through various motives, while secondary threads operate through situation-dependent orientations and dispositions. Tertiary threads relate to motivation through special, situation-dependent strategies (Figure 2). Self-efficacy is one of the first 20 most influential factors of student performance amongst the secondary threads in Hattie's list. He determined self-efficacy's level of influence to be 0.71 (while he established the lowest limit, above which a given factor is worth looking at, to be 0.4). This fact shows that this factor is worth examining when investigating dropout.

Figure 2: Hattie's Rope Model of Self-Concept (own edit)



Self-efficacy is people's opinion regarding their own abilities to attain a given goal. Bandura (1977) identified four information sources that control our actions through our self-efficacy convictions:

a) mastery experiences,
b) vicarious experiences,
c) verbal persuasion,
d) physiological and emotional state.

Of these, mastery experiences are most influential. Subsequent research added one more information source, namely, imagination experiences, to Bandura's list. Self-efficacy may be measured in many areas of life, and, accordingly, questionnaires may refer to general, academic and professional self-efficacy. Studying self-efficacy is investigated both comprehensively across classes, and regarding specific classes as well. PISA tests regularly measure natural sciences and mathematics self-efficacy (OECD, 2004; 2013; 2015; 2016; 2018; 2019, 2020). During the COVID-19 pandemic, resiliency (flexible adaptation) plays an important role in adapting to changing circumstances, and it shows a significant correlation to many factors, including self-efficacy. (Beale, 2020; Blanco et al., 2020; D'Alise, 2020; Estira, 2020; Martin and Marsh, 2009). The pandemic period offered a chance for students to learn about themselves in new situations, which necessitates reflective thinking. Self-efficacy requires a realistic and positive self-concept, which becomes uncertain without real self-awareness and self-esteem (Sziválk, 2014).

4.2 The learning approaches of students

Among the secondary threads of self-concept, Marton and Säljö (1976) determined two levels of information processing in the qualitative approach of learning: deep and surface approaches, which may both contain motives and strategic elements. Students that regard learning as an active process focus on understanding and contextualising the knowledge to be acquired, while students that regard learning as a reproductive process think the key is memorisation and mechanical practice.

Although later they identified a third mode of processing (strategic approach) this dichotomy appears a better fitting model.

4.3 Learning and visualization

Failures to pass courses play an important role in forced dropout. Teachers can influence this greatly by taking the learning preferences of Generation Z into account. In our digital age, much of the information is transferred through digital stimuli. Thus, today's generation arrive into higher education with an intensified need for visual stimuli (Prensky, 2001; Benedek, 2017). The nature of mathematics is not foreign to visuality; visualizations may be used in all areas (Nyíri, 2013). Guzmán's (2002) visual typology provides four classes depending on the strength of relationship between mathematical objects and visual appearance of them, the level of abstraction:

1. isomorphic visualization,
2. homeomorphic visualization,
3. analogical visualization,
4. diagrammatic visualization.

Research showed that Generation Z engineering students, as well as engineers, studied in a workplace environment have a visual learning style (James-Gordon et al., 2001; Jermyn, 2018; Hill et al., 2016; Kadocsa, 2018; Othman, 2019; Rothman, 2016), which places an even higher burden on the education system to build on this attribute in terms of courses and academic curricula. Based on this, I created *a matrix to present and organise the possible ways of presentation and explanatory visualization* related to knowledge and skill elements, to compliment the learning outcome-based mathematics syllabus.

Textbooks should reflect Generation Z engineering students' need for visuality. Based on the results of international textbook research, textbooks should meet the needs in three areas: scientific standards, didactical standards and preferred topics and aspects (Fischerné Dárdai, 2002). One of the didactics standards is striving for visuality, which consists of the following: the books' pictorial rhetoric should take students' changed visual culture and customs into account; in line with preferred topics and aspects, pictures should not telegraph stereotypes or prejudices. One of the recommendations is that illustrations and pictures should make up 30-50% of the page. It may seem high at first glance, but in our digital age visual dominance is present in all areas of life. This should not be different in education or writing textbooks, either. Another important aspect is that pictures should not be used as mere decoration, but should aid the understanding of the topic, deepening knowledge, exploring connections, and, last but not least, arousing interest and maintaining motivation (Fischerné Dárdai, 2000).

4.4 Active learning

Among the learning preferences of Generation Z, in addition to a tendency for visuality, we focused on active learning methods. There are two approaches to active learning in the context of 21st century interpretations of learning. One says the activeness of learning consists in the student's own decision concerning the process of learning and the aspects of learning (e.g. the active use and preparation of materials, cooperating with others, etc.). The other interpretation is related to mental activity, and describes the degree thereof; to what extent do students find using their mental capabilities challenging while learning. The latter approach is related to constructivist epistemology, where learning is a constructive process, and the student constructs knowledge actively, rather than receiving passively (D. Molnár, 2010, Feketéné Szakos, 2014; Gaskó, 2009; Nahalka, 2006).

Practices that support active learning are built into an increasing number of engineering education programs, based on recommendations by professional associations (e.g. European Society for Engineering Education – SEFI and Active Learning in Engineering Education – ALE network), political organisations (e.g. UNESCO), as well as national and international accreditation bodies. Thus, more and more research deals with active learning in engineer education.

5 Empirical research within the program of a mathematics course at Széchenyi István University

The location of my research is Széchenyi István University, a principal center of technical education in Hungary for over 50 years. Students in the technical fields at the university complete three interrelated basic mathematics courses during their bachelor's training, regardless of academic program. In the first semester, they learn Mathematics 1, which is aimed at learning about vector geometry, complex numbers, calculus (limits, derivatives and integrals), extensively building on high school knowledge. Typically, more than a thousand new students arrive at the University in the normal, September semester, joined by students repeating the course due to their unsuccessful course completion in earlier semesters. Due to the large attendance, four parallel courses are taught by several teachers. I did my research in the fall semester of 2019/2020, with the students I taught in Mathematics 1. The framework of the research was performing the activities list I created using the "hero's journey" based course planning during the course. I followed the students' progress in the role of the mentor to the heroes, and documented many aspects of it as a researcher (participatory research).

I used both deductive and inductive paths to set up questions and hypotheses, since I created some of them based on my own practical experiences, while some of them were based on the analysis of literature and other documents.

I created the following main sub-hypotheses in connection with the four research directions:

Research topic #1 (Relationships of self-efficacy, learning approaches and performance):	
1/H1	Mathematics learning by the examined students is characterised by surface, rather than deep approach.
1/H2	The mathematics self-efficacy of the participating students is primarily characterised by negative mastery experiences and, in terms of physiological and emotional state, high stress levels.
1/H3	Deep approach and positive mastery experiences increase, while surface approach and negative physiological and emotional states decrease the chances of fulfilling mid-term requirements and successfully completing the exam.
1/H4	The surface approach is typical of students taking the class repeatedly, while the deep approach is typical of those taking it for the first time.
1/SH1	The more positive the mastery experiences of students, the better students do in midterm tests.
1/SH2	The more surface the approach in learning mathematics, the worse students do in midterm tests.

1/SH3	The more deep the approach in learning mathematics, the better students do in midterm tests.

The sudden transition from attendance to remote education brought much uncertainty both for teachers and students. The drastic change in the learning environment may affect students' confidence in their own abilities, as well as studying self-efficacy, which called for creating the following, additional sub-hypothesis:

1/SH4	Mathematics learning by students examined during remote education is primarily characterised by negative mastery experiences and negative physiological and emotional states.

Research topic #2 (Investigating mathematical visualisation in the context of the learning preferences of Generation Z):	
2/H1	According to the responses of students participating in the research, visualisation supports their learning highly.
2/H2	The amount of visual illustrations per page in the Hungarian higher education mathematics textbooks I looked at falls below the requisite 30 to 50 %.

Research topic #3 (Investigating the presence of active learning in the context of the learning preferences of Generation Z):	
3/H1	Responding students do not encounter many situations that require active learning in the 1^{st} semester at the examined university.
3/H2	Generation Z engineering student participating in the study highly prefer learning methods that involve digital technologies.

Research topic #4 (Analysing midterm tests and exam results in terms of self-assessment):	
4/H1	Responding students are generally characterised by overestimating their mathematics performance.
4/H2	Students performing better on midterm tests evaluate their own performance more accurately than those performing poorly.
4/H3	There is a difference between repeat and first time takers of the course in terms of the accuracy of self-assessment; repeat students evaluate their performance less accurately than first time students.
4/H4	Students who had a chance to look at their first midterm test have more accurate self-assessment at the time of the second midterm, compared to those who did not avail themselves of this opportunity.
4/H5	The accuracy of students' self-assessment regarding their mathematics performance improves as the semester proceeds.
4/SH1	The more deep the approach students are striving for, and the less they prefer surface approach, the more accurate their self-assessment.
4/SH2	The more positive their mastery experiences, and the more positive their physiological and emotional state, the more accurate their self-assessment.
4/SH3	The self-assessment of students who make inattention mistakes is less accurate than those who do not make such mistakes during the midterm tests.

5.1 Data collection methods employed during research

My research was an exploratory research that included both qualitative and quantitative elements.

Students could complete three questionnaires throughout the term of the fall semester 2019/2020, with an additional one during the exams for those who fulfilled midterm requirements. Additionally, students also completed a questionnaire concerning remote education.

The first and second questionnaires contain five thematic units (Figures 3 and 4).

Figure 3: The structure of the first questionnaire

I. Demographics questions
II. General questions about education
III. Questions concerning preparation and preparedness for midterm tests
IV. Methods supporting active learning
V. Learning approaches

Figure 4: The structure of the second questionnaire

I. General questions about education
II. Questions concerning preparation and preparedness for midterms
III. Methods supporting active learning
IV. Visualisation
V. Self-efficacy

The third questionnaire was administered to students writing make-up tests, and contained questions concerning motivation, preparation and preparedness for the make-up midterm test. The questionnaire administered before the exam enquired about preparedness in terms of a list of 30 mathematics knowledge items.

When investigating learning approaches, I used the internationally established R-SPQ-2F questionnaire, which has not been used in Hungary before. With its 20 items, it is considered short among learning approach questionnaires. It examines two learning approaches using a five point Likert scale: deep and surface. I adapted the statements of the original questionnaire to reflect the local education circumstances, opportunities, and the mathematics education of engineering students. The original statements examine the surface and deep learning approaches from a general, non-course-specific viewpoint. I rephrased the statements so that they all relate to the mathematics class.

The self-efficacy measuring questions that I compiled use the theoretical framework created by Bandura (1977). The four information sources do not affect the self-efficacy of a person to the same extent; mastery experiences are the most dominant (Bandura, 1977, Usher and Pajares, 2008). Taking this into account, I chose two information sources when compiling the questions: mastery experiences and physiological and emotional state. When wording the items, I created my own statements regarding the mathematics course, drawing from international literature.

Ongoing research was affected by the COVID-19 pandemic. A new questionnaire was created in the spring semester of 2019/2020, where the demographic questions were followed by ones related to remote education and online learning. The last questions concerned self-efficacy, which were compared to data in the previous semester.

In a questionnaire study we need to remember that data collection is indirect, i.e. we do not get direct information about the learning habits of students, but rather, what learning habits they assume that they have. This should be kept in mind especially when measuring investigating methods supporting active learning, visualisation, learning approaches and self-efficacy, and other techniques should be used to confirm the reliability of data (Falus, 2004). This was the purpose of the student workshop that was part of the study. Through various exercises, the workshop helped gather further information about students' learning preferences, their views on methods supporting active learning (positives, negatives, how they would improve them, what other methods they saw in other courses that they would want to see in the mathematics course), self-efficacy and their views on visualisation. In several topics, I conducted a group interview with students that also contained elements of a focus group interview during the workshop.

There is a wide range of textbooks, as well as books that have not been certified as official textbooks, but are used in practice, written by higher education staff available for students either in print or online. I performed a comparative textbook analysis using mathematics textbooks that were written for institutions of higher education. The comparative analysis of higher education textbooks is complicated by the fact that they are usually closely related to the profile of the particular university, its teaching staff and local course descriptions.

During the semester, we asked students to evaluate themselves concerning the topics they studied using a questionnaire, before all three midterm tests and the exam, and also after completing the midterm tests. In the latter case they evaluated their own performance regarding each exercise.

5.2 Sample characterisation

The sample of the research consisted of engineering students that took the Mathematics 1 course I taught in the first semester of 2019/2020 in the HEIS. This was not the students' choice, but rather that of the Office of Student Affairs, mostly decided based on the academic programme. According to the primary information available for teachers in HEIS, Mathematics 1 was taken by 1201 students, 85.6% of whom (1028 students) took it for the first time, and 14.4% (173) were repeat students. Since Mathematics 1 is a first semester (fall) course for engineering students, but it is available to take in every semester, the number of fall semester re-takers is lower compared to the spring semester.

According to primary information available in HEIS, of the 258 students taking my course, 70.3% (181 students) were first-timers, and 29.7% (77 students) have already taken Mathematics 1 at least once. A further breakdown of this primary data is possible by the secondary analysis of the students' education history. Data of some earlier studies was available for several new students, and, since we are talking about a first semester class, it is reasonable to assume that these students have already taken Mathematics 1 at least once. In such cases, repeated attempts are not indicated in HEIS for the new program, and the counter restarts at 1, despite earlier unsuccessful attempts. Taking this secondary data into account, in reality 60% of students (155 students) took the class for the first time, while 40% (103) were repeat students.

The majority, 69.8% of the students were mechanical engineering students. The rest was made up of students of eleven other academic programs.

In the various phases of research, I analysed a total of 902 questionnaires (with more than 70,000 data in total). Workshops provided mostly qualitative data from 44 students.

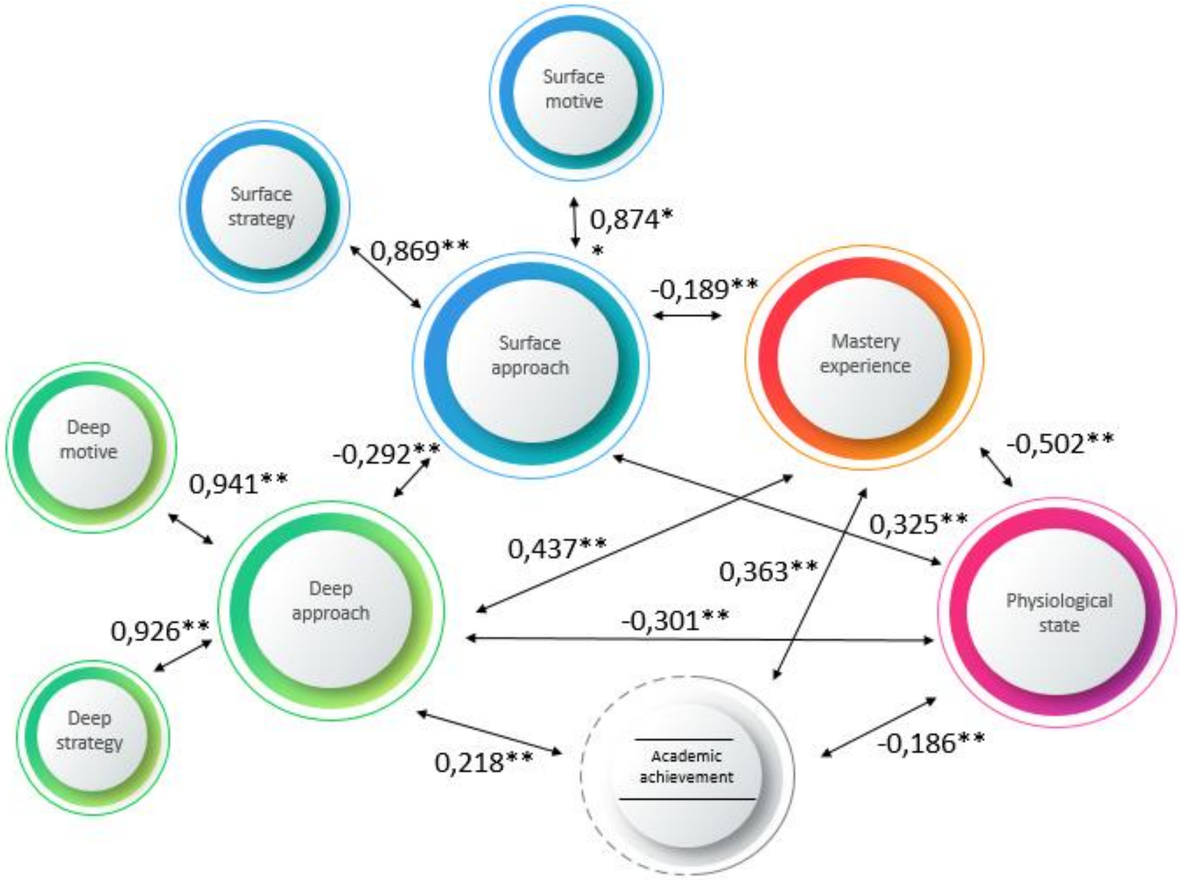
6 The results of the empirical research

6.1 Evaluating the relationships between self-efficacy, learning approaches and performance – results of Research topic #1

The first part of the research provided data concerning the mathematics self-efficacy of students and the learning approaches they used during their mathematics studies. Student self-concept information included several layers. One of these consists of how good they regard themselves at mathematics. Results shows that in high school they considered themselves significantly better at mathematics than in college. This was nuanced by the fact that there were significant differences between first time and repeat takers both in terms of their high school and college self-image concerning mathematics proficiency. Repeat takers of the course had more negative experiences already in high school compared to first timers, and this difference was further intensified in college. The second layer of self-concept had to do with self-efficacy ideas, which was informed by two sources, mastery experiences as well as physiological and emotional state. Nearly half (46.85%) of students had a high or very high score based on mastery experiences, while they had low scores regarding physiological and emotional state. This means that those who have a positive self-concept due to their earlier mathematics-related experiences and believe in their abilities experience less stress in situations related to mathematics. There is a significant correlation between the two different layers of self-concept; the better at mathematics students consider themselves at college, the better their mastery experiences and more positive their physiological and emotional states. Results show that nearly half of the engineering students (45.63%) have a moderate score for surface approach, and moderate to high score for deep approach. Overall, students evidently prefer the deep approach to the surface approach.

I performed correlation analysis for mapping the relationships between the variables. Figure 5 shows the correlations between mathematics self-efficacy (mastery experiences, physiological and emotional state) learning approaches (deep and surface approach) and the total score achieved in midterm tests. The relationships between all variables is significant with one exception: the correlation between the surface approach and total midterm score was the only insignificant one.

Figure 5: Relationships between learning approach, self-efficacy and performance in the midterm tests

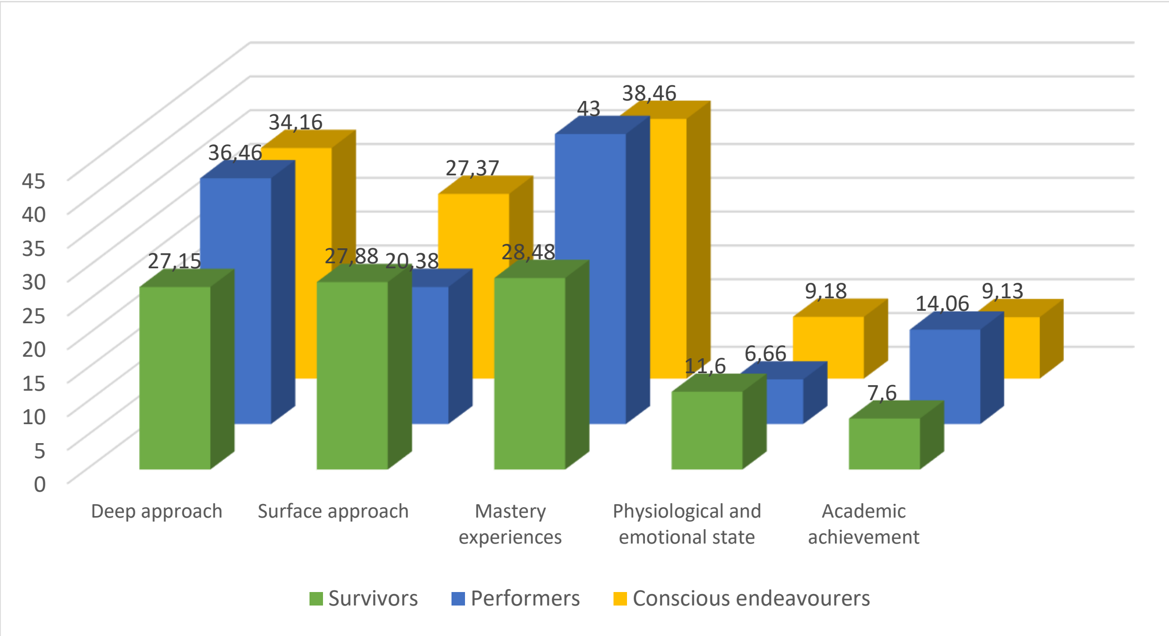


The relationship between the variables was still significant after controlling for the number of times student took the course. 14.9%, 9% and 3.7% of the variance in total midterm score was explained by mastery experiences, deep learning approach and physiological and emotional state, respectively. The fact that there were significant differences between repeat and first time takers of the course in terms of deep learning approach, mastery experiences, as well as physiological and emotional state shows the importance of repeating the course as a variable related to dropout. Repeat students have more negative mastery experiences, elevated stress levels, and strive less to study the material in a more deep, cognisant way. Using logistic regression, of all learning approaches and self-efficacy ideas, only mastery experiences were shown to significantly affect the chances of fulfilling mid-term requirements. Similarly, mastery experiences also significantly improve the chances of a successful exam.

The qualitative examination of students' self-efficacy has shown that, on the cognitive level, they have an accurate description of what (human and technical) resources they can mobilize for solving challenging mathematics exercises, which is usually accompanied by negative emotions. Despite the challenges, students tend to strive and persevere.

Based on learning approaches, the two sources of self-efficacy and performance on the midterm tests, student groups were formed. Of the hierarchical cluster analysis methods, the Ward-method was used for this. Based on the answers, students may be classified into three groups, which were named *Survivors*, *Performers* and *Conscious endeavourers*, based on their characteristics (Figure 6).

Figure 6: Student groups based on sources of learning approaches, self-efficacy, and midterm test results



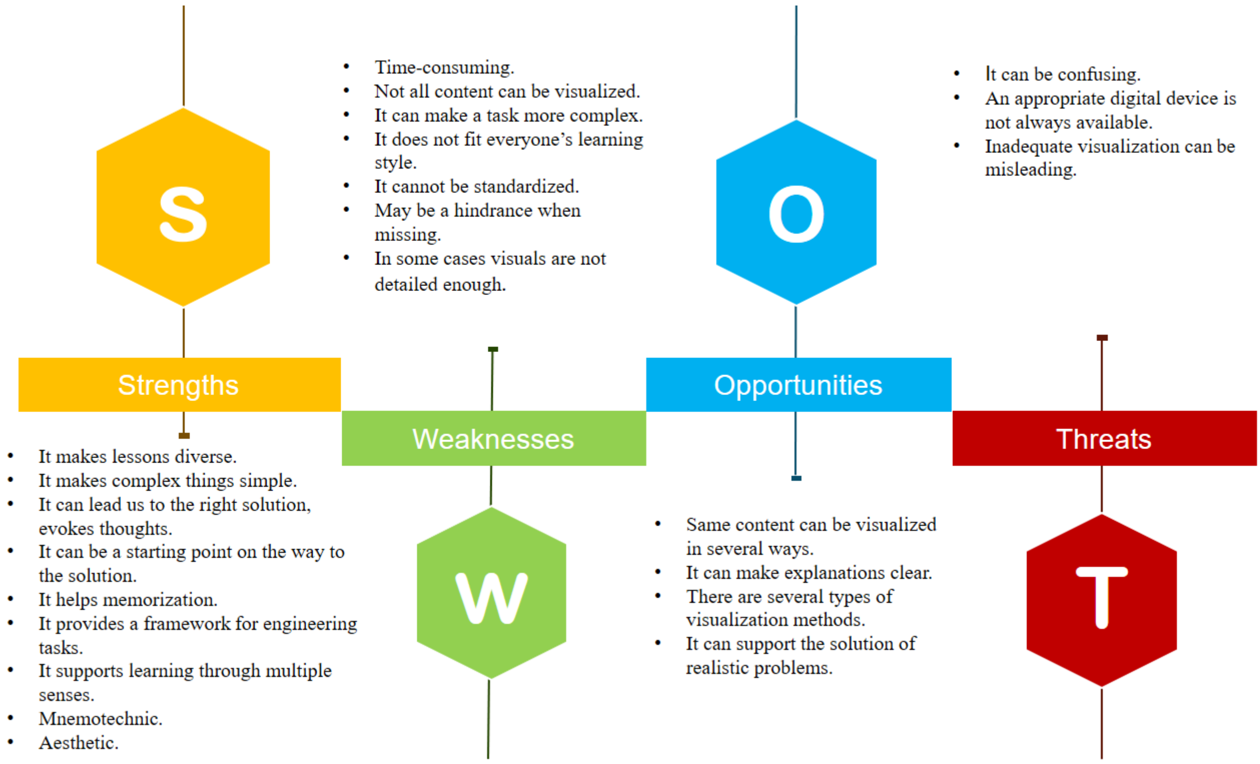
The COVID-19 pandemic has brought a drastic change in learning circumstances for students. Among these new circumstances, the self-efficacy of students showed a positive change. They had low stress levels and positive mastery experiences in the mathematics course, which may have been aided by the fast adaptation capabilities of the teachers, well-structured learning resources and well-defined requirements.

6.2 Investigating mathematical visualisation in the context of the learning preferences of Generation Z – results of Research topic #2

The second part of the research focused on learning through visual stimuli by Generation Z. Based on questionnaire data, students find the visualisation of mathematics exercises very useful, and it is important for them to have as much of it as possible in the mathematics learning aids. They mostly prefer exercises that have visualisation, and they think that this makes solving exercises much easier. Of the visual representations of mathematics reading materials, as well as other education-related information, students considered the direct visualization of mathematics reading materials most helpful in learning, followed by the visual appearance of the teacher's homepage, and the visualization of mathematics learning tips. In four cases, there were significant differences between the perceived usefulness of visual representation by students, based on how many lectures they attended. For those who regularly attended classes, visual support for the information was more helpful, because they regularly encountered this type of learning support technique.

During the workshop, a SWOT analysis was created based on students' experiences concerning their perception of strengths, weaknesses, opportunities and threats of using visualization in mathematics education (Figure 7). They classified most of the features listed as strengths and opportunities, which they justified by the fact that engineering students are visual type of learners. The students' answers clearly showed that figures, pictures, and illustrations initiate knowledge construction, which is related to constructivist epistemology.

Figure 7: The results of the SWOT analysis



In addition to visualisation in the classroom, lecture notes, textbooks and online reading materials also significantly support learning. The examination of the visual appearance of textbooks for engineering students involved in the study showed that the requisite 30 to 50 % of visual information per page is not present. Only little non-textual information is included. The number, quality, placement, diversity of figures, as well as the typography of the books fulfil the visual needs of our age only in part. Of Guzmán's types of visual typology, isomorphic visualisation, where the connection between the mathematical content and the figure is most direct, is most frequently present. Other visualisation types appear less and less frequently with the loosening of this connection, and in some textbooks they are altogether absent.

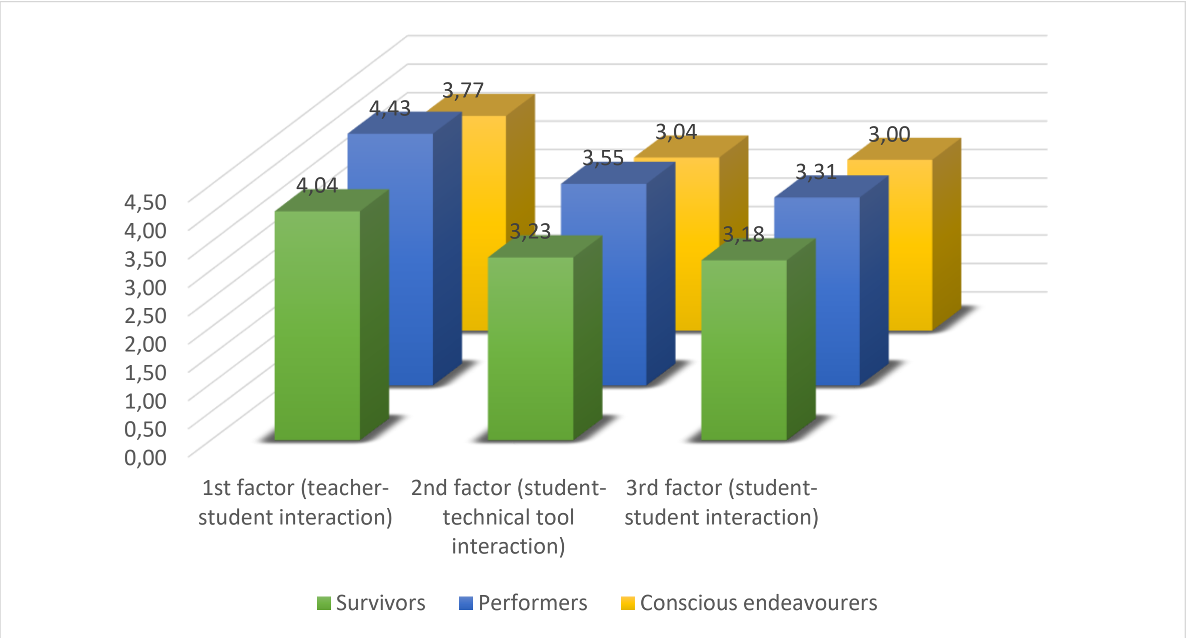
6.3 Investigating the presence of active learning in the context of the learning preferences of Generation Z – results of Research topic #3

Of the preferences of Generation Z, the third part of the research focused on education methods supporting active learning, and other methods preferred by the "Z'ers". Various methods support the learning preferences of Generation Z in different ways: taking intrapersonal learning into account, involving digital technologies in the learning process, active learning, frequent and rapid feedback. Of the classroom activities, students deemed targeted activities to prepare them for midterm tests most useful, i.e. solving a sample midterm test together, facilitated by the teacher, or writing and correcting a trial test. The special preference of methods promoting intrapersonal learning, which is typical of Generation Z, did not emerge based on the answers to the questionnaire, but in the group interview, students always stated that they needed to think individually during paired or group exercises before sharing their thoughts with others, i.e. they preferred paired and group exercises that fostered intrapersonal learning. Neither did students show a particular preference towards methods involving digital technology, mostly due to the fact that many (probably students who prefer intrapersonal learning) were unwilling to participate in group video creation exercises. They also lacked confidence in the correctness of the created videos' content, and preferred those created by the teacher instead. In case of the kahoot tests that also involve digital technology, the instant feedback was considered most valuable.

Students' experiences show that in the high school mathematics classes, as well as in other courses in higher education, the most frequently used method is solving individual exercises, collective exercises overseen by the teacher, and paired exercises. Since students were not used to such varied forms of classroom activities, many of them reported being alarmed by this in the college mathematics course. On the other hand, students with work experience confirmed that, in their experience, learning to cooperate with others and efficiently communicating about their professional knowledge is useful for them. Overall, students felt more motivated with these methods that built on their activity, compared to learning with more traditional methods.

Using factor analysis, the 15 types of learning support methods could be classified into three factors. One of these included methods where knowledge is mostly created through teacher-student interaction. In another, interaction between students is dominant, while a third one involves the dominance of another medium, i.e. technical tool. We analysed to what extent the identified methodological factors were typical of each of the three student groups (Survivors, Performers, Conscious endeavourers) identified in the first part of the research. Overall, every group preferred the methods based on teacher-student interaction the most, and all of the methods were found most useful by the Performers compared to the other two student groups (Figure 8).

Figure 8: Methods supporting active learning and other methods characteristic of each of the three student groups



6.4 Analysing midterm tests and exam results in terms of self-assessment – results of Research topic #4

Among the individual pedagogical and psychological causes related to learning, the fourth area of research dealt with self-assessment. The *bias* and *accuracy scores* calculated from the results of self-assessment following the midterm test and those of the actual tests provided the two measures to evaluate the accuracy of self-assessment. More than 80% of students overestimated their actual performance in all midterms, and this overestimation was moderate. Based on the relationship between accuracy scores and test results, students who achieved better results in the midterms gave more accurate self-assessments than those who performed poorly, which confirms the Dunning-Kruger effect in engineering education. The fact that there is a significant difference in the accuracy of self-assessment between students who fulfilled mid-term requirements and those who did not adds nuance to this picture. The self-assessments of the former was closer to the teacher's evaluation than those of the latter. A similar difference is evident between those who were successful at the exam and those who were not. This may be problematic because weaker students are less aware of their deficiencies due to their inaccurate self-assessment, and thus they may stop their preparation short of what is necessary, and may not ask for help when needed. Feedback based on their performance, i.e. the results of and mistakes made in the first midterm, may affect the accuracy of self-assessment. Feedback from the midterm caused a significant improvement in self-assessment for students who met mid-term requirements, while those who did not showed no such improvement. Thus, underperforming students did not benefit enough from the feedback from the first midterm, and the accuracy of their self-assessment did not improve. The opportunity to see the corrected test as further feedback offered another chance to improve self-assessment. Students who looked at their tests improved their self-assessment significantly by the time of the second midterm, i.e. the feedback was incorporated in their self-assessment. Self-assessment accuracy showed differences between first time and repeat students as well. First time takers of the course showed a more accurate self-assessment in each test, significantly so in terms of bias score. In addition to midterm results, exam results were also comparable to the self-assessment results given by the students for each exercise. In five of the seven exercises in the exam, student's preparedness score showed significant correlation with the actual score achieved in the exercise. This shows that the more confident students are in their ability to solve a particular type of exercise, the better they will perform in the given exercise.

When examining the relationship between self-assessment accuracy scores, the learning approaches examined earlier, and self-efficacy ideas, there were few close relationships found. There is a significant relationship between the bias score of the first midterm and the sources of self-efficacy, as well as between the accuracy score of the first midterm and the mastery experiences, i.e. the more positive mastery experiences and lower stress factors a student had in the first midterm, the more accurate the self-assessment proved to be. This relationship was no longer present at the time of the second midterm test.

Inattention errors made during the midterms may affect the accuracy of self-assessment, since committing them may be less noticeable during conscious self-assessment. In some exercises in the first midterm, inattention errors were especially frequent. Data show that students committing inattention errors have significantly more inaccurate self-assessments than those who did not make such errors.

7 Conclusions drawn from the entire research and future outlook

The research involved a consciously designed, but hitherto unknown path for students in mathematics education, which followed "*the path of becoming a hero*". The concept of the "hero's journey" provides a new kind of framework to aid transformative learning, as well as "visible learning". This novel approach may provide a step-by-step framework for designing a learning process that can be achieved as a result of purposeful design in the higher education system, or on nonformal learning platforms where studying is present as a well-defined unit, having a beginning and an end point.

Engineering students entering the higher education faced a new level of education, with new requirements and learning and teaching methods hitherto unknown to them. I guided them in this course as an educator, researcher and the mentor supporting the hero. Studying advanced mathematics is a transformation for students on the cognitive, emotional and determination levels. Following this path was aided by the fact that some of the learning preferences of Generation Z received special attention in creating the learning environment, like emphasizing visual learning, involving digital technologies in the learning process, taking intrapersonal learning into account and building on active learning.

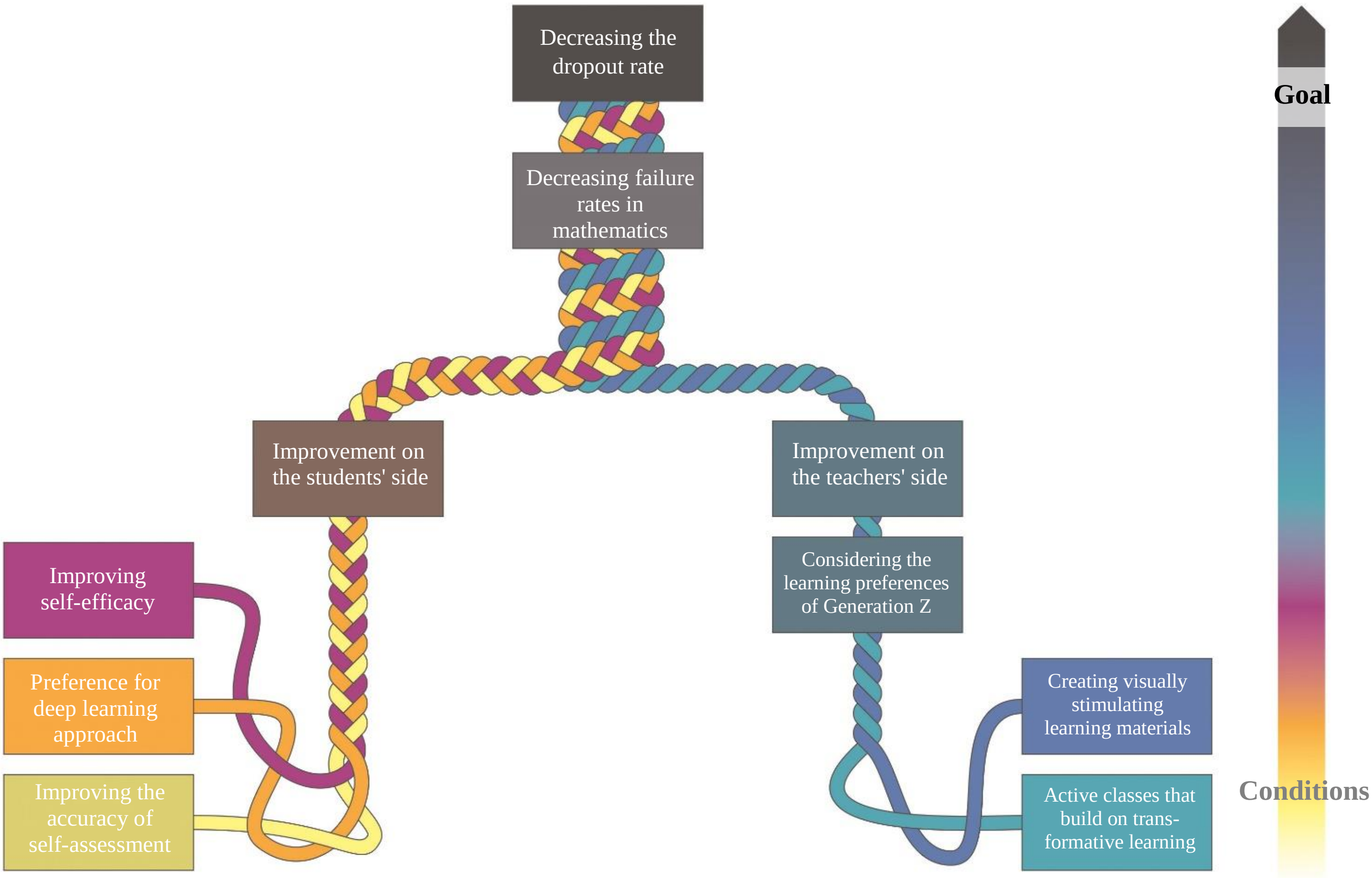
As a micro-level path to becoming a hero, the path of learning mathematics also has a beginning, where students face a series of "trials" in the form of coursework and tests, while paired and group exercises offer a chance to get to know the "allies". Questionnaires and tests affected students' self-assessment in different ways. In questionnaires, during the evaluation of learning approaches and self-efficacy ideas, respondents reflected on their mathematics learning habits, while at the midterms they performed a self-assessment concerning their already acquired knowledge. During their preparation for the tests, students were increasingly self-reliant, gradually increasing their level of autonomy. This was symbolized by first solving a sample test together with the involvement of the teacher, then writing a trial midterm and correcting it together, and finally writing the midterm test individually. The last station, the "returning with the elixir" phase, happened during the workshop, where a final retrospective and evaluation provided a real framework for students to get closure.

However, the path is not only transformative for the student, but also offers an opportunity for the teacher (mentor) to rethink her role, so that her support can aid the next hero to get to the final trial, and he would not leave the path to becoming a hero prematurely.

This doctoral dissertation can be considered a documentation of certain aspects of mathematics learning by students as "a path to becoming a hero". Another explicit goal was to generate innovative changes and transformations. Dropout is a social phenomenon that affects all levels of the education system. This research is part of the fight against dropout in higher education, which allowed for a better description of the causes of dropout outlined in the research problem tree. Overall, 6 of the 13 hypotheses were upheld, 5 were rejected, and 2 of them were partially upheld. Of the 7 sub-hypotheses, 2 were upheld, 3 were rejected, and 2 were partially upheld.

These results allowed the creation of tree of innovation goals (Figure 9). The goal-tree, aimed at reducing dropout, defines the conditions that may be achieved by a cooperation of teachers and students, based on the four focal points of the research.

Figure 9: Education innovation opportunities for reducing dropout (innovation goal-tree)



Although the self-efficacy ideas of students are positive, improving self-efficacy is indispensable, especially in case of repeat students, since this plays an important role in learning performance, as well as avoiding dropout. One way to improve it is regular, constructive feedback. Improving self-assessment accuracy may be achieved the same way. Frequent evaluation and feedback is among the learning preferences of Generation Z, which was confirmed during the COVID-19 pandemic, since cancelling midterms meant cancelling the feedback concerning their acquired knowledge for most students. Thus, building on evaluation and feedback, several goals can be achieved at the same time. There is limited opportunity within mass education for consistent personalised evaluation by the teachers in the classroom, but technology offers several options. Since the chief advantage of kahoot tests is instant feedback according to students, creating exercise banks using similar platforms that provide instant and effective feedback during learning and solving exercises, may be useful. Such feedback may not only improve the self-efficacy of students, but the accuracy of their self-assessment, while reducing unreasonable expectations towards themselves, towards the teacher and the class. Furthermore, research results show that encouraging students to view their corrected tests creates more responsibility for the teacher, even though it requires extra work. Presenting the results of positive correlation between viewing the test and improved self-assessment for students results in a higher number of students wanting to view their midterm tests, and may help integrating feedback into the learning process.

Students were primarily characterised by deep learning, but in case of repeat students in danger of dropping out this showed a markedly lower value. Thus, communicating and presenting the positive correlation between the deep approach and midterm test results towards students, and discussing learning approaches together may contribute to motivating students in cognisant learning.

The preference towards visual learning methods to address students' needs for visual stimuli was confirmed in the second part of the research. Based on these results, beyond the Mathematics 1 course involved in this study, using more visual elements in other mathematics courses would be also useful. In addition to directly supporting the learning materials visually, this should include visual aids for supplementary information related to learning as well. Results may be used in a broader context, extended to teaching other engineering subjects as well. All of these changes allow improving visual competences, too, which are indispensable in the everyday work of engineers.

An examination of higher education mathematics textbooks showed that currently these are dominated by text, mathematics formulae and expressions. There are few figures and illustrations to make mathematics more palatable for students. Based on Guzmán's typology, isomporphic visualisation dominates our textbooks. When writing and editing new higher education mathematics textbooks and lecture notes, improvements should be introduced in the areas mentioned in the research, not only in terms of quantity but also in quality. Regarding the latter, the positioning of the figures in relation to the text or exercise, use of colour in images, using more varied images according to Guzmán's typology, using exercises that require diagrams when solving them or the solution itself is a diagram, using exercises that contain images or require the mathematical interpretation of images, the typography of text or possibly decorative illustrations, should be improved. Judicious use of Guzmán's visualisation types in textbooks in relation to the various levels of understanding may support students in their mathematics education.

According to the third section of the research, students' preferences for active learning varied. Although most methods aimed at active learning received a positive evaluation, students were not used to new methods that required various kinds of activities during their earlier studies or in other classes at the university, and this rendered them counter-productive for many of them. Their feedback shows that classes that require intense activity produce frustration, and do not reach their goal in students mostly used to passivity. Teachers should use a few methods that involve activity, use them consistently, more and more frequently, not only in mathematics courses but in other classes too. Research results show that methods that build on mixing intrapersonal learning with paired and group work should be preferred.

The original goal of the dissertation was applying the generated results in attendance education. Due to the remote education as a consequence of the unexpected pandemic, the original ambitions were seemingly temporarily foisted, but results still offer application opportunities and general principles during remote education, if used in the appropriate context. Involving students in the learning process actively and using expressive, visually stimulating learning materials is even more important in such times. The quality and visual appeal of the learning materials provided is even more important. Students expect continuous feedback that helps them create accurate self-assessment and stay on track when studying even more (e.g. workshops can also be organised online during remote education). Effective learning strategies acquired earlier become more important, and former mastery experiences affect academic resiliency as well. Based on all of these, research results are applicable in remote, as well as in attendance education.

Data collected during the research allows the establishment of many further relationships not included in the dissertation. Data processing was done according the goals outlined in the introduction. In the various parts of the project, we touched on many topics related to dropout, every one of which points to further research opportunities. From a narrower perspective, developing measurement tools, the results and limitations of the research can also define new directions of investigation.

Although integrating the results of the dissertation into mathematics education may bring changes, redesigning a single course in a systematic way is unlikely to bring significant dropout reduction. We need a change in the approach used by higher education teachers, as well as the research-based rethinking of the courses in at least the first two semesters to reflect “Industry 4.0” needs and the learning preferences of Generation Z. My doctoral research may be considered as an overture to this paradigm shift.

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