Tampere University

HANNA KINNARI-KORPELA

Enhancing Learning in Engineering Mathematics Education

Utilising Educational Technology and Promoting Active Learning

Tampere University Dissertations 38

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Utilising Educational Technology and Promoting Active Learning

ACADEMIC DISSERTATION
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PREFACE

'I have no special talents. I am only passionately curious.' –Albert Einstein

I have enjoyed this journey during the past years. Without my passion for educational development, I would not be here. The process has been extremely rewarding, though it has required engagement, perseverance, a lot of time and loads of coffee. Even though the process has been a lonely exploration of the world of digitalisation, I would not be at this point without the support of various people.

I would like to thank my employer, Tampere University of Applied Sciences, for being able to carry out my studies. Without the students and their critical but also encouraging feedback, this thesis would have never come to fruition. You have been the source of my inspiration. I'm also thankful for the financial support of this study. The study was financially supported by grants from Tamperelaisen tutkimustyön tukisäätiö and OKKA-säätiö.

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I owe my deepest gratitude to my parents, Mirja and Matti, for supporting me since I was born. This thesis would have never been ready without your help, support and help taking care of Touko. You have been an invaluable help to me.

Even though many people have helped me and have been there for me during this process, there is one 'little' man above all: Touko, my precious little treasure. During the last years, you have been wondering if I draw the Turtles with my computer, as I spend so much time with it. Unfortunately, mom was not drawing the Turtles, but just writing some boring text, as you said. Thanks for being so lovely son.

Valkeakoski, January 2019

Hanna Kinnari-Korpela

ABSTRACT

This study contributes to the discussion of development of engineering mathematics education from two different perspectives: to explore the possibilities to enhance engineering mathematics teaching and learning with the help of educational technology, and to promote active learning of students. From these two perspectives, it has been explored, for example, how engineering students experience the usage of selected educational technology and does utilisation of educational technology affect students' activity or learning. The investigations have concentrated on developing a feasible framework for mathematics teaching and learning in Bachelor's level engineering education. From the theoretical perspective, this dissertation discusses instruments to promote students' active learning as a part of the framework.

The research has been conducted between 2011-2017 with four empirical studies at Tampere University of Applied Sciences. The adopted research approach is design-based research that has included several iterative cycles for developing the framework for mathematics teaching and learning. This process has included twenty-five university of applied sciences level engineering mathematics course implementations. Short educational video lectures and computer-aided assessment were the main educational technologies that were implemented during the research process.

As an outcome of the research, the guidelines for utilising selected educational technology and activating students in similar educational setting are given. These guidelines provide knowledge for developing instructional design and learning resources especially at UAS-level engineering mathematics context. The findings indicated that engineering students experience short educational video lectures and computer-aided assessment as meaningful and feasible for mathematics learning. Students used short educational videos for different learning purposes and pointed out such benefits as repeatability and having more time in peace to learn and understand the current task at hand. When non-compulsory automatically assessed online exercises were provided, high completion rate were detected among study groups.

Utilising short educational videos and computer-aided assessment provides instant feedback to students about their learning process. The findings indicated that such resources have a potential to motivate, activate and promote self-regulated learning. However, the most of the students were studying nearby the deadlines. Hence, proper and distinct assignment deadlines guide students' learning activity and are more likely to activate them.

Overall, the focus of this dissertation has been on the utilisation of potential of digitalisation and the promotion of active learning. At the center of the prevailing digitalisation hype, these both goals play a central role in higher education. Thus, the dissertation discusses topics covered in many higher education institutions nationally and internationally.

TIIVISTELMÄ

Tämän tutkimuksen tarkoituksena on tuoda näkökulmia insinöörikoulutuksen matematiikan opetuksen kehittämiseen. Tutkimusprosessin aikana on tarkasteltu erityisesti kahta toisiinsa liittyvää näkökulmaa: mahdollisuuksia kehittää insinöörimatematiikan opettamista ja oppimista opetusteknologian avulla ja edistää opiskelijoiden aktiivista oppimista. Näihin näkökulmiin liittyen tutkimus tarkastelee esimerkiksi, miten insinööriopiskelijat kokevat opetusteknologian käytön, ja vaikuttaako se opiskelijoiden aktiivisuuteen tai oppimiseen. Tutkimuksen käytännön opetustyöhön liittyvänä tuloksena syntyy toteutuskelpoinen toimintamalli AMK-tasoisen insinöörimatematiikan opetuksen järjestämiseksi. Työn teoreettinen kontribuutio koskee aktiivista oppimista tukevien elementtien sisällyttämistä toimintamalliin.

Tutkimus on toteutettu vuosina 2011-2017 Tampereen ammattikorkeakoulussa neljänä empiirisenä tutkimuksena. Lähestymistapana on käytetty design-tutkimusta, joka on pitänyt sisällään useita iteratiivisia syklejä toimivan toimintamallin löytämiseksi. Tutkimusprosessiin on sisältynyt 25 AMK-tasoista insinöörimatematiikan opintojaksototeutusta. Opetusteknologiat, joita tutkimuksessa pääosin hyödynnettiin, olivat lyhyet pedagogisesti käyttökelpoisiksi suunnitellut opetusvideot ja tietokoneavusteinen arviointi.

Neljän osatutkimuksen tulosten perusteella tutkimus on tuottanut ohjeita opetusteknologian hyödyntämisestä, opetuksen järjestämisestä ja opiskelijoiden aktivoimisesta samankaltaisessa matematiikan oppimisen kontekstissa. Tutkimuksen tulokset indikoivat, että opiskelijat kokivat lyhyet opetusvideot ja tietokoneavusteisen arvioinnin käyttökelpoisina ja mielekkäinä menetelminä. Opiskelijat käyttivät lyhyitä opetusvideoita erilaisissa oppimistilanteissa. Hyödyiksi koettiin mm. videoiden toistettavuus ja se, että omaan tahtiin videoita katsomalla oli enemmän aikaa ymmärtää ja oppia opetettuja asioita. Opiskelijat suorittivat myös ei-pakollisia automaattisesti arvioituja matematiikan verkkotehtäviä huomattavasti aktiivisemmin kuin mitä odotettiin.

Lyhyet opetusvideot ja automaattisesti arvioitavat matematiikan tehtävät tarjoavat opiskelijalle välitöntä palautetta oppimisprosessista. Tulokset indikoivatkin, että työssä hyödynnetyn opetusteknologian käyttäminen voi motivoida, aktivoida ja

edistää oppimisen itsesäätelyä. Tutkimustulosten valossa kuitenkin oppimistehtävien palautusten määräajat ohjaavat opiskelijan aktiivisuutta, sillä opiskelijat opiskelevat lähellä tehtävien palautusten määräaikoja.

Kaiken kaikkiaan tämän väitöskirjan fokus on ollut hyödyntää digitalisaation tarjoamaa potentiaalia mutta myös edistää aktiivista oppimista. Keskellä vallallaan olevaa digitalisaation hypeä, molemmilla näistä on keskeinen rooli korkeakoulutuksessa. Tämän vuoksi tämä väitöskirja pureutuu aihepiireihin, jotka ovat esillä monissa korkeakouluissa niin kansallisesti kuin kansainvälisestikin.

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ABBREVIATIONS

CAA	Computer-aided assessment
DC	Differential Calculus
DD	Double degree (including HS and VET)
ECTS	European Credit Transfer and Accumulation System
FM	Functions and Matrices
GV	Geometry and Vector Algebra
HS	High school
IC	Integral Calculus
STEM	Science, technology, engineering and mathematics
TAMK	Tampere University of Applied Sciences
UAS	University of Applied Sciences
VET	Vocational education and training

1 INTRODUCTION

The Finnish higher education system is currently in transition. Universities are facing problems as financial resources have been decreasing. Moreover, there has been a lot of discussion about how higher education should be organised in Finland, and how important is it to maintain the dual-model of higher education. However, one thing is clear: new and innovative ways to organise higher education need to be explored and implemented. Consequently, in this process, versatile learning possibilities outside the classroom will play a central role.

On the other hand, to be a lecturer in higher education is a demanding task. It is not only the substance that one needs to handle. Nowadays, lecturers must possess diverse skills, including pedagogical and technological skills, for enhancing teaching and learning process and instructional design. This research considers instructional design as systematic process that combines theory and practice to develop teaching and learning methods and resources in a consistent way to meet the needs of university of applied sciences (abbreviation UAS) level students. For facilitating teaching and learning process, educational technology plays an important role.

Technological developments have ushered in a wide range of possibilities to be utilised in education. In fact, technology plays an important role in organising education as teaching and learning have been increasingly occurring in different types of online learning environments. A good example of recently changed practices is massive open online courses (abbreviation MOOC), in which universities are providing their courses and expertise to everyone, free of charge. The approach to provide high-quality courses for free has changed the way students acquire knowledge and skills. The other example of recently changed practices is a blended model of instruction. Blended learning approach refers to instructions that takes place in both classroom and online, which is the case in this study. These types of changes naturally require adopting new pedagogy and utilisation of educational technology. As technology has become more ubiquitous, it inevitably requires versatile competencies from the instructor; technology has to be integrated meaningfully and efficiently (Niess et al., 2009).

In the wider context, this dissertation aims to contribute to the discussion regarding to the integration of technology in engineering mathematics education at UAS-level of studies and promoting students' active learning form the perspective of self-regulated learning. The following sections of this chapter introduce the research task at hand in more detail starting by an identification of the research problems. After that, research approach is presented followed by perspectives of educating UAS-level engineering students.

1.1 Research problem and questions

During the current millennium, universities have faced problems with financial resources (Teferra & Altbachl, 2004; Yang & McCall, 2014; Moody's, 2013). For example in Finland, this situation is quite new and improvements for that are not expected in the near future. In everyday teaching at UAS-level of studies, this causes a lack of time resources for teaching. Practically, there are often not enough time e.g. on mathematics courses for teaching traditionally all the necessary content. In addition, time to concentrate on those students that have problems is very limited.

However, decreasing financial resources targeted to teaching should not be reflected in learning outcomes. Thus, instead of teaching traditionally there is a clear need for a shift in pedagogy. To achieve learning objectives set for different courses, students need to use more time for studying outside the classroom. Hence, blended learning possibilities need to be implemented as a part of studies at UAS-level of studies. In other words, actions and resources to activate and engage students with their learning process also in online learning environments should be developed. Educational technology plays an important role in increasing blended learning possibilities. When a part of the learning tasks occurs in an online learning setting, it also requires changing classroom practices. This causes a practical need for a new instructional design.

Pedagogical approaches base on learning theories and they link theory and practice by providing principles for instructional design in general. During last decades, emphasising active learning methods as underlying pedagogical approach has become more popular (Prince, 2004; Armbruster, Patel, Johnson, & Weiss, 2009; Röj-Lindberg, 2001; Freeman et al., 2014). The core of active learning is to activate and engage students to their learning process (Prince, 2004). The studies have shown that active learning methods can increase learning outcomes or even increase passing rates (Prince, 2004; Armbruster et al., 2009; Freeman et al., 2014) especially in science, technology, engineering and mathematics (STEM) subjects (Freeman et al., 2014). Results of empirical research on mathematics teaching support active approach for mathematics teaching and learning (Röj-Lindberg, 2001). Active learning can be defined as 'any instructional method that engages students in the learning process (Prince, 2004, p. 223).' In active learning, students are actively responsible of their learning process instead of passively receiving information. Thus, active learning is student-centered and it is constrained to the traditional teacher-centered lecture (Prince, 2004).

On the other hand, when learning occurs increasingly in online learning environments, it can bring other challenges for learners. They require from the learners, for example, that they are able to monitor and control their learning by setting learning goals, monitoring time and resources and understanding their strengths and weaknesses as learners. In other words, students need to have adequate self-regulatory skills. Research has shown that learners that regulate their learning are active ones and they control their learning behavior in various ways (Zimmerman & Schunk, 2012). Research has indicated that mastering learning in online environments requires self-regulatory skills from the students (Azevedo & Cromley, 2004).

US Department of Education (Means et al., 2009) carried out the meta-analysis of more than a thousand empirical studies of e-learning. They found positive effects on learning with instructional design that emphasis blended or online learning. Students who engaged in online learning had better learning outcomes than those students that participated in traditional lectures. However, research of e-learning in higher education has been mostly focused on content design and curriculum development, and not on the roles and emphasis between online and on-campus learning (Gros & García-Peñalvo, 2016). A gap between learning theories and instructional design related to technology enhanced learning has been identified in different fields (Fernandes, Simo & Sallan, 2009; Lloyd & Robertson, 2012).

Based on the research evidence above, utilising educational technology and changing classroom practices are seen as possible methods to activate and engage students in their learning. Although literature supports utilisation of technology in the context of education and provides feasible examples, there is an evident lack of empirical research at UAS-level on how to enhance students' learning with educational technology, how to reorganise instructional design and how do students experience utilisation of such technology in the context of active and self-regulative learning. Thus, there is a clear lack of principles and guidelines for utilizing educational technology to activate students in UAS-level engineering mathematics learning.

This dissertation is based on a design-based research approach, providing knowledge of how to promote engineering mathematics teaching and students' active learning in UAS-level with the aid of educational technology and seeking new viewpoints and guidelines for instructional design in such context. This is later called as a framework for mathematics teaching and learning.

The dissertation includes four different studies. Even though the focus of the research varied between each study, the overall goal of the research was to contribute to the development of engineering mathematics education at UAS-level from two different perspectives:

- to explore the possibilities to enhance engineering mathematics teaching and learning with the help of educational technology, and
- to promote active learning of students.

Based on the literature, the selected perspectives led to utilise educational technology such as short educational video lectures and computer-aided assessments. Introduction and justifying the selection of these methods are given in detail in section 2.3. In the investigations of these methods, the core research questions were:

- (Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?
- (Q2) How can technology contribute to the organisation of engineering mathematics courses, including course content and assessment?
- (Q3) How is the utilisation of educational technology, such as short educational video lectures and computer-aided assessment, experienced by the UAS students in the learning and teaching of engineering mathematics?

However, while developing instructional design, it was also essential to pay attention to active learning of students with a particular focus on self-regulated learning. When discussing students' learning, the research questions are as follows:

- (Q4) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning activity in an engineering mathematics context?
- (Q5) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning outcomes in an engineering mathematics context?
- (Q6) Is Bloom's taxonomy suitable for designing test items to recognise students' level of subject related knowledge in an engineering mathematics context?
- (Q7) Do components of self-regulation, such as intrinsic/extrinsic motivation, affect students' learning experience or performance in an engineering mathematics context?
- (Q8) How can active learning of engineering mathematics with an emphasis on self-regulated learning be promoted?

Study 1 addressed Q1, Q2 and Q6 by preliminary investigating suitability of short educational video lectures and computer-aided assessment as methods to learn engineering mathematics at UAS-level. *Study 2* examined Q1, Q2, Q3 and Q7 by systematically utilising short educational video lectures as a part of engineering mathematics teaching and learning. Goal of *study 3* was to provide answers to Q4, Q5 and Q6 by analysing students activity of watching short educational video lectures and providing self-assessment instrument to support self-regulated learning of students. *Study 4* addressed Q1, Q2, Q4 and Q8 by exploring and developing the overall teaching and learning process, developing instruments for promoting self-regulated learning and developing evaluation of students. The Table 1. illustrates how the different studies address the research questions.

Table 1. Studies and research questions

	Study 1	Study 2	Study 3	Study 4
Q1	○	○		○
Q2	○	○		○
Q3		○		
Q4			○	○
Q5			○	
Q6	○		○	
Q7		○		
Q8				○

1.2 Research approach

This research adopted design-based research as a research approach. The empirical research was carried out alongside the author's daily teaching between 2011-2017. The framework for mathematics teaching and learning has been iteratively developed during the research process. The research process has included actual educational interventions based on four different studies.

Because the research deals with concepts of knowledge, also epistemology and ontology have been shortly overviewed from a philosophical perspective. Both qualitative and quantitative methods have been utilised to obtain robust data. The research methodology is presented more in detail in the chapter 3 after theoretical framework.

1.3 Research context

As the author has worked as a senior lecturer of engineering mathematics at a University of Applied Sciences in Finland, all four studies in this design-based research have been carried out in UAS-level mathematics courses. To get perspective of the research context, the Finnish higher education system is introduced after which perspectives of educating engineering students at universities of applied sciences are given. The aim of this is to get overview of target groups and set boundaries for applying results. This overview also gives perspectives, why mathematics learning resources provided for science universities do not mostly fit for the needs of UAS-level students.

1.3.1 Finnish higher education system

Finnish higher education system has a dual structure, in which both universities and universities of applied sciences offer higher education. A total of 23 UAS and 14 universities operate within 'the administrative branch of the Ministry of Education and Culture in Finland' (Minedu).

The emphasis of education at research universities is on scientific instruction and research. Education provided by universities of applied sciences is more practical and emphasis of research is on practice-based research. Whereas universities of applied sciences put the majority of resource volume on education that is practical and working life relevant, research universities put their major resource volume on scientific research. However, universities of applied sciences put also resources for practice-based research that serve educational purposes and have been targeted for developing regional industry. Thus, the primary scopes of universities and universities of applied sciences are different.

In the field of engineering, universities of applied sciences provide Bachelor's degree programmes. The extent of engineering studies at universities of applied sciences is 240 ECTS. Studies include compulsory 30 ECTS of practical training. After graduation and three years' working experience, students can apply for Master's degree programmes. At research universities, students can study for Bachelor's, Master's, Licentiate and Doctoral degrees. Basic degree studies at research universities aim for Master's degree.

Students with high school (abbreviation HS) degree, Finnish matriculation examination or vocational education and training (abbreviation VET) are eligible for admission to universities of applied sciences. Matriculation examination or high school give general eligibility for research universities. In practice, top students apply for research universities, whereas students of universities of applied sciences don't possess i.e. in-depth mathematical proficiency.

1.3.2 Education provided by Tampere University of Applied Sciences

Tampere University of Applied Sciences (abbreviation TAMK) is a multidisciplinary higher education institution located in Pirkanmaa area in Finland. TAMK provides education for seven fields of study including seventeen Bachelor's degree, fifteen Master's degree and over 40 degree programmes. About ten thousand degree students from different fields study annually at TAMK, being one of the biggest UAS in Finland. For example, in the field of technology, the annual intake of engineering students at TAMK was second biggest in Finland in 2017. In the spring 2018, over 5200 applicants applied for engineering studies at TAMK, which was the second biggest applicant amount in the field of technology in Finland (Vipunen).

The studies of this research have been conducted during basic degree studies in the field of technology at TAMK. As the basic degree studies at UAS aim for Bachelor's degree, the participants of the study have been first or second year Bachelor's level engineering students. As TAMK is one of the biggest engineering educators at UAS-level in Finland, the results of this study are feasible also in other UAS in Finland. The following section focuses on the target groups of this research.

1.3.3 Educating engineering students at universities of applied sciences

Basic degree students of UAS in the field of technology aim for Bachelor's degree. Students with HS degree, matriculation examination or VET are eligible for admission. Most UAS use entrance examination to test applicants' suitability for engineering studies. The entrance examinations test basic skills and knowledge of logical reasoning, mathematics, physics and chemistry. Despite the qualification of the candidates, incoming students' mathematical proficiency varies greatly in the field of technology.

Figure 1 shows the background studies of incoming engineering students at TAMK between 2009-2011, at the time that this research process started. During that time period, the annual intake of engineering students varied between 540 – 580 and about 30 % of the incoming students had VET background.

For example, at the time that this dissertation process started, one-third of the incoming students had VET degree and about half of the students had HS background. The rest had studied double degree (abbreviation DD), which means that students had both HS and VET degrees. Based on difference in background studies, incoming engineering students have different abilities for example to study mathematics and natural sciences. This needs to be taken into account of in many levels: in curriculums, in planning learning materials and in overall instructional design.

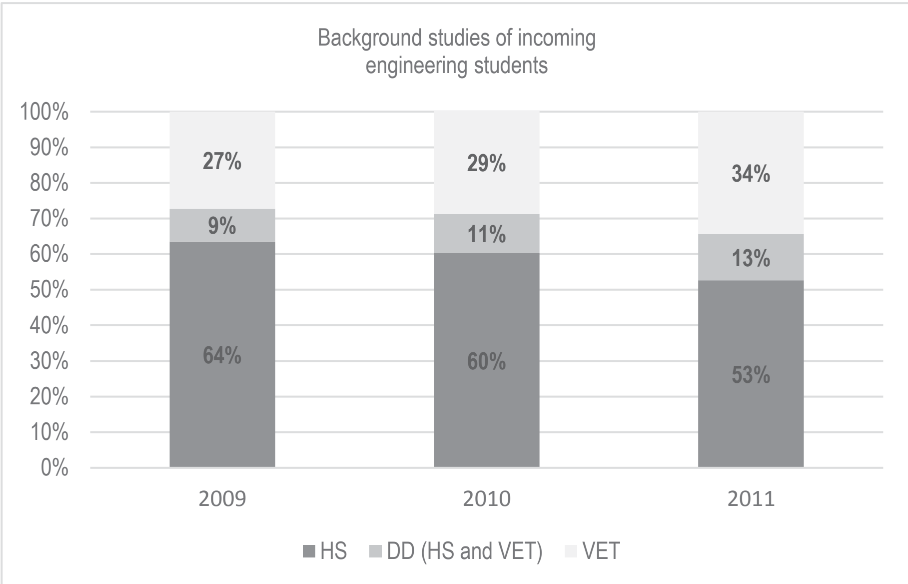

Figure 1. Background studies of incoming engineering students at TAMK

However, not only the background degree studies affect students' ability to study engineering. Mathematical proficiency has a major role, for example. At TAMK in the field of engineering, the incoming students' mathematical proficiency was measured with mathematics level test at the beginning of 21st century. The test was compulsory for all incoming engineering students. For example in 2011, 221 of degree programme students in the field of technology reported that they have studied advanced syllabus in HS. The distribution of their mathematics grades in matriculation examination is shown in Figure 2. The figure shows that two-thirds of the incoming students in 2011 that have studied advanced syllabus in high school have achieved satisfactory or weaker grade in mathematics matriculation examination. The weakest grade in Finnish matriculation examination is i, which means 'fail'. After that are a, b, c, m, e and l from the weakest grade to the best.

To summarize the issues discussed, at the time that this dissertation process started, one-third of incoming students had VET background. Practice has shown that VET students have major deficiencies in their mathematical proficiency. Also, the most of the students with HS background had inadequate mathematics skills.

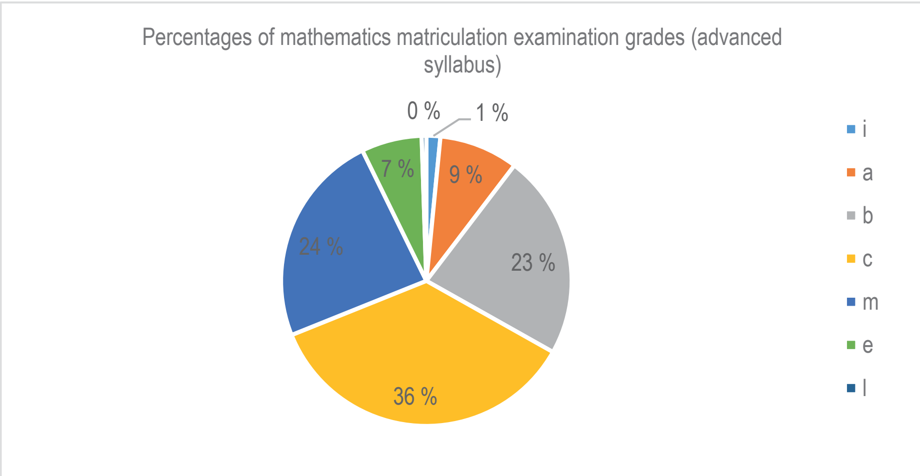

Figure 2. Distribution of matriculation examination grades of incoming students at 2011 in the field of engineering

The problems related to incoming students mathematics proficiency have been discussed in the 21st century (Näätänen, 2005). On the other hand, it has been recognised that the depth of the subject matter content at the Finnish UAS-level mathematics courses are different than science universities (Rahkola, 2016), the competency requirements at the starting level in UAS are low and the used methods don't meet the requirements of science university level mathematics (Pohjolainen, 2005). Hence, for example learning resources used in science universities, do not mostly fit in UAS-level of studies.

1.3.4 Engineering mathematics studies at TAMK

To obtain a holistic view of the basic mathematics courses at TAMK, their extent and some practical issues related to the organisation of courses are briefly discussed in the following.

The extent of every compulsory engineering mathematics course at TAMK has been three credits since curriculum reform in 2013. The mathematics courses before and after 2013 are presented in Table 2.

Typically, the compulsory mathematics courses are organised during one academic period that usually lasts seven or eight weeks. In practice, five to six hours of contact teaching are organised in a week, including both theory teaching and exercise sessions. Thus, there are not separate lectures or practical sessions, but in-class sessions are organised as a combination of theory and exercises.

Table 2. Mathematics courses at TAMK before and after 2013

	Compulsory courses (VET)	**Compulsory courses (HS)**
Courses before autumn 2013	Introduction to Engineering Mathematics (5 ECTS) Mathematics 1 (5 ECTS) Mathematics 2 (5 ECTS) Engineering Mathematics 3 (only for EE and ICT, 5 ECTS)	Mathematics 1 (5 ECTS) Mathematics 2 (5 ECTS) Engineering Mathematics 3 (only for EE and ICT, 5 ECTS)
	Compulsory courses for all (VET and HS)	
Courses after autumn 2013	Geometry and Vector Algebra (3 ECTS) Functions and Matrices (3 ECTS) Differential Calculus (3 ECTS) Integral Calculus (3 ECTS) Discrete Systems (3 ECTS) (depends on degree programme) Statistics (3 ECTS) (depends on degree programme)	
	Free choice course (VET and HS)	
	Orientation for Engineering Mathematics (3 ECTS)	

During one academic year four teaching periods are organised. From engineering student's point of view, there is principally one mathematics course in every period of their first academic year (this slightly varies between the degree programmes). In addition, first year students can select an optional introductory course in mathematics prior their studies at UAS.

Taking into account of incoming students' mathematical proficiency, there are abundant amount of new topics to be learnt with the tight schedule in each mathematics course. During the first academic year, students take courses such as

Geometry and Vector Algebra, Functions and Matrices, Differential Calculus and Integral Calculus. Each of these courses is taught in seven to eight weeks, including approximately twenty-seven to thirty-three contact hours. Altogether, the subject matter that is dealt within one course week is abundant. Due to the tight schedule and abundant subject matter, the learning process of students should be initiated immediately after enrollment. Unfortunately, way too often, students are not active, and they prefer learning prior to the exam or compulsory assignments. Consequently, learning practically concentrates on rote learning, instead of on deeper learning.

On the other hand, various problems had been encountered during traditional mathematics in-class sessions before this research process. The most common problems were:

- Some students have negative experiences or attitudes towards mathematics learning, or they are not that eager to learn mathematics, which can be recognised during in-class sessions.
- Students are not taking enough responsibility of their learning process or are not putting in enough effort to comprehend the tasks at hand.
- Some students do not concentrate on teaching or are inactive during the in-class session. They might spend in-class time talking with peers or using social media. Additionally, they might have problems with attendance at lectures.
- Some students are studying only for tests/exams, and after that, the topics and the content can be forgotten.
- Some students do the homework exercises regularly, but others only complete the assignments randomly or never.
- Some students copy the exercises from others and are not eager to learn.
- Some students expect the teacher to explain and help them through difficult exercises rather than thinking through ideas by themselves.
- Some students want the help of lecturer immediately after facing a difficulty, instead of solving the problem actively.

Above mentioned problems, insufficient time resources for teaching tradiotionally all the necessary course contents and students' lack of mathematical skills and knowledge laid the basis for this development process. During in-class sessions, there was typically not enough time for concentrating on those students who may need the most help. It was evident that there was a clear need for shift in pedagogy.

Developing instructional design that promotes students' active learning and taking responsibility of their own learning process was considered important. Also literature supported emphasising active learning methods.

2 THEORETICAL FRAMEWORK AND REVIEW OF LITERATURE

This chapter presents a contextual framework and key concepts of the research. The aim of the chapter is to provide a structured lens through which the research can be viewed and the results observed, analysed and applied. All the studies that are a part of this research have been conducted at Tampere University of Applied Sciences. An overview of the Finnish higher education system and perspectives on educating engineering students at the UAS-level have been discussed in the previous chapter. This chapter focuses on the theoretical perspective of the research.

The underlying goal of this research is to develop a framework for learning engineering mathematics at UAS-level – one that promotes active learning of students and utilises the appropriate educational technology. To understand the key concepts of the research, the following sections discuss the concept of knowledge in general, instruments to recognise and measure it and the constructs of mathematical knowledge. As active learning methods require self-regulative skills, self-regulation is used as a concept that cuts across the various stages of this research, and it will be discussed in more detail later.

Because this research has focused on developing instructional design and utilising educational technology, different types of content knowledge are introduced to explain how to teach effectively and understandably (Shulman, 1986). The reasons for selecting particular educational technologies are also presented.

2.1 What is knowledge?

This research discusses the questions related to students' active learning of mathematics and implementing appropriate educational technology in engineering mathematics teaching and learning. From the perspective of this study, philosophy of mathematics education enquires i.e. 'what is the significance of educational technology in the teaching and learning of mathematics and 'what is the nature of mathematics teaching and learning' (Ernest, 2013). Even though, the focus of this research is not on philosophy of mathematics education, philosophical perspectives are shortly introduced.

The philosophy that explores the theory of knowledge is called epistemology. Learning-related epistemological questions include such as 'What does it mean to possess knowledge of certain subject, or to be proficient in some subject?' and 'What does depth of knowledge mean (e.g. in mathematics or physics)?' Moreover, epistemology deals with the limitations and validity of knowledge.

On the other hand, ontology is a philosophy that deals with the existence of entities, attributes and their relations. In general, ontology deals with the kind of things that exist, whereas epistemology is more concerned with what and how we know (Peressini & Peressini, 2007). From a philosophical perspective, this study possesses both ontological and epistemological characteristics. For example, when designing learning materials (section 2.3.2.3), an attention was paid to the questions that had philosophical nature also.

Students' active learning is often connected to self-regulation. Self-regulation of learning has both epistemological and ontological characteristics. However, these facets have not received much attention in literature (Jakešová & Kalenda, 2015). Even though, epistemic beliefs have a role in self-regulated learning (Greene, Muis & Pieschl, 2010), the focus of this study is not on students' epistemic beliefs. However, for this work, it is important to understand the components of self-regulated learning and the nature of mathematical knowledge.

2.1.1 Conceptual and procedural knowledge

Exploring questions such as 'What is mathematical knowledge?' and 'How do students learn mathematics and how can they be taught efficiently?' often lead to discussions about the type of knowledge that is the most important in mathematics. In fact, for centuries, researchers have debated what should be the emphasis and the balance between skill and understanding in mathematics instruction (Hiebert & Lefevre, 1986).

The many theories of learning do not offer a consensus on the different types of knowledge in mathematics. Piaget, Tulving and Anderson distinguished between conceptual understanding and successful action, semantic memory and episodic memory and declarative and procedural knowledge (Hiebert & Lefevre, 1986). One of the most well-known distinctions posited by Hiebert and Lefevre (1986, p. 3–4) is the one between conceptual and procedural knowledge in mathematics learning. They defined conceptual knowledge as: '… knowledge that is rich in relationships. It can be thought of as a connected web of knowledge, a network in which the linking relationships are as prominent as the discrete pieces of information. Relationships pervade the individual facts and propositions so that all pieces of information are linked to some network.'

Thus, conceptual knowledge is related to mathematical concepts, rules (algorithms, procedures, etc.) and problems occurring in various forms (Haapasalo, 2003; Kadijevich & Haapasalo, 2001). Kadijevich and Haapasalo (2001, p. 156) defined procedural knowledge as: '…dynamic and successful utilization of particular rules, algorithms or procedures within relevant representation form(s), which usually require(s) not only knowledge of the objects being utilised, but also knowledge of the format and syntax for the representational system(s) expressing them.' Hence, procedural knowledge can be described as 'rules or procedures for solving mathematical problems' (Hiebert & Lefevre, 1986, p. 7). While conceptual knowledge typically requires conscious thinking, procedural knowledge is automated and includes unconscious steps (Haapasalo, 2003).

Even though, developing mathematical proficiency rests on enhancing both conceptual and procedural knowledge (Star, 2005, 2007; Rittle-Johnson, Schneider & Star, 2015) the use of these terms is not unambiguous. Literature provides different and contradictory interpretations of conceptual and procedural knowledge (Star, 2005; Baroody, Feil & Johnson, 2007; Star, 2007; Star & Stylianides, 2013). Typically psychological research (Star & Stylianides, 2013) describes conceptual and procedural knowledge as types of knowledge, and mathematics educators (Star & Stylianides, 2013) as qualities of knowledge (Maciejewski & Star, 2016), for example. According to Star and Stylianides (2013) a type of knowledge 'refers to what is known' and a quality of knowledge, how well something is known and understood. Hence, questions such as 'How should we teach to promote students' mathematical understanding?' and 'How to promote students' mathematical understanding?', are closely connected to qualities of knowledge (Star & Stylianides, 2013).

Recent research has indicated that conceptual and procedural knowledge are interrelated (Star, 2005, 2007; Baroody et al., 2007; Maciejewski & Star, 2016) and the relation between conceptual and procedural knowledge is bidirectional (Rittle-Johnson, Schneider & Star, 2015). This means that developing conceptual knowledge often supports improvements in procedural knowledge and vice versa (Rittle-Johnson, Schneider & Star, 2015).

2.1.2 Mathematical knowledge and skills

The extant body of literature offers slightly varying concepts and meanings for recognising and exploring performance in mathematics. Researchers have used terms such as mathematical power (NAEP), mathematical competence and literacy (PISA) and mathematical proficiency to describe this performance (Kilpatrick, Swafford, & Findell, 2001; Joutsenlahti, 2005). This thesis has used the term 'mathematical proficiency' to describe mathematical competence of engineering students.

The concept of mathematical proficiency can be approached from various perspectives. It has been linked to everyday life mathematics, school mathematics, numeracy or, more specifically, to the proficiency in certain fields (e.g., engineering mathematics) (Hihnala, 2005; Näätänen, 2005; Pisa, 2003; TIMSS, 2015).

On the other hand, mathematics encapsulates a vast number of fields (i.e., algebra, geometry, trigonometry, etc.). In practice, students' performance almost always varies between the different fields to some extent. Therefore, it is difficult to measure students' mathematical proficiency in general. However, teaching and learning in educational institutions are based on curriculums as well as the premise that proficiency will be tested. Proficiency can be tested, for example, through examinations, assignments, etc. Hence, defining a reliable framework for learning and proficiency testing is important.

Various definitions and methods are available for the measurement of mathematical proficiency. However, a key factor of mathematical proficiency is the ability to understand and use definitions. This does not mean memorising the definition but rather understanding why it is stated as it is (Milgram, 2007). As the concept of mathematical proficiency is difficult to define, research has attempted to classify categories of mathematical proficiency. Schoenfeld (2007) classified mathematical proficiency into the following categories: knowledge base, strategies, metacognition (using what you know effectively) and beliefs and dispositions. Schoenfeld expects that students should be able to use their knowledge of mathematics, not just limit themselves to producing facts or using certain procedures.

Furthermore, Schoenfeld (2007) highlighted the importance of metacognition skills such as monitoring strategies and self-regulation. Based on his study, students must be given opportunities to effectively use the skills and knowledge they have obtained. He also emphasised the importance of beliefs in mathematics. Especially the relevance of beliefs can be seen for example in students' exam and exercise responses. If students are only used to pick up the number facts from mathematical problems, ignoring the real life context, and see the mathematical problems only through the numbers as meaningless operators and procedures, they will probably produce nonsensical responses without any thinking about the rationality of their results (Schoenfeld, 2007). Practice has shown that this is one central issue teachers face every day in teaching. Far too often, students are producing responses clearly lacking the sense of thinking or practically relying on answers given by a calculator.

Several frameworks have been developed to help recognise mathematical knowledge and identify mathematical proficiency on some standard level. One such well-known conceptual framework is the five strands of mathematical proficiency, defined by Kilpatrick, Swafford and Findell (2001, p. 116). The framework covers five interdependent strands of mathematical proficiency that represent different aspects:

- 'conceptual understanding: comprehension of mathematical concepts, operations, and relations,
- procedural fluency: skill in carrying out procedures flexibly, accurately, efficiently, and appropriately,
- strategic competence: ability to formulate, represent, and solve mathematical problems,
- adaptive reasoning: capacity for logical thought, reflection, explanation, and justification,
- productive disposition: habitual inclination to see mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy.'

Kilpatrick, Swafford and Findell's (2001) framework is a tool for identifying the components of mathematical proficiency. Mathematical proficiency is as an important notion in this research for exploring the knowledge base of students and reviewing the produced content.

2.1.3 Depth of knowledge

To recognise and assess the depth of knowledge in a certain domain, several frameworks are available. Bloom's hierarchical taxonomy is the most well-known and widely used among them (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). It consists of six different levels of cognitive knowledge: knowledge, comprehension, application, analysis, synthesis and evaluation (see Table 3.), that classify thinking

(Forehand, 2010). The basic premise of Bloom's taxonomy is that gaining depth of knowledge is a cumulative process. Thus, mastering a certain level includes mastery in the lower levels as well. In other words, to master comprehension-level thinking, students must first master knowledge-level thinking (Bloom et al., 1956).

The six levels of knowledge are often grouped into two. The first group comprises knowledge, comprehension and application levels and is often linked to lower-order thinking (Thompson, 2008, 2011). The second group consists of analysis, synthesis and evaluation and is connected to higher-order thinking (Thompson 2008, 2011). In the context of mathematics, Bloom's taxonomy has been applied, for example, in developing and assessing exam items (Highley & Edlin, 2009; Kastberg, 2003).

While Bloom's taxonomy is one of the most-well known framework for defining learning behaviour and assessing depth of knowledge in certain domains, other frameworks are also relevant. Anderson, Krathwohl and Bloom (2001) proposed a revised version of Bloom's taxonomy that is also widely utilised. Their revised dimensions of cognition are remember, understand, apply, analyse, evaluate and create. These levels encapsulate common definitions and descriptions of actions that students need to possess at a certain level. The revised version is better suited to classifying teaching objectives (Tallman, Carlson, Bressoud, & Pearson, 2016).

Table 3. Bloom's taxonomy of educational objectives in the context of mathematics (Bloom et al., 1956; Kastberg, 2003)

Level	Short Description
Knowledge	Recalling, remembering and recognising mathematical information, fact, procedure, method, definition etc. mostly in a form, which they have been presented.
Comprehension	Comprehending and understanding the meaning of some fact, method, procedure etc. based on prior learning and being able to demonstrate that understanding.
Application	Being able to use and apply previously learned information and skills in a new situation/context and in problem solving.
Analysis	Being able to analyse, classify and put into separated components the information that has been previously learnt. Being able to understand the relations between the components.
Synthesis	Combining, integrating, applying and expanding the mathematical components and the piece of information into a new situation based on the previously learned information.
Evaluation	Evaluating, interpreting and justifying the value of information, solutions, methods and materials for given purpose to choose the best method for problem solving.

Smith et al. (1996) used Bloom's original taxonomy and modified it to better fit a mathematics context. However, their taxonomy was mostly designed for instructors – to help them design and structure exam items. Joutsenlahti (2005) and Wilson (1971) also developed taxonomies suitable to reviewing the depth of knowledge in mathematics. These models are based on Bloom's taxonomy, but their structure is simpler than the structure of original taxonomy.

Taxonomies such these are widely utilised in different disciplines. In mathematics, Abdullah et al. (2017), Brändström (2005), Highley and Edlin (2009), Kastberg (2003), Thompson (2008, 2011), and Vidakovic, Bevis and Alexander (2003), among others, have provided useful examples related to the application of the original Bloom's taxonomy.

Interestingly, even though revised versions of Bloom's taxonomy have been developed, research does not suggest that the original one is obsolete. The revised taxonomies have mostly concentrated on the dimensionality of taxonomy (Joutsenlahti, 2005; Wilson, 1971) or have been designed for a specific purpose (Smith et al., 1996). As the phenomenon under investigation in this research is quite complex, Bloom's taxonomy is considered the most suitable framework for capture this complexity.

2.1.4 Knowledge for teaching

Promoting students' learning not only requires recognising students' knowledge but also demands thorough knowledge of the content and teaching expertise. While Bloom's taxonomy focuses on reviewing the depth of subject matter knowledge, Shulman developed the theory of content knowledge for teaching (1986). Shulman's model is seminal, widely recognised (Loewenberg Ball, Thames, & Phelps, 2008) and applied in the context of mathematics teaching and learning research (e.g., Kersting, 2008; Cueto, León, Sorto, & Miranda, 2017). The model categorises domains of content knowledge for teaching into subject matter content knowledge, pedagogical content knowledge and curricular knowledge (Shulman, 1986).

In practice, adequate subject matter content knowledge is necessary to teach effectively and understandably (Shulman, 1986). Subject matter content knowledge refers to a teacher's content knowledge about the concerned subject. To teach effectively, a teacher must have deep understanding of the course content.

Otherwise, explanations can easily remain incomplete, and the logic behind certain procedures and structures may be communicated ineffectively (Shulman, 1986).

The second domain of content knowledge, pedagogical content knowledge (PCK), is an intersection of content knowledge and pedagogical knowledge (Kansanen, 2009; Shulman, 1986). It reconciles content knowledge and ways of representing and teaching it (Ball, Thames, & Phelps, 2008). Shulman (1986, p. 9) defined this knowledge as follows:

'…the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations- in a word, the ways of representing and formulating the subject that makes it comprehensible to others.

…PCK also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons.'

PCK deals with how some specific part of subject matter knowledge is 'organized, adapted, and represented for instruction' (Mishra & Koehler, 2006). It deals with teaching the subject matter in the most comprehensible way to a specific student cohort. It can thus be seen as an essential type of knowledge for developing instructional practices.

The third domain of content knowledge, curricular knowledge, is 'represented by the full range of programs designed for the teaching of particular subjects and topics at, a given level, the variety of instructional materials available in relation to those programs, and the set of characteristics that serve as both the indications and contraindications for the use of particular curriculum or program materials in particular circumstances.' (Shulman, 1986, p. 10)

Research studies have linked the concept of content knowledge to mathematics education. Ball et al. (2008) defined mathematical knowledge for teaching and subdivided content knowledge into common content knowledge and specialised content knowledge. Further, Ball categorised pedagogical content knowledge into knowledge of content and students and knowledge of content and teaching (Ball et al., 2008). Hill et al. (2008) explored subject matter mathematical knowledge for teaching and its association with the quality of mathematical instruction.

Overall, differences are evident not only in the concepts describing teacher knowledge but also in the interpretation of terminology related to didactics, education and pedagogy. In mathematics, the terms 'didactic' and 'subject-matter didactics' are used especially in France and Germany, whereas 'pedagogy' is the more commonly used term, especially in Nordic countries. On the other hand, English-speaking countries prefer to use the term 'education' (Kansanen, 2002, 2009; Kilpatrick, 2008).

In general, all these terms refer to the teacher's subject matter knowledge and the ability to teach the subject in a way that students understand and learn the content. Kansanen (2009) explains that a teacher needs adequate subject matter content knowledge and pedagogical content knowledge to present the content and promote active interaction with students.

2.1.5 Technological pedagogical content knowledge

This study has used a design-based research approach, which has been introduced in the chapter 3. In the early half of the current decade, the use of educational technology for teaching and learning engineering mathematics at UAS-level was relatively uncommon. In fact, not much research literature is available about utilising educational technology in mathematics at UAS-level. One reason for selecting a design-based research approach, at the beginning of this research process, was the lack of understanding on how to teach subject matter content using technology (due to insufficient technological pedagogical content knowledge). There was also a lack of instructional materials produced with the selected technology.

At the core of successful teaching using technology are key factors of teacher's knowledge such as technology, pedagogy and content knowledge and their relationships (Koehler & Mishra, 2009). The interconnection and intersection of technology, pedagogy and content knowledge (see Figure 3.) - technological pedagogical content knowledge (TPACK) - provides a framework for understanding teachers' knowledge, both in theory and practice, needed for learning and teaching in a digitalised world (Mishra & Koehler, 2006). TPACK encompasses the collection of skills and knowledge required for effectively integrating technology, pedagogy and content knowledge in the teaching of the subject matter. It is a framework of teacher knowledge needed for successful technology integration (Koehler & Mishra, 2009; Mishra & Koehler, 2006; Niess et al., 2009; Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013).

TPACK has its origins in the PCK concept, proposed by Shulman (Shulman, 1986; Voogt et al., 2013). The main idea of TPACK is that teaching is a demanding task that requires the possession and adoption of different types of knowledge about content, pedagogy and technology. Instead of seeing technology ability as a separate knowledge set, TPACK considers it as an integral aspect for ensuring high-quality teaching. Thus, there exists a sophisticated interaction between these three types of knowledge (Mishra & Koehler, 2006).

Content knowledge (CK) and PCK have been presented in section 2.1.4. Pedagogical knowledge (PK) refers to a knowledge of pedagogy. Teachers with pedagogical knowledge are familiar with practices and methods for teaching and learning and understand how the students learn (Koehler & Mishra, 2009).

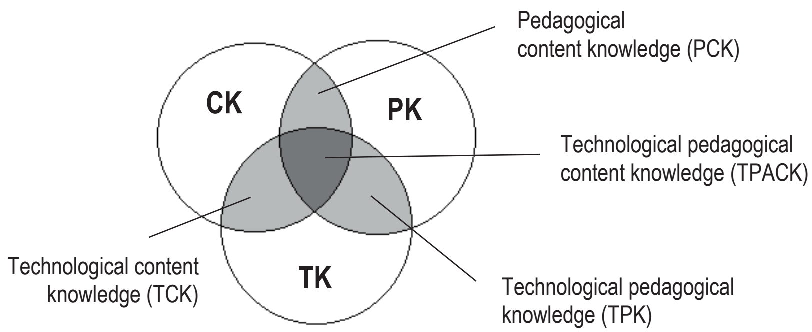

Figure 3. The circle of content (CK), pedagogy (PK) and technology (TK) (Koehler & Mishra, 2009; Mishra & Koehler, 2006)

Technology knowledge (TK) refers to the skills and knowledge that are required to operate a particular technology and to use various forms of technologies (Mishra & Koehler, 2006). A teacher that has technological content knowledge (TCK) has an understanding of 'the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of particular technologies' (Koehler & Mishra, 2009, p. 65). Technological pedagogical knowledge (TPK) is knowing the capabilities of specific technologies in learning settings (Mishra & Koehler, 2006). Hence, it is knowledge about how using a specific technology might change or improve teaching and learning (Koehler & Mishra, 2009).

Technological pedagogical content knowledge (TPACK) plays a major role in this thesis. It influences both practices and materials to be utilised in developing a framework for mathematics learning.

2.2 Regulation of learning

One line for educational and psychological research is students' learning and elements of developing and increasing students' competence. A learner that regulates his/her own learning is considered to be metacognitively, motivationally, and behaviourally active in the learning process (Zimmerman, 1986, 1989). Metacognition, self-regulation and self-regulated learning constitute the main cognitive control processes (Schunk, 2008), but in literature, these concepts are often used interchangeably (Dinsmore, Alexander, & Loughlin, 2008). Processes of metacognition and self-regulation are distinct but parallel and intertwining constructs (Fox & Riconscente, 2008).

Metacognition plays a central role in self-regulation and self-regulated learning, and it is 'any knowledge or cognitive activity that takes as its object, or regulates, any aspect of any cognitive enterprise' (Flavell, 1985, p. 104). More generally, metacognition refers to thinking about thinking or knowledge about knowledge. Hence, it is individual's knowledge about cognition, their own cognitive process and information-processing skills.

The concepts of metacognition, self-regulation and self-regulated learning are rooted in the works of Piaget, Vygotsky and James (Fox & Riconscente, 2008). However, Flavell (1985) (metacognition), Bandura (1986) (self-regulation) and Zimmerman (2000) (self-regulated learning) have also heavily influenced contemporary research on the subject (Schunk, 2008).

Self-regulation has been of special interest for educational and psychological researchers because of its role in enhancing students' academic learning. Many studies have explored key processes that support it (Panadero, 2017). Regulating learning requires cognitive, motivational, emotional and social factors (Puustinen & Pulkkinen, 2001).

Learners that master their learning process often also succeed in their studies (Zimmerman, 2008). Using active learning strategies for mastering the learning process requires regulatory skills. Research has shown that those who regulate their learning are active learners, and they control their learning behaviour in various ways (Zimmerman & Schunk, 2012). This can occur, for example, by adopting optimal and effective learning strategies that are based on feedback from previous learning efforts (Zimmerman & Campillo, 2003). Self-regulatory skills are also necessary for lifelong learning and developing and sustaining professional knowledge (Hytönen, 2016; Nokelainen, Kaisvuo, & Pylväs, 2017).

Zimmerman and Schunk (2011, p. 1) define self-regulation as ‘the processes whereby learners personally activate and sustain cognitions, affects, and behaviours that are systematically oriented towards the attainment of personal goals.’ Thus, self-regulation is not a mental ability but a task-related process, where a learner controls and modifies the learning behaviour for achieving academic goals (Zimmerman, 2013).

Self-regulation is a complex concept that covers important constructs of student learning such as motivational, behavioural, metacognitive and cognitive constructs (Panadero, 2017). However, typically, educational research does not recognise or agree on standard or unified universal definitions for these key concepts. This is also the case with self-regulation (Pintrich & DeGroot, 1990). Nonetheless, defining these key concepts of research is vital for interpreting and applying research results (Schunk, 2008; Dinsmore et al., 2008). The aim of the following sections is to discuss self-regulation within the context of this research and to provide a structured lens through which the research can be viewed. The overall objective is to establish that self-regulation plays a central role in developing competence in higher education.

Self-regulated learning is often discussed along with academic achievement, students’ engagement, activity and motivation (Richardson et al., 2012; Schunk & Zimmerman, 1998; Zimmerman & Schunk, 2012). Self-regulation is not an innate ability; it can develop over time (Schunk & Zimmerman, 1998). Students’ study motivation (Schunk & Zimmerman, 1998) and learning outcomes (Hattie et al., 1996; Richardson et al., 2012) may improve with time by supporting the development of self-regulation in their studies. Wigfield and Eccles (2002) characterised self-regulation as ‘one of the main ways in which individuals translate motivation into achievement (p. 5).’

Designing learning activities that are meaningful and functional can stimulate self-regulation (Rowe & Rafferty, 2013). Instructional design that supports students’ self-regulation can promote students’ satisfaction and achievements (Nicol, 2009). In a mathematics context, appropriate instructional design can promote motivation towards mathematics learning (Middleton & Spanias, 1999).

In recent years, more emphasis has been placed on the other forms of learning regulation: co-regulated learning and socially shared learning regulation. Hadwin and Oshige (2011) define co-regulation as ‘a transitional process in a learner’s acquisition of self-regulated learning, within which learners and others share a common problem-solving plane, and self-regulated learning is gradually appropriated by the individual learner through interactions’. Hence, typically, in co-regulation, individual learners embrace regulation in degrees through collaboration with peers or other advanced students. Co-regulation involves interaction and distributed regulative actions between the individuals, and it shifts individual regulation towards shared regulation (Järvelä et al., 2017). Effective and coherent co-regulation is a prerequisite for shared regulation, and therefore, these two forms of regulation might be difficult to separate (Järvelä et al., 2017). However, unlike co-regulation, socially shared regulation refers to a collective activity that includes shared regulation performed by group members such as goal setting, performing, monitoring and evaluating (Hadwin, Järvelä, & Miller, 2011; Hadwin & Oshige, 2011). Hadwin and Oshige (2011) defined socially shared regulation as 'the processes by which multiple others regulate their collective activity. From this perspective, goals and standards are co-constructed, and the desired product is socially shared cognition.'

The focus of this research is on developing a teaching and learning process for engineering mathematics that promotes students' active learning and engagement in the learning process. Developing a teaching and learning process that fosters students' self-regulation activities has been seen as more important than promoting co-regulation or shared regulation. Developing and identifying elements of instructional design that promote students' self-regulated learning is considered important. In the following sections, self-regulation is discussed from the point of view of this research.

2.2.1 Models of self-regulation

To plan and construct elements to support students' self-regulated learning, it is important to understand how a student can self-regulate one's own learning (Moos & Ringdal, 2012). Although a number of self-regulation models that cover different constructs and processes have been proposed, they share some common assumptions about learning and students' regulation (Pintrich, 2000, 2004). Pintrich (2000, 2004) outlined four basic assumptions that are common to most self-regulated learning models (Moos & Ringdal, 2012; Pintrich, 2000, 2004):

1. Learners have a potential to monitor, control and regulate some part of their own cognition, behaviour and motivation.
2. Learners actively construct their own meanings, goals and strategies from the learning context, their prior knowledge of the subject matter and their prior experiences. Hence, the learning process can be considered as a constructive process.

3. Learners can set task-specific goals, monitor the progress and regulate and adapt cognition, motivation, and behaviour for achieving these goals.
4. Self-regulatory activities mediate the relationship between a learner's task-specific performance, contextual factors and individual characteristics.

Despite several theories and models of self-regulation (e.g. Boekaerts, 1992; Borkowski, 1996; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 2000), there is no single model that can be directly utilised for developing elements to support self-regulation in the context of this thesis. However, the existing models provide theoretical foundation for understanding the processes of self-regulation in higher education and developing subject matter competence.

Table 4. presents the different models of self-regulation and their theoretical background, as described by Puustinen and Pulkkinen (2001). Five different models of self-regulated learning are compared based on four criteria: background theories, definitions, components included in the models and empirical work. The five chosen models are Boekaert's model of adaptable learning (Boekaerts & Niemivirta, 2000), Borkowski's process-oriented model of metacognition (Borkowski, 1996), Pintrich's general framework for self-regulated learning (Pintrich, 2000), Winne's four-stage model of self-regulation (Winne & Hadwin, 1998) and Zimmerman's social cognitive model of self-regulation (Zimmerman, 2000). In these models, learning is considered a process that includes some kind of preliminary, performance/task completion and adaption phases (Puustinen & Pulkkinen, 2001). However, the terminology used and the details and emphasis of self-regulation processes vary. Barring Pintrich's and Zimmerman's models, which are similar, the models are rather different (Puustinen & Pulkkinen, 2001).

Table 4. Models of self-regulation (applied from Puustinen & Pulkkinen, 2001)

Models of Self-Regulation	Background Theory
Boekaerts' model of adaptable learning (Boekaerts & Niemivirta, 2000)	action control theory, transactional stress theory
Borkowski's process-oriented model of metacognition (Borkowski, 1996)	information processing perspective, metacognitive research tradition
Pintrich's general framework for self-regulated learning (Pintrich, 2000)	social cognitive theory
Winne's four-stage model of self-regulation (Winne and Hadwin, 1998)	heterogeneous theoretical background (i.e. information processing; cognitive science)
Zimmerman's social cognitive model of self-regulation (Zimmerman, 2000)	social cognitive theory

Puustinen and Pulkkinen (2001) noted that the theoretical background of models is an important feature that differentiates them. Social cognitive theory (Bandura, 1986) has contributed to both Pintrich's and Zimmerman's models. Both these models have aspects of motivation in self-regulated learning that emphasise goal orientation.

In general, the social cognitive perspective has contributed immensely to the research on self-regulated learning (Bandura, 1986; Pintrich, 2000; Zimmerman, 2000). It is the most widely used perspective in research on learning regulation (Järvenoja et al., 2015). This research, too, focuses on the social cognitive perspective of self-regulation and utilises Zimmerman's model of self-regulation.

2.2.2 Self-regulation from social cognitive perspective

From a social cognitive perspective, self-regulation is a cyclical process of an individual's self-generated feelings, thoughts and actions that occur while attaining personal goals (Zimmerman, 2000). Self-regulation is not a permanent mental ability, rather it involves transforming self-generated mental abilities into academic skills (Zimmerman, 2002). Learning is seen as a proactive student activity rather than a reaction to teaching (Zimmerman, 2002). A student that self-regulates his/her learning is proactive during the learning process. In general, a learner that regulates his/her own learning is metacognitively, motivationally, and behaviorally active in their learning process (Zimmerman, 1986, 1989; Winne & Hadwin, 1998; Pintrich, 2000).

Self-regulated learning is often connected with a learning activity and the learner's motivation towards the subject matter. A self-regulated learner actively monitors and modifies behaviour while fulfilling his/her personal educational goals. Thus, instead of been passive, a self-regulated student contributes actively to his/her learning goals and has a control over achieving these goals (Schunk, 1989). However, for monitoring, controlling and modifying behaviour, feedback from learning processes is necessary (Schunk, 1989).

Research on self-regulated learning recommends laying emphasis on developing instruments and elements that enhance students' self-regulated learning (Zimmerman, 2002). A student that regulates his/her own learning, actively monitors and modifies learning behaviour while attaining personally set learning goals. Self-regulation can be taught, and it can increase students' academic achievement, engagement and motivation (Schunk & Zimmerman, 1998; Zimmerman, 2000; Zimmerman & Schunk, 2001, 2008, 2012).

This research utilises Zimmerman's (2000) model of self-regulation, which is based on the social cognitive perspective of learning. Zimmerman's model is a cyclical process that includes three phases: forethought, performance/volitional control and self-reflection. Each phase is further divided into classes. In this model, feedback from prior performance efforts is used to regulate and control one's learning behaviour as the learning tasks are in progress (Zimmerman & Campillo, 2003). The cyclical process is presented in Figure 4.

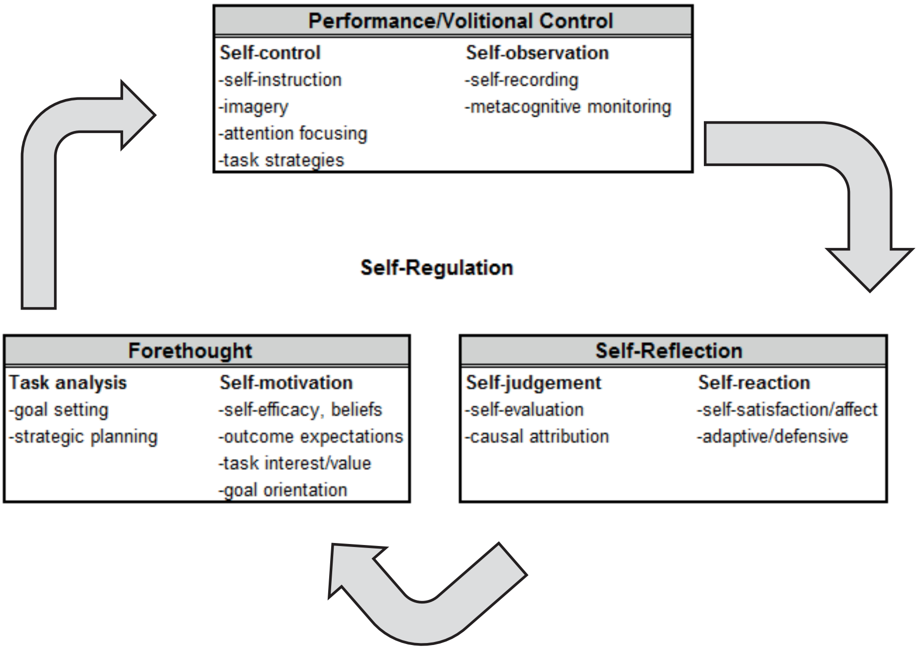

Figure 4. Zimmerman's (2000) model of self-regulated learning

Forethought phase

The first phase of Zimmerman's model is the forethought phase, which consists of two classes: task analysis and self-motivation. This phase occurs before actual learning efforts are undertaken – when a student analyses the task at hand and sets goals for completing the task. At the same time, the student may have outcome expectations and self-efficacy beliefs about his/her performance, and the task may hold some value for the student. This phase lays the foundation for learning of a specific learning task.

Task analysis consists of goal setting and strategic planning. Goal setting is a key activity for self-regulation, and it refers to analysing the learning task at hand and setting specific goals for completing it (Zimmerman & Campillo, 2003; Zimmerman & Moylan, 2009). A student that self-regulates one's own learning selects appropriate strategies and methods that are needed to perform and accomplish the learning task at hand (Zimmerman & Campillo, 2003).

Self-motivation class includes several elements. One of these are self-efficacy beliefs about personal capability to perform a specific task. These beliefs influence motivation (Bandura, 1997) and the types of goals and strategies that a student sets. However, other self-motivation components such as task value, outcome expectations and goal orientation are factors that affect motivation towards completing a specific learning task (Bandura, 1997; Zimmerman, 2002; Zimmerman & Campillo, 2003). Experiencing a learning task as useful promotes motivation towards the task and can contribute to the use more strategies for learning (Wigfield et al., 2008). If students can connect a specific learning task to personal goals and experience the task as useful and meaningful, they are more likely to be motivated and active learners.

Performance phase

The performance/volitional control phase covers two groups of processes: self-control and self-observation (Zimmerman & Campillo, 2003). These occur, when a student is executing the learning task and monitoring his/her performance simultaneously. A self-regulated learner typically monitors the used strategies and his/her effectivity in pursuit to complete the task.

To be able to maintain attention and motivation during the performance phase, students need different metacognitive and motivational methods and strategies (Panadero & Alonso-Tapia, 2014). Self-control processes help put into action the methods and strategies that have been selected in the forethought phase (Zimmerman, 2002). These methods and strategies include self-instruction, imagery, attention focusing, and time and task management strategies (Zimmerman, 2000). These help students to focus on the task at hand, maintain their attention on the performance (Zimmerman & Campillo, 2003) and cognitively engage with and stay motivated towards completing the task (Panadero, 2017).

The other class of performance phase, a self-observation, refers to students' tracking of current performance and behaviour systematically (Zimmerman, 2000; Zimmerman & Campillo, 2003). It consists of self-recording and metacognitive monitoring. Self-recording is, for example, keeping a learning journal and observing one's own performance through records. Through self-recording, students receive information about their learning progress, and it helps them recognise the sources of success and failure in performance. The other component of self-observation is metacognitive monitoring. It reflects metacognitive awareness and activities that a learner may employ while performing a task at hand (Pintrich, 2000). Metacognitive monitoring refers to adequacy of learning, and it is a student's subjective monitoring (Winne & Hadwin, 1998).

Self-reflection phase

Self-reflections on one's current performance influence the forethought phase, thus completing the cyclical nature of model (Zimmerman & Campillo, 2003). The self-reflection phase consists of self-judgement and self-reaction classes. This phase occurs after the students' learning efforts. In this phase, students effectively evaluate performance, used strategies and the reasons for the results (Panadero & Alonso-Tapia, 2014; Zimmerman, 2000, 2002). Students also manage positive or negative emotions related to the learning experience. Self-reflections and reactions can influence future performance (Panadero, 2017).

Self-judgement class consists of self-evaluation and causal attribution (Zimmerman, 2000, 2002). As part of self-evaluation, students evaluate their performance against personal goals or some standard evaluation criteria (Zimmerman, 2002; Zimmerman & Campillo, 2003). They may also evaluate their current performance against their previous performance (Zimmerman & Campillo, 2003). Causal attributions refer to 'beliefs about the cause of one's errors or successes' (Zimmerman, 2002, p. 68). Essentially, students evaluate the cause of a failure: whether the failure was due to the lack of ability or due to insufficient effort (Zimmerman & Campillo, 2003). Depending on their attribution styles, they are likely to experience negative or positive emotions that may influence their future motivation, goal setting and performance (Panadero & Alonso-Tapia, 2014; Zimmerman, 2000). However, attributions are strongly connected to the prior motivation factor and are not direct outcomes of self-reflections (Zimmerman & Campillo, 2003).

Attributions can lead to positive or negative self-reactions (Zimmerman, 2000, 2002). The self-reaction phase consists of two classes: self-satisfaction/affect and adaptive/defensive responses. Self-regulated students have feelings of satisfaction or dissatisfaction about their performance (Zimmerman & Campillo, 2003). Naturally, individuals seek actions that leads to satisfaction and positive affect. Positive self-satisfaction and affect related to performance can promote future motivation, whereas negative self-satisfaction can dilute future motivation and learning efforts (Zimmerman, 2002; Zimmerman & Campillo, 2003).

Self-reactions also include adaptive or defensive reactions. Adaptive reactions occur when the student modifies learning strategies in order to achieve better results in future learning attempts. On the other hand, defensive reactions refer to resistance to performing a task again to evade failure (Zimmerman, 2000, 2002). Defensive actions include disengagement, task avoidance and helplessness (Zimmerman & Campillo, 2003).

Self-regulation is cyclical in that self-reactions have an impact on the forethought phase. For example, feelings of satisfaction may increase future self-efficacy beliefs, task interest, expectations and intrinsic motivation (Zimmerman & Campillo, 2003).

2.2.3 Motivation and self-regulation

Being motivated 'means to be moved to do something' (Ryan & Deci, 2000). Individuals have different types and levels of motivation that vary according to the task at hand.

Motivation is the one of the main areas of self-regulated learning as it activates, leads and sustains actions and behaviours during the learning task. Zimmerman's model of self-regulation discusses motivational constructs that influence self-regulated learning. Self-motivation is a crucial element of the forethought phase (Panadero, 2017).

Motivation and affect can be regulated in the same fashion as cognition (Pintrich, 2000). Per the social cognitive perspective of self-regulation, students have sources of motivation such as goal orientations, interests, intrinsic motivation, self-efficacy beliefs, outcome expectations, task value and causal attributions (Zimmerman & Schunk, 2012).

Some theories categorise motivation into intrinsic and extrinsic forms (Ryan & Deci, 2000) even though this distinction is a problematic. Interestingly, these two types of motivation constitute a significant part of an individual's experience derived from being involved in different types of activities (Vallerand, 1997).

Some authors link intrinsic motivation to task interest while others connect it with the satisfaction gained from engagement in a task (Ryan & Deci, 2000). Typically, intrinsic motivation is connected to an individual's interest and enjoyment with an activity or task (Zimmerman & Schunk, 2012). Ryan and Deci (2000) defined intrinsic motivation as 'doing of an activity for its inherent satisfactions rather than for some separable consequence'. In contrast, extrinsic motivation refers to an activity that is performed for its instrumental value leading to a separable outcome (Ryan & Deci, 2000). Many activities related to the academic context are not intrinsically motivated. For example, if an engineering student is completing mathematics exercises only because he or she believes that doing so is valuable for later studies, then the exercises are being performed because of their instrumental value. The student's motivation in such a case can be considered extrinsic as he or she does not find the exercises personally interesting.

Even though motivation factors influence self-regulation and learning outcomes, motivation only plays a minor role in this thesis. This research has focused on developing a framework for engineering mathematics learning that includes elements to promote self-regulation of learning. Motivational factors are therefore presented as a minor part of research – intrinsic and extrinsic motivations are discussed only as a part of study 4.

2.3 Educational technology

Educational technology refers to facilitating learning with the help of a variety of technological tools, applications and resources (Richey, Silber, & Ely, 2008). It is an interdisciplinary field that is witnessing rapid advances. As a result, defining concepts pertaining to educational technology is not easy. Spector (2013, p. 10) defined educational technology as follows: 'Educational technology involves the disciplined application of knowledge for the purposes of improving learning, instruction, and/or performance.' In this research, educational technology is utilised to support students' active learning and self-regulation.

In the past few decades, ubiquitous technology and technological developments have constantly increased the possibilities to utilise educational technology for learning and teaching purposes. Moreover, technology offers opportunities to engage and activate students systematically. In fact, the use of technology for learning purposes can engage students directly or push them to undertake traditionally challenging activities (Hennessy, Ruthven, & Brindley, 2005). However, in many educational institutions, the use of technology for teaching mathematics is still limited to overhead projectors and transparencies. The reasons for using obsolete methods are e.g. a lack of understanding of the impact of technology on teaching and learning and changing instructions are time-consuming. Teachers continue to employ the teaching methods that were used in the time they were studying (vs. Mishra & Koehler, 2006). However, despite new and advanced methods, good lectures will always be valuable.

Overall, literature suggests that the most common barriers to the successful utilisation of technology in teaching are a lack of confidence, a lack of competence and a lack of access to resources (Bingimlas, 2009; Joy et al., 2014; Kinchin, 2012). Additionally, it has been observed that the frequency of technology use by students are teacher-dependent (Tay, Lim, Lim, & Koh, 2012). This is understandable because when a teacher has a positive attitude towards any kind of development, the attitude is likely to transform into the enthusiasm of students. In fact, the attitudes, beliefs and practices of teachers and students are crucial for successful technology integration, especially in the domain of mathematics (Joubert, 2013). Many researchers believe that technology has been underused in the teaching of mathematics – its potential is underexploited and it lags behind expectations (Clark-Wilson, Oldknow, & Sutherland, 2011; De Witte & Rogge, 2014; Drijvers et al., 2010; Koehler & Mishra, 2009; Mishra & Koehler, 2006).

2.3.1 The educational technology aspect of the study

While technology itself does not generate learning outcomes, it can improve learning by facilitating active learning (McLoughlin & Loch, 2013). Activating and engaging students is at the core of active learning (Prince, 2004). The main idea behind using educational technology in this study was to activate and engage students outside the classroom. Educational technology was used in an attempt to address the problems encountered in classrooms such as the lack of time for teaching and heterogeneous student cohorts.

As instructional design emphasises student-centred learning, the learning techniques utilised in this research needed to facilitate active studying. Dunlosky, Rawson, Marsh, Nathan, and Willingham (2013) discussed ten effective easy-to-use learning techniques to promote students' self-regulated learning. Practice testing and distributed practice were two of the techniques that received high utility assessments. In other words, the two techniques produced results that are robust and widely generalisable (Dunlosky et al., 2013, p. 7). Moreover, the two techniques can be utilised in various learning conditions, they benefit learners of different proficiency and they can improve students' performance.

According to Dunlosky et al. (2013), practice testing refers to, for example, self-testing on the learnt topics, and it seems to improve learning. Research has shown that practice testing may enhance the ways students mentally organise information. The effects of practice testing can be divided into direct and mediated effects. 'Direct effects refer to changes in learning that arise from the act of taking a test itself, whereas mediated effects refer to changes in learning that arise from an influence of testing on the amount or kind of encoding that takes place after the test' (Dunlosky, 2013, p. 30).

Distributed practice refers to scheduling of practice and studying activities over time. It can be used with different types of learning materials. Studies have shown that in mathematics, distributed practice and practice testing can benefit learners (Dunlosky, 2013). Budé et al. (2011) found out that, students who participated in statistics course including distributed practice performed better than students who were studying subject matter in a brief time interval. Their study strongly suggests using distributed practice as a learning technique.

The mathematics courses at TAMK are held for a short, usually seven- to eight-weeks period. Given the students' mathematical proficiency, the time for learning new topics is quite restricted. If using educational technology aims to enhance learning outcomes, it should be part of students' learning process and should be taken into account in instructional design. According to Ali and Jameel (2016), the main reasons for poor performance in mathematics are lack of effort and practice. This is understandable as mathematical proficiency consists of various interwoven strands (Kilpatrick, Swafford & Findell, 2001). Hence, instructional design should offer resources for not only developing mathematical ability but also supporting practice and students' own efforts.

Computer-aided assessment enables practice testing, distributed practice and students' own activity and practice. Short educational screencast videos mainly support distributed practice, but they also aid students' own activity and practice. In this study, educational technology such as computer-aided assessment and screencasts was used in mathematical engineering studies.

2.3.2 Lecture capture

Usually the term lecture capture refers to an educational audio or video recording of classroom activities that are made digitally available. It also refers to software or a system that enables the production of such recordings. The term applies to many methods, such as screencasts, podcasts and recording of authentic face-to-face lectures (Zhu & Bergom, 2010; O'Callaghan, Neumann, Jones & Creed, 2017).

Lecture capture is not a new invention; many different lecture capture techniques have been in use for years. There is an abundance of literature on the different types of lecture captures in different disciplines (Al-Nashash & Gunn, 2013; Andersson & Nilsen, 2006; Bollmeier et al., 2010; Day & Foley, 2006; Green et al., 2012; Hofacker

& Ernie, 2009; Karnad, 2013; McDonald, 2008; McGarr, 2009; Mettiäinen & Karjalainen, 2012; O'Callaghan et al., 2017; Owston et al., 2011; Pinder-Grover et al., 2011; Prodanov, 2012; Pursel & Fang, 2011; Secker et al., 2010; Soong et al., 2006).

Earlier, the most common method for lecture capture was recording authentic face-to-face lectures (Pursel & Fang, 2011). However, recording face-to-face lectures might have negative effects on students' class attendance and it restricts the structure of in-class sessions (O'Callaghan et al., 2017).

Literature provides a variety of examples regarding to lecture capture techniques in higher education and STEM subjects. These examples includes techniques such as i.e. providing slides accompanied by an audio narration of a lecturer and providing authentic video from the classroom (Al-Nashash & Gunn, 2013; Andersson & Nilsen, 2006; Karnad, 2013; Oktaviyanthi & Herman, 2016; Owston et al., 2011; Prodanov, 2012).

The lecture capture method utilised in this study – the short screencast videos – is introduced next. Subsequently, the used technology for making screencasts is presented.

2.3.2.1 Screencast as a lecture capture method

Screencast is a method for making lecture captures via recording of computer-screen activities, including audio content (Brown et al., 2009). In the recent years, recording screencasts has become a very popular method because of the availability of tablet computers and easy-to-use applications freely available online. Also publishing screencast videos is very easy on YouTube or other cloud services. Thus, the barriers to begin using new technology are low.

This study concentrates on screencast videos. Because all the screencasts for this work have been pedagogically planned, the produced videos are called short educational video lectures even though the videos have been produced by the screencast method. Each screencast video is a couple of minutes in length, includes an audio narration by a lecturer, and created using a tablet or PC. The term short educational video lectures has been used to emphasise that the videos are compact and short entities produced by a lecturer.

Screencasts have been chosen for making lecture captures for a number of reasons. First, we have used videos to activate students' learning, enable blended learning possibilities and provide additional resources. Thus, we made short videos instead of recording face-to-face lectures because students tend to prefer shorter videos over longer ones. A study by Guo, Kim and Rubin (2014) showed that with video lectures, the most significant indicator of student engagement was video length: the shortest videos had the highest engagement. Shorter videos might engage more also because they are meticulous planned (Guo et al., 2014). Soong et al. (2006) and Pursel and Fang (2011) also noted that students will watch videos only on the topics that are most useful to their current learning purposes.

In addition to short, we made easy-to-use videos, as students may not use the videos if they are too difficult to use. Thus, it was important to ensure that the students were able to watch the videos on their tablets, computers or smart phones. In fact, if students' experience e-learning resources as easy to use, it may have a positive impact on their motivation and help them 'use their available cognitive capacity for appropriate cognitive processing during learning' (Sung & Mayer, 2012).

As TAMK uses Moodle as a learning management system, it was possible to deliver the course materials, including the videos, through Moodle. In that way, short videos were easily managed. Moodle also enables the monitoring of students' activity through log files.

2.3.2.2 Research on screencasts in engineering studies

The utilisation of screencasts in mathematics and engineering studies have been investigated broadly (e.g., Dunn et al., 2015; Green et al., 2012; Harrison et al., 2009; Hsin & Cigas, 2013; Mullamphy et al., 2010; Pinder-Grover et al., 2011). Many positive effects of the utilisation of screencasts have been reported. One of them is the increase in flexibility and accessibility provided by screencasts (Mullamphy et al., 2010). Students also appreciate the possibility to pause and replay the content, which allows them to watch the videos at their own pace during revision, for example (Mullamphy et al., 2010).

Overall, in engineering studies, screencasts have been perceived to be useful for explaining concepts and procedures (Green et al., 2012). However, it appears that students may prefer direct interaction and immediate feedback, especially when dealing with challenging concepts that may be difficult to explain in a screencast (Mullamphy et al., 2010).

Evidence indicates that screencasts also have a positive effect on students' performance (Loch, Jordan, Lowe & Mestel, 2014). In engineering studies, the students who relied more on screencasts achieved significantly higher course grades and competency than others (Green et al., 2012). The utilisation of screencasts may also provide a deeper understanding of course concepts (Green et al., 2012).

However, learning can occur in various scenarios through various resources. It is difficult to establish which activities have had an effect on students' learning.

Typically, mathematics screencasts are produced by a lecturer who uses writing and audio narration. Screencasts like this allow communication through different channels (see multimedia learning, Mayer, 2003), such as narration and visual aids (Mullamphy et al., 2010). Because of these different channels, it appears that screencasts, including visual and audio elements, might be more effective in helping students learn than learning from text or narration alone (Dunn et al., 2015). This notion is derived from cognitive science about human learning and especially multimedia learning (Mayer, 2003). According to this theory, students can gain a deeper understanding of content from a combination of narration, text and pictures than from narration, text or pictures alone (Mayer, 2003). In general, an instructional challenge in utilising educational technology for learning purposes is 'how to encourage learners to engage in appropriate cognitive processing during learning' (Mayer, 2008, p. 762).

2.3.2.3 Short educational video lectures used in this study

For this study, screencasts were produced mainly with iPad using the ShowMe (see Figure 5.) and Educreations applications. Additionally, Echo360 and Jing were used in some cases to develop screencasts for PCs. Research has shown that tablet videos with handwriting are considered engaging (Cross et al., 2013), and students engage more with handwriting tablet videos than with other type of videos (Guo et al., 2014). The term short educational video lecturing has been used to refer a short and compact educational screencast video with audio narration produced by a lecturer. The author designed and recorded all the video materials by herself. The reasons for this approach are explained in section 4.2.2.

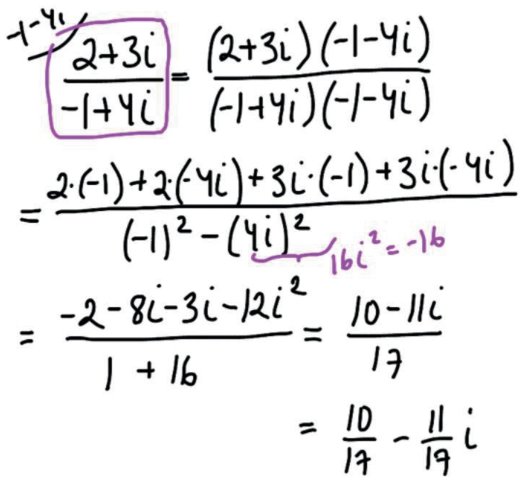

Figure 5. Screenshot of an example produced with iPad using ShowMe

Nokelainen (2006) explains that interesting digital learning material can promote learner's activity and own control. Thus, breaking down the learning materials into meaningful packages (Wilson & Myers, 2000) can support learning. Nokelainen (2006) created a list of ten criteria for assessing the pedagogical usability of digital learning materials: learner control, learner activity, cooperative/collaborative learning, goal orientation, applicability, added value, motivation, valuation of previous knowledge, flexibility and feedback. These usability criteria also take into account learner's proficiency. When designing learning materials, attention should be paid to the topics that will most likely be challenging for the learners and supplementary materials should be provided for these topics. Hence, when designing learning materials, both the learner's proficiency and the ongoing learning process should be considered (Nokelainen, 2006; Wilson & Myers, 2000).

The aim of the short educational video lecture used in this study was to deliver a select part of the subject matter content in a short video format. Before creating the video, questions such as these were asked: 'What is the most relevant and important content in the current topic?', 'How can the content be presented in a simple way without losing any important details?', 'Which topics will most likely cause problems for the students?' and 'What are the students' prerequisites for the topic?'. The focus of the design was on pedagogical usability while promoting students' active learning.

The content taught in each video was first planned on paper. Next, pre-designed slides were audio recorded. Thus, each short educational video lecture was carefully planned and scripted before recording. This method ensured that the videos were short and the pedagogical usability was high (Nokelainen, 2006). For designing content of videos, the author relied on her pedagogical content knowledge to identify 'what makes learning of specific topics easy or difficult' (Shulman, 1986, p. 9).

As each video was planned and scripted before recording, the videos were pedagogically designed entities. One entity included, for example, a brief teaching of theory and example exercises with step-by-step solutions. As all the videos were pre-designed, and each recording was as short as possible without any unnecessary delays or pauses. If the same content were taught in a classroom, it would have taken at least three times the teaching time, given the pauses and delays. It was important to keep the videos as short as possible to provide students the most useful content for their learning purposes and increase the pedagogical usability. Literature has supported this viewpoint. Meticulously planned short videos have facilitated better student engagement than longer ones (Guo et al., 2014). It also appears that students watch only certain parts of videos – those that are the most useful for their current learning purposes (Soong et al., 2006; Pursel & Fang, 2011).

During this research process, a versatile set of short educational video lectures were designed, produced and tested. The short educational video lectures were used in the following ways:

- as an introduction to a new topic,
- as a revision of a topic,
- as a supplementary example,
- as supplementary material to a challenging topic, and
- as a step-by-step solution for an exercise.

The short educational video lectures were designed and recorded for different educational purposes and delivered through TAMK's Moodle. However, as ShowMe and Educreations provide cloud storage for videos, only the links for these short video lectures were released via TAMK's Moodle. Thus, the materials were easy to manage and access through the Moodle.

2.3.3 Computer-aided assessment

Assessment plays an important role in educational learning; in fact, it is an integral part of learning. Students' accomplishments and assignments require some kind of assessment and feedback. With assessments, it is possible to motivate and engage students to study. However, it may also affect students negatively.

Overall, the measuring of competences varies greatly across subjects. Whereas some subjects require evaluation of participation or physical activity, others call for the measurement of performance with a final exam or a more continuous assessment approach. Since engineering studies are mathematical in nature, assessment has typically concentrated on measuring competence through exercises and different kinds of exams. In recent years, technology has begun to offer new opportunities for assessment. In fact, technology facilitates assessments in various ways, and one of them is computer-aided assessment (CAA). In this thesis, the term CAA refers to the use of computers to deliver, control, assess and analyse students' mathematics assignments.

An overall notion is that utilising technology in assessment can motivate students as they receive instant feedback about their progress (Sousa, 2016). Instant feedback is a criterion for pedagogical usability of digital learning materials, and it can help learners identify the problematic segments of their learning (Nokelainen, 2006).

Armbruster et al. (2009) implemented weekly quizzes to provide regular feedback and to help the students actively engage with the course material. They noticed that the students found the weekly quizzes to aid their learning. Studies have shown that providing clear feedback on students' performance can lead students to better learning outcomes (Hattie, 2012). Formative assessment such as quizzes appears to enhance students' learning more effectively than summative assessment (Sousa, 2016). Formative assessment concentrates on evaluating students' progress and providing feedback for promoting learning during the learning process. On the other hand, summative assessment evaluates students' learning typically at the end of the course against some specific learning outcome criteria.

This study concentrates on assessment only from the point of view of CAA. To facilitate students' activity and engagement, continuous formative assessment was implemented with the help of technology. In this study, CAA has been implemented in the form of mathematical online exercises. Mathematical online exercises support learning techniques such as practice testing and distributed practice (Dunlosky et al., 2013). The following section introduces existing research on CAA in mathematical engineering studies and mathematics. The subsequent section discusses the CAA utilised in this study.

2.3.3.1 Research on CAA in engineering studies and mathematics

Even though the CAA is not yet being used on a large scale, the number of teachers and students that already use CAA is growing (Sangwin, 2013). In general, it seems that mathematics (and mathematical engineering studies) teaching and learning are likely to change with information technology, as CAA can be used to assess not only simple procedural calculations but also more advanced problems (Rasila, Malinen & Tiitu, 2015).

In recent years, open-source e-assessment systems such as STACK, Numbas, DEWIS and Math have become widely available (Henderson, Gwynllyw, Hooper & Palipana, 2015). Further, the literature provides encouraging examples of the use of CAA in programming (Ala-Mutka, 2005; Hsiao, Sosnovsky & Brusilovsky, 2010; Ihantola, Ahoniemi, Karavirta & Seppälä, 2010; Pieterse, 2013), mathematics (Henderson et al., 2015; Henderson, Gwynllyw & Hooper, 2016; Rasila, Harjula & Zenger, 2007; Rasila, Havola, Majander & Malinen, 2010; Sangwin, 2010, 2013, 2015; Majander & Rasila, 2010) and chemistry (Lowry, 2005).

Overall, in mathematical engineering studies, CAA can be used as follows (adapted from Csapó et al., 2012; Sangwin, 2013):

- to develop and deliver different types of mathematical exercises, exams and quizzes automatically and semi-automatically,
- to make adaptive quizzes and tests, where the next question depends on students' responses or achievements,
- to generate mathematical exercises automatically, also using randomised parameters and questions,
- to check the syntax of students' responses automatically,
- to check the correctness of students' responses in mathematical exercises automatically and semi-automatically,
- to give personalised and instant feedback on mathematical exercises, exams and quizzes and
- to score performance automatically and semi-automatically.

In the context of mathematics, it has been reported that CAA is useful for learning the basics of mathematics (Rasila et al., 2011). Further, conducting exams with CAA has had a positive effect on students' learning (Henderson et al., 2016). In addition, it appears that CAA is more successful in engaging students (Henderson et al., 2015) and identifying those who are struggling with their studies (Henderson et al., 2016). In the following section, STACK CAA – a system used for student assessment in mathematics – is briefly introduced (Sangwin, 2013).

STACK has been developed by Chris Sangwin, and it can be integrated with Moodle. STACK exploits the CAS Maxima to:

- 'randomly generate problems in a structured mathematical way,
- establish the mathematical properties of expressions entered by the student,
- generate feedback, as necessary, which may include mathematical computations of the student's answer,
- help the teacher analyse the attempts at one question, or by one student' (Sangwin, 2015, p. 4).

A part of this study used STACK CAA for assessing students' competencies.

2.3.3.2 CAA in this study

In this study, CAA was implemented in the form of mathematical online exercises, delivered via TAMK's Moodle. In study 1 and 4, different kinds of Moodle questions were employed. The question types in STACK have been (only study 4) introduced previously (section 2.3.3.1). Figure 6. presents an example of a STACK exercise. In the example, the student has given an answer that the system has interpreted. The visual elements of STACK question type can be seen in the Figure 6.

Online exercises were provided to the students two to three times in each week of the seven- to eight-week mathematics courses. Though the online exercises were not compulsory, students were rewarded based on their activity. During the research, online exercises were provided for all of the author's mathematics courses. By the end of the design-based research process, online exercises were an integral part of the assessment and completion of the author's mathematics courses.

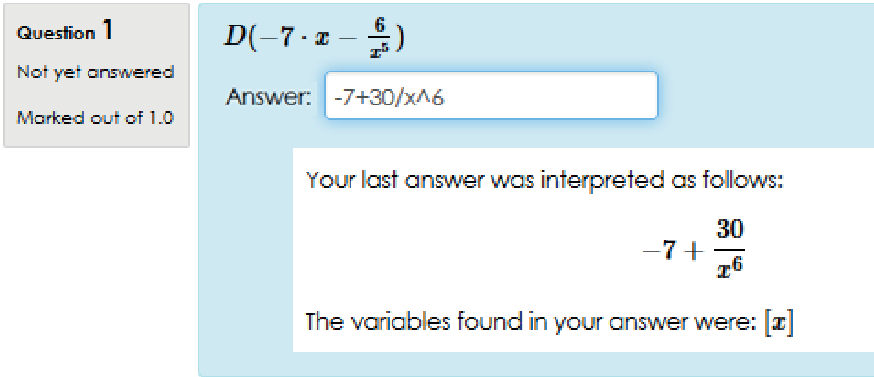

Figure 6. An example of STACK exercise

3 RESEARCH METHODOLOGY

This chapter summarises the overall research process of this study. The study concerns enhancing mathematical engineering education with the help of technology. The problems have been identified locally but, in the literature, similar problems have been recognised internationally. This work has been concentrated not only on developing separate methods. Instead, the focus has been more on developing the teaching/learning process and materials for that, and to advance knowledge about the utilisation of these and their effects. Since the core of these experiments was to develop the overall teaching/learning process, to transfer the results into practice and provide principles for changing instructional design, the research adopted a design-based research approach (also known as educational design research). The research task has been approached with interventions that have been developed and tested during the research process in UAS-level engineering mathematics teaching and learning context.

3.1 Design-based research

The term design-based research is usually comprised of a family of related research approaches with some variations in characteristics (Van den Akker, Gravemeijer, McKenney & Nieveen, 2006). The underlying notion and goals of these approaches are similar even though their focuses vary (Wang & Hannafin, 2005). The literature has also encompassed other labels for these approaches, such as design research, design studies, design experiments, development/developmental research and formative research (Herrington, McKenney, Reeves & Oliver, 2007; Van den Akker et al., 2006; Wang & Hannafin, 2005).

Recently, design-based research has become an important approach utilised in educational research contexts. For example, Swedish mathematics education research often utilises educational design research as a research approach (Liljekvist, Mellroth, Olsson, & Boesen 2017). Design-based research is 'designed by and for educators that seeks to increase the impact, transfer, and translation of education research into improved practice' (Anderson & Shattuck, 2012, p. 16). It is used to provide ‘how to do’ guidelines for instructor to enhance i.e. students mathematics learning (Liljekvist et al., 2017).

The overall aim of conducting design-based research is to build a stronger connection between an authentic learning context and theoretical research with designing and testing interventions that aims to improve some local educational practices (Amiel & Reeves, 2008; Design-Based Research Collective, 2003). Educational design-based research is a methodology for understanding, why some innovative educational practice works in real educational context. Hence, design-based research links educational practices and theoretical research, and helps to understand the relationship between them (Design-Based Research Collective, 2003). The needs of educational design-based research typically grounds from local practices and it ‘can provide a lens for understanding how theoretical claims about teaching and learning can be transformed into effective learning in educational settings’ (Design-Based Research Collective, 2003, p. 8).

Outcomes of design-based research are typically guidelines or design principles of some educational setting. Usually, design-based research is pursued to find an optimal solution for complex educational real-life problems. In fact, design-based research is suggested to conduct when there are not direct guidelines, how to approach some problem (Kelly in Van den Akker et al., 2007). Kelly (in Van den Akker et al., 2007, p. 76) also recommended using design-based research if one or more of the following statements apply:

- ‘When the content knowledge to be learned is new or being discovered even by the experts.
- When how to teach the content is unclear: pedagogical content knowledge is poor.
- When the instructional materials are poor or not available.
- When the teachers’ knowledge and skills are unsatisfactory.
- When the educational researchers’ knowledge of the content and instructional strategies or instructional materials are poor.
- When complex societal, policy or political factors may negatively affect progress.’

In design-based research, the nature of learning is typically explored through authentic learning context such as in a classroom or technology-enhanced learning environment. Even though design-based research experiments are conducted to develop theories (Cobb, Confrey, Lehrer & Schauble, 2003) about the learning process and means to support learning (Gravemeijer & Cobb, 2006), the main point of research is to have a local impact and influence on participants' learning (Barab, 2006). However, the idea of design-based research is not to explore the collection of activities that influence learning, but rather to understand learning ecology and its function (Cobb et al., 2003). Hence, conducting design research is not just designing and testing some educational interventions but understanding relationship between theory and practice in educational context (Design-Based Research Collective, 2003). Actually, the intent of design-based research is to develop, test and improve instruction theory locally, and to understand how it works (Gravemeijer & Cobb, 2006). One typical characteristic for design-based research is that the researchers work in close collaboration with the practitioners.

The central goal of educational design-based research is to connect theoretical claims about learning and practice. The research process (see Figure 7.) typically starts with identifying and analysing a real-world problem to which a solution will be sought. This phase includes reflections on existing experiences and exploring theory, following by the development of solutions. The core of design-based research is in iterative cycles in which the solution for educational problem is tested in practice. Typically, the research process encapsulates multiple cycles of development, testing and refinement to design, test and revise the design in a real educational context (Wang & Hannafin, 2005; Van den Akker et al., 2006; Reeves, 2006) and to understand why some theory-based design works in practice (Design-Based Research Collective, 2003). Even though the nature of design-based research is cyclical and interventions are designed and tested locally, the research process does not only evaluate the interventions, but it aims to understand and refine the solutions in practice and produce design principles to enhance similar research (Reeves, 2006; Amiel & Reeves, 2008).

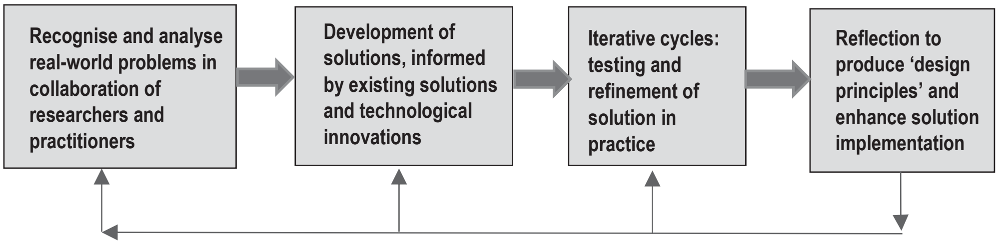

Figure 7. Phases of design-based research (Reeves, 2006, p. 59)

Figure 7. illustrates phases of design-based research (Reeves, 2006). However, other models for conducting design-based research have been introduced. Gravemeijer & Cobb (2006) have used and refined a somewhat simplified interpretation of conducting design-based research in mathematics education. They classified the phases of experiment as 1) preparing for the experiment, 2) experimenting in the classroom, and 3) conducting retrospective analyses. They also pointed out that typically, the goal of design-based research cannot be formulated in the form of one research question. In fact, new research questions might arise during the research process.

Whereas models for conducting design-based research vary, also the used terminology varies. This is quite typical in educational research. However, some characteristics that are typical for most design studies can be identified. Van den Akker et al. (2006, p. 4) characterised design-based research as follows:

- 'Interventionist: the research aims at designing an intervention in the real world.
- Iterative: the research incorporates a cyclic approach of design, evaluation and revision.
- Process-oriented: a black box model of input-output measurement is avoided; the focus is on understanding and improving interventions.
- Utility-oriented: the merit of a design is measured, in part, by its practicality for users in real contexts.
- Theory-oriented: the design is (at least partly) based upon theoretical propositions; and field testing of the design contributes to theory building.'

Hence, educational design-based research is rather flexible but theory-driven method to enhance local practices. However, it is not just for developing local practices but it can provide explanations of innovative practices and design principles for similar educational context beyond the local context (Design-Based Research Collective, 2003).

3.2 Selection of research approach

The aim of this research was to develop a model framework for engineering mathematics learning. Aim of this model was to decrease the problems identified in UAS-level mathematics courses and to activate and engage the students with the learning process. The problems identified were not only local, similar problems e.g. related to mathematical proficiency have been recognised internationally. There were also local problems that had been identified during mathematics courses at TAMK. These typical problems have been presented in section 1.3.4.

The concrete task at hand was to explore the ways to change teaching and learning practices by exploiting technology to achieve the research objectives. Hence, the research task focused on finding future-oriented and new solutions for engineering mathematics teaching and learning practices. Educational research has often been criticised for not being practice related. Design-based research as a research approach can contribute the linkage between theory and practice (Amiel & Reeves, 2008; Van den Akker et al., 2006) and increase the impact and transfer of research results into teaching practices (Anderson & Shattuck, 2012).

Design-based research has similarities with action research, especially with participatory action research. Different papers have acknowledged both similarities and dissimilarities between action research and design-based research. Also, integration of these two approaches have been used. However, design-based research is more characterised by new innovations (i.e. technological) whereas action research relies more on safe and known solutions (Goldkuhl, 2013). Typically, action research aims to enhance local organisation and to improve target problem or current practices. The intention of action research is not to generate design principles or guidelines of some educational setting, that is in design-based research, but to provide more local influence (Plomp in Van den Akker et al., 2007). Where design research emphasis future-oriented solutions, educational action research emphasis rather safe and retrospective problem solutions (Sloane, 2006).

On the other hand, research rarely finds a solution to practical educational problem at one time. Rather, solving complex practical problem requires designing, testing, evaluating and re-designing. This was the case also in this research process. The research encapsulates four different studies that approached the task at hand from different perspectives and had different emphasis. As the overall focus of the different studies was to develop the teaching and learning process by exploiting technology and promoting self-regulated learning, transfer the results into practice and provide principles for changing instructional design, the research adopted a design-based research approach.

During the research process, the author worked as a mathematics lecturer. Hence, it was natural to carry out the development process in the author's engineering mathematics courses. The different studies and experimentations have been conducted locally alongside the author's daily teaching.

The selection of a design-based research approach was supported also by the fact that the research task at hand was a complex problem to solve. There were no concrete how-to-do guidelines for solving the task (Kelly in Van den Akker et al., 2007). With the research it was wanted to have a local impact on students learning (Barab, 2006) but also to develop the teaching/learning strategies and materials, and to advance knowledge about the utilisation of these and their effects. The intention was not only influence locally but more widely transfer the results into practice and provide principles for changing instructional design.

However, how to change classroom practices and utilise technology in a meaningful way was unclear. In fact, at the beginning of the research, there were not instructional materials that were produced with the help of selected technology (e.g. screencasts and CAA) for UAS-level engineering mathematics studies. Because, utilising educational technology such as screencasts and CAA in engineering mathematics courses at UAS was in the early stages, the author did not have enough robust experience of instructional strategies to be utilised for changing classroom practices with the help of technology. All these factors supported the selection of a design-based research approach (Kelly in Van den Akker et al., 2007).

3.3 Research process

The overall research process started in 2011. There were local problems that had been recognized and identified during mathematics courses at TAMK. These problems have been presented in the section 1.3.4. Based on the local observations and literature, it was clear that the focus should be on students' activation.

After recognising the local problems in mathematics teaching and learning, the author familiarized herself to concepts and theories regarding to the task at hand and started to build the theoretical framework for the research. At this stage, the emphasis was on literature and familiarisation of available technology. As activating the students for learning was a central goal, promoting self-regulated learning was seen to be essential. Utilisation of educational technology provides possibilities for supporting self-regulated learning and students' activation. Hence, the focus of development process was on developing framework for engineering mathematics teaching and learning that utilises educational technology.

Based on literature, it was decided to implement screencasts and computer-aided assessment in mathematics teaching and learning framework. The research process included four studies after which educational interventions were put into practice. During the research process, the emphasis of development slightly varied depending on the stage of process. Thus, also the research questions varied during the process. Different studies and interventions are presented in Table 5.

The actual process of developing framework for mathematics teaching and learning started with testing suitability of new types of materials: short educational video lectures and online exercises as one part of Discrete Mathematics course. Students' competences were evaluated with pre- and posttest design. These actions were completed during the study 1. As an intervention of study 1, short educational video lectures were taken as instruments for mathematics learning in studies 2 and 3 and computer-aided assessment in study 4.

During the study 2, short educational video lectures were planned, produced and tested for 184 engineering students. As there were not appropriate screencast videos already produced, the author needed to produce the video materials at first. Short level test was one method that helped to target planning and production of learning materials. After implementing short educational video lectures on mathematics teaching and learning framework, students were asked to respond to the online questionnaire that measured their learning experience and motivation factors. Based on analysed results and observations, as an intervention of study 2, short educational video lectures were decided to implement more systematically in mathematics teaching and learning framework. As study 2 concentrated on learning experience and motivation factors, during study 3, the actual learning activity and learning outcomes were decided to review while utilising short educational video lectures more systematically.

The focus of study 3 was on viewing activity of short educational video lectures, learning analytics and learning outcomes. Students' performance were reviewed between the test and control groups. As an intervention of study 3 (and not forgetting the study 1), it was decided to develop the framework in the next direction. Hence, CAA was taken as integral part of engineering mathematics courses during the study 4. This phase included development of the overall framework including several iterative cycles and interventions: instruments for promoting self-regulated learning, CAA as an integral part of engineering mathematics courses and developing assessment of courses.

The typical design-based research process includes iterative cycles of development, testing and refinement (e.g. Wang & Hannafin, 2005; Van den Akker et al., 2006; Reeves, 2006). So did this study. The development process involved a total of twenty-five course implementations including, step-by-step development of solutions.

As the process encapsulated all the mathematics courses taught by the author, the key learning goals for each course needed to be examined and refined during the cycles. Special attention was paid on observing the most important parts of the course, and to help students to learn these vital topics. Which topics require more attention and which could be learnt by self-studying? The preliminary agenda for each of the courses was also identified, even though the schedule was naturally changed due to the needs of study groups.

Table 5. Different studies and interventions

Study	Year	Focus	Source of data	Participants	Type of data	Intervention after study
1	2012	Testing suitability of new types of materials: short educational video lectures and online exercises. Exploring competence changes with pre- and posttest design.	Pretest, posttest, experiences of lecturer and observations	pretest *n* = 22; posttest *n* = 18	qualitative and quantitative data	Short educational video lectures were taken as instruments for mathematics learning. Students learning experiences to be reviewed in study 2.
2	2013	Suitability of short educational video lectures. Learning experience and motivation factors.	Online questionnaire, level test, experiences of lecturer and observations	Participants *n* = 184, Respondents in questionnaire: *n* = 140	qualitative and quantitative data	Systematically utilisation of short educational video lectures. Learning activity and learning outcomes to be reviewed in study 3.
3	2014	Viewing activity of short educational video lectures, learning analytics and learning outcomes.	Moodle log files, final grades, experiences of lecturer and observations	test group *n* = 70, control group *n* = 59	qualitative and quantitative data	Developing overall framework (during study 4) including several iterative cycles and interventions: instruments for promoting self-regulated learning, CAA as an integral part of engineering mathematics courses, developing assessment.
4	2014-2017	Developing the overall framework for mathematics learning in UAS-level. Developing instruments for promoting self-regulated learning and developing evaluation of students.	Moodle log files, final grades, experiences of students and lecturer, observations	online exercises: 16 courses, 5 study groups, 171 students, 539 course completions, 104 feedback responses	qualitative and quantitative data	Developing grading and scaling the framework for requirements of different courses.

3.4 Target groups and data collection

The research was conducted at Tampere University of Applied Sciences with first year Bachelor's level engineering students. The study included twenty-five course implementations, and the participants were the members of study groups taught by the author.

During the research process, both qualitative and quantitative data was collected and analysed between the years 2011–2017. Due to the nature of the research, multiple methods for collecting the data were used. In fact, the mixed methods and variety of research tools (Anderson & Shattuck, 2012) are typically utilised in design-based research to better utilise the design (Wang & Hannafin, 2005).

The data collection method varied depending on the research task at hand. The following instruments of data collection were used during the research process:

- pretest and posttest (Bloom's taxonomy was utilised for planning the items) (study 1),
- short level test to explore the proficiency related to a certain topic (study 2),
- self-assessment test (Bloom's taxonomy was utilised for planning the items) (study 3),
- surveys in the form of online questionnaires to collect feedback from students in different studies (typically Likert scale: 1 = fully agree, 5 = fully disagree, 6 = don't know/haven't tried) (studies 2 & 3)
- observations during the in-class sessions and from Moodle platform (studies 1-4),
- Moodle log files to monitor students' learning activity and to assess online exercises (studies 3 & 4),
- Google Docs for reviewing students' activity of making exercises (studies 2-4),
- Moodle quizzes for delivering and assessing online exercises (studies 1 & 4),

- online polls (Socrative) to review students' homework activity (studies 2-4),

- log files of videos to determine how many students had watched a certain video (studies 1-4), and

- course scores, final grades and passing rates for the purpose of analysing the impact (studies 2-4).

The links for the online questionnaires (studies 2 and 4) can be found in Appendix. These questionnaires were used for collecting feedback from the students. However, not all the data collected with these questionnaires were utilised in this research.

The questionnaires were planned based on theoretical framework of the research. However, being able to collect course specific feedback, questionnaires included questions related to that. Even though generic measuring instruments have been widely used for all disciplines, in many cases discipline or course specific measuring instruments fit for the purposes of the study concerned better. This was the case in this study. Many generic measuring instruments include abundant amount of items that are outside the scope of this research. On the other hand, in engineering education context, various self-reporting instruments have been successfully developed and used to measure i.e. students' self-efficacy (Carberry, Lee & Ohland, 2010; Gerber et al., 2012; Schar, 2017), motivation constructs (Jones, Paretti, Hein & Knott, 2010) or effects of instructional practices (DeMonbrun et al., 2017; Shekhar et al., 2015). For the purposes of this study, the course specific online questionnaires were considered to serve the goals of the research the best.

Students' self-reporting is not necessarily the best way to measure things. However, as the overall goal of the research was to develop feasible framework for mathematics teaching and learning, collecting students' learning experiences was important and meaningful.

Overall, most of the data collection methods during the research process provided quantitative data. This data was analysed with descriptive statistics, including summaries of sample (percentages), distributions of variables (mean, standard deviation) and cross tabulations. The proper statistical method was chosen based on the type of data. In addition, the qualitative data was collected to obtain information about genuine user experiences and feedback about the experiments. The qualitative responses were analysed with a summative content analysis approach.

The student responses were grouped in categories during the data analysis, and overall the analysis was drawn based on the responses (Hsieh & Shannon, 2005).

3.5 Ethical considerations

Ethical considerations and data security were taken into account of during the whole research process. The Finnish National Advisory Board on Research Ethics gives national guidelines regarding to research ethics (TENK, 2012). They divide ethical principles of research in the humanities, social and behavioral sciences as following categories:

- respecting the autonomy of research subjects,
- avoiding harm, and
- privacy and data protection.

This research follows these national guidelines.

According to the national guidelines (TENK, 2012), participation in the research should be based on voluntary in institutional setting, and the participants need to be well informed about the research and its purposes. A special attention should be paid to what degree personal matters are dealt with in the research. This was the case in this research.

All the participants of the studies have been adult students from TAMK and they have been informed about the purposes of the ongoing research and what participating in the research means. During the research process, different questionnaires have been used but answering to these questionnaires has been voluntary. Hence, research has respected the students' autonomy to make decisions, whether or not to participate in the research.

When considering research context, the topics concerned include experiences of individuals. These experiences can include personal feelings and mental strains. In this research, the sensitive nature of data has been taken into account of. The participants and their responses have been treated with the great respect. Any data that could have been used for identifying the participant students, have been anonymised in reporting the results. These actions are in line with the national guidelines (TENK, 2012). According to national guidelines, the research should avoid causing any mental, financial or social harm.

As this research has been conducted in academic setting with authentic learning situations, different types of data have been collected and stored during the research process. All this data have been collected, processed, used and stored only by the author with the respect of systematic data and privacy protection. The electronic form of data has been stored securely. Only minor part of data is in a paper format and it has been stored in double locked place at TAMK. Only the author has an access to the research data.

4 STUDIES

This thesis builds on four different studies that examine the development of engineering matematics education from different perspective. The aim is to provide new viewpoints to instructional design of UAS-level engineering mathematics courses. The focus of the thesis has been on utilisation of educational technology to support students' active learning.

Different methods have been developed, tested and analysed during the research process. As the development has been examined from different perspectives, the research task at hand varied during the research process. The design-based research approach was used for developing the overall framework for mathematics teaching and learning. The research methodology is presented in the chapter 3.

4.1 New instruments for mathematics learning (Study 1)

4.1.1 Purpose of the study 1

At the beginning of the academic year 2013, curricula for engineering degree programmes at TAMK were reformed. As the result of reform, most degree programmes removed separated groups for VET and HS backgrounded students. Regarding to engineering mathematics, the reform has meant following things:

- All compulsory mathematics courses are three ECTS and last for one academic period.
- Regardless the background studies, students have the same mathematics curriculum.
- The students with VET and HS background could study in the same study groups.
- Heterogeneity of the study groups increased.

The engineering mathematics courses at TAMK and curriculum reform are described in more detail in section 1.3.4.

The study was carried out during eight weeks Discrete Mathematics course (2 ECTS) for one group of students in 2012. The course was organized one semester before reform at the same time when new engineering curriculums were planned. Discrete Mathematics course was free choice course for all engineering students. However, it was mainly marketed for ICT and Electrical Engineering students.

Discrete Mathematics course covered a vast variety of topics related to mathematical logic. This study was targeted to propositional logic, which was one part of the course. In general, propositional logic is taught only in free choice courses at HSs in Finland. Thus, the overall prerequisites for participants had to be almost the same for everyone.

The aim of the study was to test suitability of new materials and developments in engineering mathematics teaching and learning. At the first time, learning materials included short educational video lectures and online exercises/tests that were delivered through Moodle. Even though the far-reaching goal was to develop engineering mathematics education more widely, in this phase, only the suitability of used materials were tested with a small and controlled group. The suitability of materials was examined based on the participants' performance in the pre- and posttests (Dunlosky et al., 2013).

There were several reasons for that. First, it was expected that forthcoming curriculum reform (introduced in the section 1.3.4) would cause problems for organising mathematics courses. In the future, the lack of time resources and heterogeneity among study groups would challenge instructional design. However, it should be able to provide quality instructions for all students regardless of their mathematical proficiency and support students' active learning. With the small group that had relatively similar prerequisites for topic concerned, it was more controllable to test new types of materials. The one group pretest/posttest design can be used as pre-experimental design (Cohen, Manion & Morrison, 2002). Educational experimental research typically aims to manipulate some educational conditions and events in which are explored and observe, if there is an effect on the value of explored variable (Cohen, Manion & Morrison, 2002). In this study, the explored variable was students proficiency in propositional logic.

On the other hand, self-regulated learning is often discussed in relationship with students' learning activity. A student that self-regulates his/her learning, actively monitors and modifies learning behavior while obtaining personal learning goals (i.e. Zimmerman, 2013). For monitoring learning behavior, feedback from learning process is required (Schunk, 1989). New types of materials, short educational video lectures and online exercises/quizzes were seen as possible elements to promote self-regulated learning (Nicol, 2009). Also pre- and posttests were expected to support students self-regulation and show possible lack of their competence. Pretests can lead students to practice tested substance (Cohen, Manion & Morrison, 2002).

Overall, this study aims to preliminary explore the following research questions:

- (Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?
- (Q2) How can technology contribute to the organisation of engineering mathematics courses, including course content and assessment?
- (Q6) Is Bloom's taxonomy suitable for designing test items to recognise students' level of subject related knowledge in an engineering mathematics context?

4.1.2 Method

This study used the one group pretest and posttest design (Cohen, Manion & Morrison, 2002) to evaluate competence of participant students related to propositional logic. The pretest was carried out before the topics of propositional logic were studied with new methods. The exact same posttest was conducted after topics of propositional logic had been studied. Bloom's taxonomy (Bloom et al., 1956) of educational objectives were applied for designing of test items.

In mathematics context, the different levels of Bloom's taxonomy can be separated as follows (Bloom et al., 1956; Kastberg, 2003):

- **knowledge** - recalling, remembering and recognising mathematical information, fact, procedure, method, definition etc. mostly in a form which they have been presented.
- **comprehension** - comprehending and understanding the meaning of some fact, method, procedure etc. based on prior learning and being able to demonstrate that understanding.
- **application** - being able to use and apply previously learned information and skills in a new situation/context and in problem solving.

- **analysis** – being able to analyse, classify and put into separated components the information that has been previously learnt. Being able to understand the relations between the components.
- **synthesis** - combining, integrating, applying and expanding the mathematical components and the piece of information into a new situation based on the previously learned information.
- **evaluation** - evaluating, interpreting and justifying the value of information, solutions, methods and materials for given purpose to choose the best method for problem solving.

These levels are often grouped into two separated layers: the first level consist of taxonomy level one to three (or in some cases one to two) and the second layer levels four to six (or three to six). The first layer is often related to lower-order thinking and the second one to higher-order thinking (Thompson, 2008, 2011).

For example, Wilson (1971) and Joutsenlahti (2005) have created models for classifying mathematical exercises. Both of these models are based on Bloom's taxonomy but are much simpler. For example, Joutsenlahti has simplified Wilson's four level of cognitive knowledge into three levels. The reason for that was the difficulty of recognising the level on which a student is operating (Joutsenlahti, 2005). As students' prerequisites and mathematical proficiency vary, an exercise that represents application level for one can be analysis level exercise for someone else (Joutsenlahti, 2005). However, Joutsenlahti i.e. classified students' mathematical proficiency based on their test performance and explored differences in mathematical proficiency in national level. Simplified taxonomies appear to fit better for these types of generalizations.

Even though, it is difficult to separate in a specific exercise, which level of cognitive knowledge a student operates, Bloom's taxonomy was seen applicable for the purposes of this study. First, propositional logic is taught only in free choice courses at Finnish HSs. Hence, subject related prerequisites had to be almost the same for all the participants and the problematics regarding to proficiency difference (Joutsenlahti, 2005) didn't concern this study. Second, the course was new also for the instructor. The purpose was to explore, if Bloom's taxonomy is suitable for designing test items but also to test suitability of new materials and developments based on the students' performance in the pre-/posttests (Dunlosky et al., 2013). Hence, the focus was not on analysing mathematical proficiency more extensively. Propositional logic was one part of the course and using complex taxonomy for designing test items for specific part of the course was consider to help designing the test questions more sophisticated. Including six specific levels, Bloom's taxonomy was considered the most suitable framework for capturing the complexity of designing test items for specific topic.

4.1.2.1 Participants

The participants of the study were engineering students at TAMK. A total of twenty-two students completed the pretest. Their degree programmes were electrical engineering (six representatives), ICT engineering (fifteen representatives) and mechanical engineering (one representative). Eighteen students participated in both test (pre- and posttests).

4.1.2.2 Procedure

This study was targeted to learning of propositional logic, that was one part of Discrete Mathematics course. Before studying propositional logic, students' subject related prerequisites were tested with pretest (see Appendix). After students had studied propositional logic that included classroom teaching, short educational video lectures, online exercises/test and theory materials, they made the exact same test (posttest) again. The pre- and posttests were not exams and they didn't influence on the course grades. The participants were not asked to prepare to the tests. Hence, the students' performance in posttest mainly reflects the learning outcomes of the course. However, only general conclusion can be drawn, since there might be some other factors affecting the results of an individual student (Cohen, Manion & Morrison, 2002).

Bloom's taxonomy of educational objectives were applied for designing of test items to review the level of knowledge that respondents had after completing the propositional logic module. With the pretest/posttest results, suitability of used materials and methods were reviewed.

Taking into account of participants previous studies, their proficiency in propositional logic were expected to be quite low. Therefore the test items were designed to fit in the Bloom's taxonomy levels one to three (lower-order thinking). Also literature supported the idea. It is argued that undergraduate engineers usually operate on levels one to three (Suryanarayanan and Kyriakides, 2004). However, the level of knowledge is strongly context related as individual's cognitive level of knowledge varies depending on the subject matter.

The both tests, pretest and posttest, contained exact same propositional logic test items (see Appendix). In the pretest, students were also asked the general information such as a student ID-number, the gender, an engineering discipline, a starting year of studies and a short description about their mathematical proficiency. The student ID-numbers identified and combined the test results between the pretest and posttest. The analysis of other general information is not reported in this study.

Both tests contained six test items. The maximum score of the test was 24. By using the characterisation from the literature, the items were classified with Bloom's taxonomy as follows (the maximum points (abbreviation p) of each exercise are in brackets):

- Exercise 1 a, b, c, d and e: Knowledge (5 p)
- Exercise 2 a and b: Knowledge (2 p)
- Exercise 2 c and d: Comprehension (3 p)
- Exercise 3: Application (4 p)
- Exercise 4: Application (4 p)
- Exercise 5: Analysis (3 p)
- Exercise 6: Application (3 p)

Exercises 1 and 2 consisted of several short exercises and the other ones (exercises 3-6) only one exercise per test item including explanations, criticising and arguing inside the exercises. The test item one consisted of short exercises to memorise the logical connectives. This test item was ranked on knowledge level. The item two contained simple illustrations with the truth tables. This test item was ranked on knowledge and comprehension levels. The test item three required application level knowledge. In this item, students needed to be able to formalise the given statement and understand, when the statement is true. The item four was an exercise that combined the formalisation of statements with the concepts logical equivalence and tautology. This exercise was ranked on an application level as the solving of this exercise requires applying of the priorly learnt information in a new situation.

In the item five, students needed to demonstrate a method to define the given connective with two given connectives. This exercise required e.g. an ability to evaluate and combine the given information. Thus, the item was ranked on analysis level. In the exercise six, students needed to evaluate the value of the given statement. The statement demonstrated an error code of a machine. It required an ability to generalise the information and apply it on problem solving and was ranked on application level.

4.1.2.3 Results

After students completed the tests (pretest and posttest), their test answers were assessed. The maximum points of each question were presented in previous section. The tests were not course exams and students didn't prepare to the tests.

The results of the tests are described with descriptive statistics. A non-parametric Wilcoxon signed-rank test was used to analyse the results between the pre- and posttests as the data was not normally distributed. Non-parametric tests can be utilised especilly for small samples (Cohen, Manion & Morrison, 2002).

A total of twenty-two students completed the pretest and eighteen of those completed also the posttest. The general statistical indicators are presented separately for the both tests. However, the comparison between the test results was made only for those eighteen exactly the same students to be comparable.

The easiest test item was exercise 1 in the pretest although, the average score was quite low (Avg/Max = 29 %). In the posttest, the easiest test items were exercises 2 (Avg/Max = 90 %) and 1 (Avg/Max = 83 %). Overall, the students performed weakly in the pretest as the second most difficult test item in the posttest got higher average points than the easiest test item in the pretest.

Reflecting the posttest results through Bloom's taxonomy, the students performed quite well in the knowledge and comprehension level test items. On the other hand, e.g. the analysis level knowledge was practically unreachable. The application level scores differed from 38 % to 63 % in the posttest. By taking into account the students' proficiency of propositional logic, it's easily understood that for novices the analysis level knowledge is difficult to adopt. These results are mostly consistent with the literature.

In the pretest, students didn't show comprehension, application or analysis level knowledge. Only the knowledge level test item (exercise 1) got average points (Avg/Max) near 30 %. In the posttest, only evaluation level test item got mean under that. In general, this illustrates that before studying the propositional logic, a part of the students recognised certain fact or method but didn't have (or had shortage of) conceptual understanding or procedural fluency (concepts applied from Kilpatrick, Swafford, and Findell, 2001, 116). The posttest results indicated that students achieved conceptual understanding and procedural fluency related to propositional logic during Discrete Mathematics course. The posttest also showed that a part of the students had strategic competence and they were able to apply knowledge they had learnt during the course.

Table 6 shows the results of the pre- and posttests. In general, it can be easily observed that students performed much better in the posttest by comparing either total points or each test item separately. As the maximum points varied between the test items, the percentages that describe the mean points per maximum points are presented for each item. The results showed that the most difficult test item was exercise five and only eight students attempted to solve it in the posttest.

Table 6. Pre- and posttests results per test item

Test item	Pretest			Posttest			Max
	Avg	Sd	Avg/Max [%]	Avg	Sd	Avg/Max [%]	
1	1,45	1,28	29 %	4,14	1,40	83 %	5
2	0,70	1,06	14 %	4,50	0,73	90 %	5
3	0,33	0,71	8 %	2,28	1,29	57 %	4
4	0,23	0,61	6 %	2,53	1,46	63 %	4
5	0,05	0,21	2 %	0,25	0,55	8 %	3
6	0,16	0,42	5 %	1,14	1,15	38 %	3
Total	2,92	3,33	12 %	14,83	4,34	62 %	

As the sample was small and the data was not normally distributed, a non-parametric one-tail Wilcoxon signed-rank test was used to analyse the results between the pre- and posttests (Cohen, Manion & Morrison, 2002). *Z*- and *p*-values for each test item and total scores are presented in Table 7.

Table 7. z- and p-values

Test item	*z*	*p*
1	3,61	0,0002
2	3,71	0,0001
3	3,50	0,0002
4	3,50	0,0002
5	-	-
6	2,53	0,0057
Total	3,71	0,0001

The Wilcoxon signed-rank test indicated that the posttest scores were statistically significantly higher than the scores in the pretest when considering the test items 1-4 total scores ($p < 0{,}001$) and test item 6 ($p < 0{,}006$). Only five students were able to change their scores in the exercise 5, and therefore the Wilcoxon was not applied.

4.1.2.4 Discussion

This study was carried out during Discrete Mathematics course for one group of students in 2012. The current course was free choice course for engineering students. During the study, it was tested suitability of new types of learning materials in engineering mathematics context and to explore, if the Bloom's taxonomy can be utilised for designing test items to recognise students' proficiency in mathematics context. At the first time, learning materials included short educational video lectures and online exercises/tests.

Typically, educational experimental research explores some educational event or condition, which is manipulated and after that it is observed, if the manipulation has an effect on the value of explored variable (Cohen, Manion & Morrison, 2002). This was the case in this study, where the explored variable was students' proficiency of propositional logic.

The suitability of new types of materials was tested with a small and controlled group by using pre- and posttests for measuring participants' performance before and after studying topics of propositional logic with new materials. Bloom's taxonomy was applied for planning the test items. Wilcoxon signed-rank test was used for analysing pre-/posttest data as the data was not normally distributed (Cohen, Manion & Morrison, 2002).

The pretest indicated that the participants' prerequisites of propositional logic was weak. This was expected result as mathematical logic is only taught in free choice courses at HSs in Finland. The posttest results indicated that students' performance had significantly increased during the course and they had learnt conceptual understanding and procedural fluency (Kilpatrick, Swafford, and Findell, 2001) in propositional logic. In addition, a part of the students learnt to apply knowledge they had learnt during propositional logic. The results are consistent with the literature. It is argued that undergraduate engineers usually operate on Bloom's taxonomy levels one to three (Suryanarayanan and Kyriakides, 2004). From this perspective, the participants of the study achieved mostly the expected learning outcomes.

When considering the results, it's important to notice that the study only indicates that with this sample, participants performed significantly better in the posttest. The method for example didn't recognise, how the students had achieved their increased competence and which activities they had put in action. Without a control group, it's difficult to observe whether the improvments have effects on students learning. Also literature recognises this problematic in educational research (Cohen, Manion & Morrison, 2002). Although, based on the results of the pre-experimental design, it appears that the new types of learning materials are useful and feasible for UAS-level students' learning purposes as the expected learning outcomes were achieved. At the first time, the learning materials included short educational video lectures and online quizzes/exercises.

It is also important to recognise that this study only gives guidelines about student's proficiency in propositional logic. For example, if special attention is paid on some test item type during the contact lessons, it will probably influence on the test result. In tests like this, some student may also misunderstand some test items. Thus, more reliable test results would require more test items and more participants especially if the results would be used for measuring students' proficiency in general (which in fact is not recommended). For example, if a student fails the application level test item it doesn't necessarily implicate that the student totally lacks the application level knowledge. However, the method and its results served the purposes of the study well enough and the conclusions related to used materials can be drawn.

Alltogether, applying Bloom's taxonomy for designing the test items was valuable. When putting attention on level of knowledge while designing the test items, it forced to consider the format of questions more sophisticated and consider what exactly students' should know about the topic. Therefore, Bloom's taxonomy served well the designing of test items in the context of this study, where the course was new for the instructor.

From the perspective of self-regulation, this study gave encouraging results. Short educational video lectures and online exercises/quizzes can be feasible elements when promoting students' self-regulated learning (Nicol, 2009; Dunlosky et al., 2013). In the process of self-regulation, monitoring learning process and learning behavior are essential. Hence, getting feedback about performance during the learning process is important (Schunk, 1989). However, more research is required to explore the potential of short educational video lectures and online exercises/quizzes to support students learning regulation.

Based on encouraging experiences of the study 1, short educational video lectures (studies 2 and 3) and computer-aided assessment (study 4) were taken as instruments for mathematics learning in the engineering mathematics courses of the author. Study 1 gave perspectives on designing of short educational video lectures and online exercises. The experiences showed that attention should be paid to designing the content of videos more sophisticated. Furthermore, the purpose and importance of online exercises as a part of students' learning process should be explored in more detail.

4.2 Short educational video lectures in mathematics learning (Study 2)

4.2.1 Purpose of the study 2

Despite educational videos have been utilised for teaching and learning purposes for years, research on UAS context has been limited. Research on university level can be applied for some extent but it has limitations. First, mathematics courses at UAS are typically organized in 30-45 students' groups. Thus, the teaching is not organized in lecture halls but in classrooms. Secondly, the in-class sessions at TAMK include both theory and practice (Rahkola, 2016). Typically, a lecturer does not keep lectures but rather teaches, keep interaction with the students and guide them with calculations. Thus, in-class sessions are combination of traditional lecture and exercise class but still largely teacher-centered activity. Third, UAS students possess weaker mathematical competence than students of science universities. This can be easily observed e.g. from (Figure 1.). As one-third of the incoming students have vocational school (VET) background, their mathematical proficiency are different, than the students with high school (HS) background. Overall, it has been recognised that the depth and extent of the subject matter content at the UAS-level mathematics courses are different than science universities (Rahkola, 2016). The competency requirements at the starting level in UAS are low and the used methods don't meet the requirements of science university-level mathematics (Pohjolainen, 2005).

As an intervention of the study 1, short educational video lectures were taken as instruments for mathematics learning. The main purpose of this study was to examine the short educational video lectures in order to explain

- (Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?
- (Q2) How can technology contribute to the organisation of engineering mathematics courses, including course content and assessment?
- (Q3) How is the utilisation of educational technology, such as short educational video lectures and computer-aided assessment, experienced by UAS students in the learning and teaching of engineering mathematics?
- (Q7) Do components of self-regulation, such as intrinsic/extrinsic motivation, affect students' learning experience or performance in an engineering mathematics context?

As the study 1 mostly concentrated to reflect students' competence and using new types of educational technology such as screencasts and CAA, this study concentrates in learning experience and motivation factors. The overall goal of this dissertation is to develop a model framework for effective and meaningful mathematics learning by taking advantages of educational technology. This goal includes that students actively take response of their learning process. The research on learning self-regulation suggests putting emphasis on developing instruments that promote students' self-regulated learning (Zimmerman, 2002). Self-regulated learning is often connected with students' motivation and learning activity. A student that self-regulates one's own learning, actively monitors and modifies learning behavior while attaining personally set learning goals. For monitoring, the feedback from learning process is required (Schunk, 1989). Self-regulation can increase students' academic achievement, engagement and motivation (Schunk & Zimmerman, 1998; Zimmerman, 2000; Zimmerman & Schunk, 2001; Zimmerman & Schunk, 2008; Schunk & Zimmerman, 2012). Using educational technology such as short educational videos (Kitsantas, 2013) especially in higher education context can promote learners' self-regulative processes (Kitsantas & Dabbagh, 2010) that may improve learning outcomes (Dabbagh & Kitsantas, 2004).

4.2.2 Pedagogically planned short educational video lectures

During this study, pedagogically planned short educational video lectures were implemented for three mathematics courses: Introduction to Mathematics, Mathematics 2 and Geometry and Vector Algebra courses. The term short educational video lectures has been used to emphasise that the videos are compact, short, pedagogically planned and produced by a lecturer.

Even though during the study 1, the short educational video lectures were tested, Mathematics 2 was the first course, where video materials were utilised more widely. Mathematics 2 was organized in the spring semester 2013 and Introduction to Mathematics and Geometry and Vector Algebra in the autumn semester 2013.

As the incoming students' background studies differ in UAS, their mathematical proficiency varies also. For example, in Mathematics 2 course, some of the students were familiar with the calculation of the derivatives and the others had not even heard of it. To meet the needs of the students, video content needed to plan. On that account, students' mathematical proficiency related to the derivatives was tested with the short level test to get more information about the students' prerequisites. From the perspective of self-regulation, the test worked for the students also as an element to recognise the subject matter knowledge. The results of the level test were used when planning the content for the short educational video lectures.

The author planned and recorded all the video materials by herself. There were several reasons for that. First, the author wanted to teach course topics in the most comprehensible way to a specific student cohort by using her pedagogical content knowledge (Shulman, 1986). Second, during this study, appropriate video materials were not available in Finnish. After that, i.e. Opetus.tv has published significant number of videos for mathematics learning purposes. However, at that time, only limited amount of short educational videos narrated in Finnish were freely available at the course context. On the other hand, videos wanted to be as compact as possible. In the light of early research (Soong et al., 2006; Pursel & Fang, 2011), meticulous planning of videos was expected to increase videos' usability and applicability.

4.2.3 Method

4.2.3.1 Participants

The study 2 was carried out during three mathematics courses in 2013: Introduction to Mathematics, Mathematics 2 and Geometry and Vector Algebra. The study participants were 184 technology students at TAMK in which 140 students responded to electronic survey. The majority of survey participants was male (88 %) and the minority female (12 %). 40 % of participants had studied in HS, 39 % in VET and 21 % had double degree (DD).

4.2.3.2 Procedure

As an intervention of study 1, pedagogically planned short educational video lectures were implemented as a part of author's mathematics courses. The different courses were selected to be able to test short educational video lectures for different types of mathematics courses and for different study groups. During the study 2, the videos were used for different purposes such as introducing theory, supplementary examples and step-by-step solution for exercises. As the focus of the study was on students' learning experience, collecting feedback of the students' experiences was important. The students' experiences of short educational video lectures were explored with the electronic questionnaire. The questionnaire identified in what ways the short educational video lectures served or enhanced the students' learning. As students self-regulate their own learning more effectively when they are motivated towards the learning task (Zimmerman & Schunk, 2008; Zimmerman, 2008), it was wanted to explore if students learning experience and some motivation factors are related.

The student questionnaire was planned under the themes students' background, motivation factors, experiences of mathematics learning and experiences of short educational video lectures. The background pattern explored gender, degree programme and background studies. For designing the questions related to motivation factors and experiences of mathematics learning, early studies were utilised (Huikkola, Silius & Pohjolainen, 2008; Pintrich et al., 1993; Pohjolainen et al., 2006; Tuan, Chin & Shieh, 2005).

The feedback was collected with the questionnaire at the end of the mathematics courses (Introduction to Mathematics, Mathematics 2 and Geometry and Vector

Algebra). The questionnaire included both qualitative and quantitative questions. Most of the quantitative statements were constituted using 5-point Likert scale in addition with the 'don't know/haven't tried' option (1 = fully agree, 5 = fully disagree, 6 = don't know/haven't tried). The link for the questionnaire can be found in Appendix.

Measuring learning experience

In general, different instruments and methods have been developed to measure students' self-regulated learning using interviews (Zimmerman & Martinez-Pons, 1986), questionnaires (Weinstein, Schulte & Palmer, 1987; Pintrich et al., 1991) and online measures (Zimmerman, 2008). The questionnaires such as Learning and Study Strategies Inventory LASSI (Weinstein, Schulte & Palmer, 1987) and Motivated Strategies for Learning Questionnaire MSLQ (Pintrich et al., 1991) include about 80 test items. Students respond to these questionnaires by self-rating. Self-Regulated Learning Interview Scale SRLIS (Zimmerman & Martinez-Pons, 1986) is a structured interview instrument, in which six questions are asked from the students. The problem in such questionnaires/interviews is that they classify measured components of self-regulation in different phases. Such component is for example anxiety that is classified to be included in motivation (LASSI and MSLQ) and in self-evaluation reactions (SRLIS) (Zimmerman, 2008). Also, compiling statements that measure only the desired ability is challenging. Some authors relates e.g. intrinsic motivation in terms of interesting tasks and the others in terms of satisfaction gained from engagement task (Ryan & Deci, 2000).

The questionnaires that measure students' attitude or motivation toward science learning have also been developed. Such questionnaires are for example SMTSL (Tuan et al., 2005), TIMSS (Martin & Kelly, 1996) and PISA (Pisa, 2003). However, these questionnaires do not measure course related motivation or learning experience. The purpose of the study 2 was to explore usability of short educational video lectures in mathematics learning context and review students' learning experience related to them. Hence, the purpose of the study was not on measuring students' overall motivation or self-regulatory processes but rather promoting self-regulated learning. As students self-regulate learning more effectively when they are motivated towards the learning task (Zimmerman & Schunk, 2008; Zimmerman, 2008), it was wanted to explore if some motivation factors and students experiences are related. Therefore, questionnaires such as LASSI and MSLQ were not relevant in the context of this study.

Academic motivation varies between the courses and different learning tasks. Motivation constitutes of various factors but also the levels of motivation fluctuate (Ryan & Deci, 2000). For example, motivation factors in MSLQ (Pintrich, 1991, Pitrich et al., 1993) are intrinsic goal orientation, extrinsic goal orientation, task value, control of learning beliefs, self-efficacy for learning and performance and test anxiety. Intrinsic and extrinsic motivation factors were the components that were reviewed as a part of the questionnaire.

Ryan and Deci (2000) defined intrinsic motivation as 'doing of an activity for its inherent satisfactions rather than for some separable consequence'. Hence, the emphasis is on process of attempting to accomplish something rather than in the result (Carbonneau, Vallerand, & Lafrenière, 2012). As the intrinsic motivation is important and pervasive for learning and results in better learning outcomes (Ryan & Deci, 2000), it was wanted to explore especially if the students intrinsic motivation correlates with learning experience. However, not every educational task is intrinsically interesting. Some activities need to be done because of its instrumental value. Extrinsic motivation refers to an activity that is done because of its instrumental value leading to a separable outcome (Ryan & Deci, 2000). Studying mathematics in engineering is not averagely considered as intrinsically motivating but rather studying needs to be done. Hence, the students' extrinsic motivation was explored and discussed in connection with their learning experience.

4.2.3.3 Results

A total of 184 technology students participated in the study 2. After they have completed the mathematics courses, they were asked to respond to the electronic questionnaire. 140 students responded to the questionnaire, which was 78 % of the participants. The questionnaire explored students' background, motivation factors, experiences of mathematics learning and experiences of short educational video lectures. 40 % of the respondents had previously studied in HS, 39 % in VET and 21 % had DD.

As the study 2 focused on exploring usability of short educational videos and reviewing learning experience related to them, the motivation factors of the students had a minor role in the research. Hence, only motivation factors such as intrinsic and extrinsic motivations are discussed. However, exploring the motivation factors in some extent brought added value to the research.

Regarding to motivation factors, the participants' intrinsic/extrinsic motivation were reviewed. About 30 % of the respondents had high and about half the medium level of intrinsic motivation. About quarter of the respondents had high and about half the medium level of extrinsic motivation. When combining these motivation factors, 13 % of the students had both high intrinsic and high extrinsic motivation. 11 % of the students had high intrinsic and medium extrinsic motivation.

About one-fifth of the respondents experienced mathematics learning as highly meaningful and 60 % as moderate meaningful. Meaningfulness is one component of mathematics interest (Mitchell, 1993). On the other hand, individual interest promotes self-regulated learning (Lee, Lee & Bong, 2014). When exploring the respondents' experiences related to videos, almost three-quarters experienced that 'studying mathematics from videos is meaningful'. Only 10 % of the respondents felt the opposite. The results were consistent regardless of the explored motivation factors.

Students were also asked, if the videos have affected on their motivation towards the course. Almost half of the respondents experienced that 'using videos as a teaching method increased my motivation towards the course'. The distribution of students' responses is presented in Figure 8. In addition, 40 % or the respondents that were not intrinsic motivated, experienced that 'using videos as a teaching method increased my motivation towards the course'.

The questionnaire included also open-ended questions to find out more in detail the experiences of the students. From the open-ended responses, the following factors that have impact on students' motivation could be identified (classified from the highest occurrence to the lowest):

- More classroom time for studying and calculating a lot of exercises including personal support from the lecturer,
- Supporting learning with different types of examples: step-by-step calculation examples, video examples and model solutions for homework exercises,
- Teaching methods and pedagogy,
- Nice and good lecturer.

Students experienced that they would need more in-class time for especially calculating exercises. They preferred to have different types of step-by-step calculation examples. The responses implicated that the amount of theory materials was sufficient but the students preferred to have model solution for as many exercises as possible. They experienced that the correct answer in not enough. A part of the students also responded that teaching methods and 'nice and good teacher' influence their motivation.

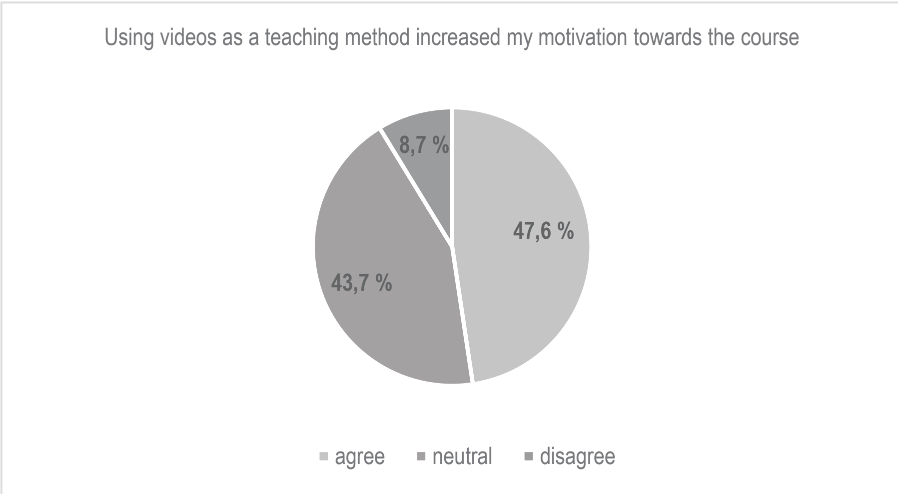

Figure 8. Distribution of motivation statement

Students' experiences related to importance of videos were also identified with open-ended questions. The most common issues that the students elicited were:

- Repeatability of videos. Being able to pause and replay the content.
- Step-by-step solution for exercises explained by the lecturer
- Independence from time and place
- Video with audio.

Especially, the students experienced the repeatability of the video content as beneficiary for their learning. They experienced that when viewing videos they have more time in peace to learn things, pause the videos and have time to think topic concerned. They can view videos whenever and wherever they want and this was experienced to be useful. A part of the students also responded that they learn better from the videos that include audio than reading the exact same content from the book. Mayer's (2003) cognitive theory of multimedia learning supports the results. As videos include both visual and audio elements, they have a potential to promote learning more effectively than learning the same content from text or audio alone (Dunn et al., 2015).

From the students responses can be noted that students paused and reviewed the videos in order to understand the content. For example, a part of the students reported that they tried to calculate exercises first at their own pace. They highlighted that if they were struggling, they have possibility to check step-by-step video solution which helped them to understand their mistakes and correct their exercise solutions.

The students were also asked to rank different learning methods based on, how they experienced they learn the best (maximum 5 and minimum 1). Table 8. shows the results that are classified according to the background studies of the participants. DD students were not classified as the students' mathematical background could not be identified. In this ranking, the students experienced 'doing exercises during the in-class sessions' as the best method to learn and 'listening teaching' as the second best method. An interesting note is that the students experienced 'learning theory materials on my own time' as the worst method to learn. Videos were excluded in the statement.

Table 8. The learning methods ranked by the students

Method	AVG VET	AVG HS	AVG Total
Doing exercises during the in-class sessions	4,1	4,1	4,1
Listening teaching	3,8	3,3	3,5
Doing homework exercises on my own time (excluding videos)	2,8	3,1	3,0
Learning from short educational video lectures	3,0	2,7	2,7
Learning theory materials on my own time (excluding videos)	2,0	2,4	2,2

The other thing worth noting is that the VET backgrounded students experienced 'learning from short educational video lectures' as slightly more important that ‘doing homework exercises on my own time’ whereas HS backgrounded experienced the importance of these methods in the opposite (unpaired t-test for equal variances, p = 0,05). This may be explained by weaker mathematics proficiency of the VET backgrounded students. When comparing intrinsic and extrinsic motivation factors and the learning methods, the results were consistent with overall results. There was no statistically significance difference between the students intrinsic or extrinsic motivation in relation to the learning methods.

In Mathematics 2 course, the student responses and respondents’ course grades were initialized (n = 45). The course grades of the respondents were distributed as follows: 18 % had grade 0 or 1, 33 % grade 2, 33 % grade 3 and 18 % grades 4 or 5. An interesting detail was that all the students with the grades 4 and 5 had high intrinsic motivation. Also 60 % of the students with a grade of 3 had high intrinsic motivation. On the contrary, 86 % of the students with the grades 0 or 1 had not intrinsic motivation. High level of intrinsic motivation had a negative correlation with the grade (r = -0,68, n = 45, p < 0,001). Taking into account of the used scale (1 = fully agree, 5 = fully disagree) this result indicates that high intrinsic motivation correlates with higher grades.

When comparing extrinsic goal orientation levels of the respondents, 91 % of the students with a grade of 3, 4 or 5 had medium level extrinsic goal orientation. This result is consistent with the literature. Lin, McKeachie and Kim (2003) reported that in terms of course grades, students with medium level of extrinsic goal orientation are more likely to perform better. Especially the students that had high intrinsic and medium extrinsic motivation typically perform well (Lin et al., 2003). The results of this study indicate that well-performing students had high intrinsic and medium extrinsic motivation. However, more research needs to be done in order to consider this result validity.

When interpreting lecturer’s experiences and students’ feedback, the observations and results indicate that it is possible to develop and improve course content, teaching/learning process and to promote self-regulated learning with short educational video lectures. During the in-class sessions, there is not time to offer e.g. additional examples to the students who would need extra resources. On the other hand, as the prerequisites vary in engineering mathematics courses, all the students are not in the same level of proficiency. However, to facilitate learning it would be important to be able to provide the most appropriate learning materials for individual learners (Wilson & Myers, 2000). Short educational video lectures enable providing e.g. supplementary materials for learners with different prerequisites.

Overall, short educational video lectures seem to make the learning process more flexible. This was also highlighted in the students' responses. The repeatability of videos was experiences as a helpful feature. Mullamphy et al. (2010) have reported a similar result. For example, the students that did not have any earlier experience with derivatives were able to learn basic differentiation rules from the videos at their own pace. Hence, they were able to use the time they required for understanding the topics concerned.

4.2.3.4 Discussion

Meticulous and studious instructional design can promote students' motivation towards mathematics learning (Middleton & Spanias, 1999). Designing different types of learning activities carefully and putting emphasis on instructional design, the stimulation of self-regulated learning can be promoted (Rowe & Rafferty, 2013). Instructional design that provides opportunities for students' self-regulation can promote learning outcomes and students' satisfaction (Nicol, 2009). In technology-enhanced learning environments, this requires a proper technological pedagogical content knowledge from the lecturer (Niess et al., 2009; Mishra & Koehler, 2006; Koehler & Mishra, 2009; Voogt et al., 2013).

The study 2 was carried out during Introduction to Mathematics, Mathematics 2 and Geometry and Vector Algebra courses during 2013 and it focused on exploring the students experiences related to short educational video lectures. Minor emphasis was on exploring, if intrinsic or extrinsic motivations are related to learning experience or students' performance. Similar design has been utilised before in the same context but the smaller sample and different theoretical framework (Kinnari-Korpela, 2015; Kinnari-Korpela & Korpela, 2014). The students' learning experiences were reviewed with the course specific online questionnaire.

The studies have indicated (Green et al., 2011; Green et al., 2012) that the students who utilised more screencasts in engineering had achieve significantly higher course grades and increasing competency due to their utilisation of screencasts. With the short educational videos students self-regulation can be supported (Kitsantas & Dabbagh, 2010) that may also improve learning outcomes (Dabbagh & Kitsantas, 2004).

Overall, the results indicate that short educational video lectures are meaningful and beneficiary in mathematics context. Three-quarters of the students experienced that studying mathematics from videos is meaningful. In fact, almost half of the students experienced that using videos as teaching method had increased their motivation towards the course. The results were consistent regardless of the motivational orientation (intrinsic/extrinsic). Lee et al. (2014) suggested promoting individual interest for encouraging students' self-regulated learning as interest is a direct predictor of self-regulated learning. Also in that sense, the results indicate that videos have a potential to promote self-regulated learning.

Students reported various benefits related to videos including repeatability and studying at their own convenience. A part of the students experienced that, when they were able to pause and replay the video content, the step-by-step video solutions helped them recognise their knowledge and understand their mistakes. From this point of view, the result indicates that short educational videos can promote students self-regulation process (Zimmerman, 2002), especially self-observation and self-judgement classes during performance or volitional control and/or self-reflection phases.

The students also ranked different learning methods based on, how they experienced they learn the best. VET backgrounded students experienced learning from videos as slightly more important that doing homework exercises. VET students typically have weaker mathematics proficiency, which can be recognise for example as a lack of algebraic routines (Näätänen, 2005; Tuohi, 2009). This result indicates that especially the students that are low proficient may benefit the videos the most.

Some of the students experienced they learn better from the videos than studying the exact same content from the book. Mayer's (2003) cognitive theory of multimedia learning supports the results. As videos include both visual and audio elements, they allow communication through different channels (Mayer, 2003; Mullamphy et al., 2010). Thus, short educational videos have a potential to promote learning more effectively than learning the same content from text or audio alone (Dunn et al., 2015).

The study 2 indicates that using short educational video lectures as a part of mathematics teaching and learning, the students' self-regulated learning can be promoted and their mathematics learning can be enhanced. As an intervention of this study, short educational video lectures were decided to implement more systematically in the authors' engineering mathematics courses. This means that a vast variety of short educational video lectures (examples, solutions of exercises, theory materials, hints for exercises etc.) were provided for different learning purposes for the students through Moodle. However, as the study 2 focused on students learning experience, for example learning activity or learning outcomes were not explored. The study 3 will focus on these aspects.

4.3 Viewing activity and supporting self-regulated learning (Study 3)

4.3.1 Purpose of the study 3

The study 1 mostly concentrated to reflect students' competence and using new types of educational technology such as screencasts and CAA. Instruments for measuring learning outcomes were pre- and posttests. On the other hand, the study 2 concentrated in learning experience. However, to get overall perspective and to be able to develop a model framework for effective and meaningful mathematics learning, it is not enough to explore only the student experience. On that account, this study concentrated to analyse students' activity of watching short educational video lectures. Also, elements for supporting self-regulated learning were provided during the courses.

The study was carried out among eight weeks Differential Calculus course for three separated study groups (A, B and C). The in-class teaching was organised for all the study groups. However, additional short educational video lectures were provided only for the test groups A and B. The control group C participated in classroom teaching without any additional short educational video content. The analytics of students' short video viewing activity has already been reported in (Kinnari-Korpela & Korpela, 2015). This study reports results by using self-regulated learning as theoretical framework.

The original publication explored the participants' activity of watching short educational video lectures and they effectiveness. That study concentrated on three questions: 1) 'How much the students utilized the short educational video lectures?', 2) 'How the viewing activity was distributed between different course score classes?' and 3) 'By comparing the course scores, does there seem to be any differences between the test and the control groups.' (Kinnari-Korpela & Korpela, 2015) This study expands the results by reflecting students' self-regulated learning with viewing activity and course scores.

This study aims to respond to the following research questions:

- (Q4) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning activity in an engineering mathematics context?

- (Q5) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning outcomes in an engineering mathematics context?
- (Q6) Is Bloom's taxonomy suitable for designing test items to recognise students' level of subject related knowledge in an engineering mathematics context?

Taking into account of the nature of the questions, also following research questions are indirectly related to this study:

- (Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?
- (Q2) How can technology contribute to the organisation of engineering mathematics courses, including course content and assessment?

4.3.2 Method

4.3.2.1 Participants

The participants of the study were 129 students of the separated study groups A, B and C. The students were bachelor's level engineering students that were studying their first spring semester. The study was carried out during compulsory Differential Calculus course. Before enrolling the course, the participants had studied same syllabus of mathematics in the UAS. The topics of Differential Calculus course cover i.e. concepts of limit and derivative when solving technical problems, interpreting derivative as rate of change, determining derivatives using graphical, numerical and symbolic methods and error estimates with differential method.

Forty-one of the participants represented the group A, twenty-nine the group B and fifty-nine the group C. The groups A and B were the test groups and C was the control group. The distributions of participants and their background studies have been presented in Table 9. The groups A and B consisted of the students that had high school degree or vocational school degree. All the group C students had high school degrees.

Table 9. Distribution of participants and background studies

Group	Number of Participants	High School	Vocational School
A	41	63 %	34 %
B	29	69 %	31 %
C	59	100 %	0 %

The students that had high school degree had studied either advanced or short syllabus in mathematics. This was the case in all the groups. The both high school mathematics syllabuses, advanced and short, included topics of the course. E.g. interpreting derivative as a rate of change and determining derivatives have been covered in high school mathematics syllabus at some extent. Mathematics syllabus of vocational school doesn't include any differential calculus.

On the other hand, practice has shown that students with vocational school background mainly have inadequate mathematical skills for engineering studies. Metsämuuronen (2016) highlighted, that only in few cases, vocational school provides necessary mathematical prerequisites for higher education. In terms of background of study groups, mathematical prerequisites for Differential Calculus was averagely weaker among the test groups' students.

4.3.2.2 Procedure

The study was carried out during eight weeks Differential Calculus course for first year engineering students. The in-class teaching was organised for all the study groups. However, additional short educational video lectures were provided only for the test groups A and B students. The control group C participated in classroom teaching but they didn't have any short educational video content available. The amount of provided short educational videos for the groups A and B was not exactly the same therefore the groups A and B were reviewed separately. Utilising the videos was optional for the students.

The learning materials of the courses were same for all the groups A, B and C. However, test groups' students had additional short educational video lectures available outside the classroom activities. The video lectures were offered of the topics that were challenging to the participants or where prerequisites varied most. Overall, thirteen short educational video lectures were provided for the group A and twelve for the group B. The lengths of the videos varied between three to twelve minutes. The total length of videos were over seventy minutes for the test group A and over sixty minutes for the test group B. Average length of videos was slightly over five minutes for both groups.

All the short educational video lectures were published in Moodle learning environment as additional resources. The test groups' activity of watching these videos were analysed to find out, how actively and to what extent students utilise the short videos. As Moodle provides log data from each user, students' watching activity was monitored individually. However, Moodle log data doesn't include any information about the length of an activity, thus the short video watching activity was monitored per-view. Due to this, for example possible pausing or replaying the video content does not appear in statistics. Students' viewing activity are discussed in self-regulated learning framework.

In addition to short videos, to support self-regulated learning of the test groups' students, they had possibility to recognise their course related knowledge by testing it with self-assessment form. The form based on Bloom's taxonomy of educational objectives and it was applied with course's review exercises (see Table 10.) about a week before course exam. All the groups got the review exercises but the students of test groups had possibility to review their knowledge also with self-assessment form. Utilising the form was not mandatory for the students. The meanings of different level of knowledge were also introduced to the students. For example, by managing 'knowledge'-level items, students' subject related knowledge was in a weak level.

The self-assessment form was one element to promote students' regulation of learning. The purpose of the self-assessment was to help students to recognise their knowledge and skills and to identify possible lack of it. Students also reported their experience on the usefulness of the form. The information collected with form was utilised to compare students' self-evaluation prior exam and their exam performance.

Table 10. Examples of self-assessment items for reviewing knowledge and skills

Level of knowledge	Test your knowledge and skills. Test items base on the review exercises.	Choose: (1) I think I know it (2) I am sure I know it (3) I do not know it
Knowledge: recalling, remembering and recognising mathematical information, fact, procedure, method, definition etc. mostly in a form which they have been presented.	1. I know, what does $\lim_{x \to 0-} f(x)$ mean in exercise 1. 2. I remember how to construct differential of a function. 3. I know, what does $f'(x) = 4$ mean and how to calculate it (exercise 6).	

At the end of the Differential Calculus courses, the final exam was held for all the test and control groups' students. The exam items were not exactly the same but they were planned to demand the same requirements in the knowledge. The course scores of the test groups and the control group were compared. All the short videos were published in Moodle learning environment as additional resources and the viewing activity was explored from Moodle logs files.

4.3.2.3 Results

The original publication (Kinnari-Korpela & Korpela, 2015) has reported students' viewing activity in Differential Calculus course and made comparison of performance between different study groups. This study reports key results of original publication and reviews results from the perspective of self-regulation.

Data from viewing activity

The original publication (Kinnari-Korpela & Korpela, 2015) reported that 86 % of test groups' students watched the short educational videos. This figure includes both active and passive students. However, there were variations in viewing activity between the students. Viewing activity between the participated students varied between zero and thirty-three watched videos. This discrepancy was expected due to the nature of short educational video lectures and the fact that the video resources were only additional materials. The viewing activity of test groups is presented in Table 11. (Kinnari-Korpela & Korpela, 2015). Overall, a total of 560 video views were recorded during the eight-week course, even though the videos were only additional resources.

How does the viewing activity correlate with final grades was not measured due the nature of short educational video lectures. However, the results in original publication indicated that the students with satisfactory or good mathematical knowledge (final grades 2 or 3) seemed to be the most active video watchers and the students with the grade 0 have watched only few videos. This was the case also with the students that had excellent mathematical knowledge (final grade 5). However, by considering the nature of videos, it was assumed that the students with the excellent subject matter knowledge do not benefit significantly from provided video content.

Table 11. Viewing activity of students (adapted from Kinnari-Korpela & Korpela, 2015)

Test Group	Total Amount of Views	Views/Partici pants	Views/Active Participants
A	378	9,2	10,2
B	182	6,3	7,9

The original publication (Kinnari-Korpela & Korpela, 2015) compared average scores of final exam between test groups and control group. The comparison is presented in Table 12. The passing rate of the course was higher in the test groups than in the control group. Furthermore, the average score in final exam was significantly higher in the test groups (mean = 16,1; sd = 5,32) than in the control group (mean = 14,3; sd = 5,5) using unpaired t-test for equal variances (t = -1,85; p = 0,03). The results of original publication indicated that the test groups performed significantly better than control group.

Table 12. Summary of the groups' performance (adapted from Kinnari-Korpela & Korpela, 2015)

Group	Number of Students	Average Score in Final Exam (Max 30)	Total Video Views	Passing Rate
Test (A, B)	70	16,1	560	86 %
Control (C)	59	14,3	0	78 %

In original publication, the distributions of the course scores were compared (Kinnari-Korpela & Korpela, 2015). The distributions have been presented in Figure 9. It can be easily observed, that in terms of course scores, test groups performed better. Almost 60 % of control group's students achieved less than half points from their final exam. The test groups performed better also in this comparison, as about one-third of them, got less than half points from final exam (Kinnari-Korpela & Korpela, 2015).

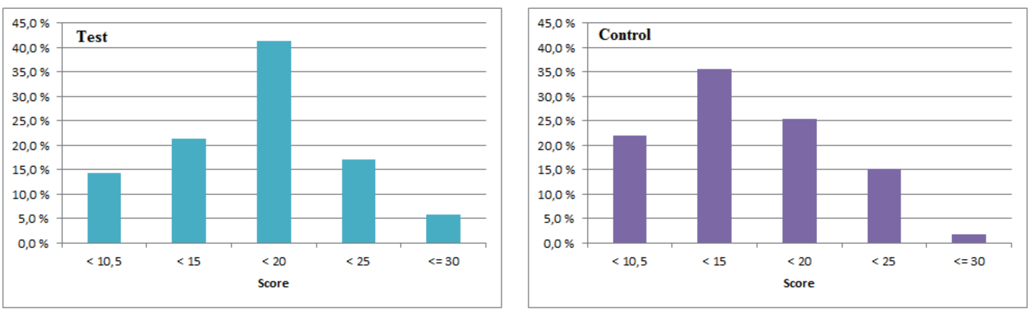

Figure 9. The distributions of scores between the test and control groups (Kinnari-Korpela & Korpela, 2015)

Students' self-regulation

To support self-regulated learning of the test groups' students, they had possibility to recognise their course related knowledge by testing it with self-assessment form (see Table 10.). Utilising the form was not mandatory for the students. After the final exam, the self-assessment forms were analysed and compared to the students' performance in final exam. Self-assessment form was linked to the review exercises and the students needed to reflect their course related knowledge based on, how they experienced to know the given items. 78 % (*n* = 70) of test groups' students completed the self-assessment form.

In the comparison of self-assessment form and final exam performance, each form item and students' self-assessment were checked and compared these to their performance in the final exam. As self-assessment form applied Bloom's taxonomy in the course's review exercise context, students were able to review their level of knowledge with thirteen test items. The meanings of different level of knowledge were also introduced to the students. For example, by managing "knowledge"-level items, it was explained that a student subject related knowledge was in a weak level.

From the comparison, the following dimensions were identified:

(1) weak skills/knowledge and does not recognise it,

(2) weak skills/knowledge and recognises it,

(3A) average skills/knowledge and does not recognise it,

(3B) average skills/knowledge and recognises it,

(4) good skills/knowledge and does not recognise it,

(5) good skills/knowledge and recognises it.

The categories of competence (weak, average and good) based on students' performance in the final exam and the categories of self-assessment (does not recognise and recognises) based on students' self-assessment responses.

In terms of usability of self-assessment form, 89 % of the respondents felt that with the form, they were able to reflect their skills and knowledge, 9 % were partly able to reflect their competence and 2 % were not able to reflect that. Helping to recognise subject related knowledge with the form emerged also from the open responses:

> 'It made me thinking, what I know already.'
>
> 'I recognised, which topics I know with certainty.'
>
> 'It helped me to recognise, which topics I need to practice most to improve my skills.'
>
> 'This is definitely a good review and much clearer way to go through your own skills than browsing material.'
>
> 'With the test, I recognised that I do not know enough about the topics.'
>
> 'It helped me to recognise, what do I need to practice to pass the course.'
>
> 'When you stop and think, you notice what you really know and what you do not know.'

The distribution of students for different identified dimensions has been presented in Table 13. One respondent did not write his/her name on the form and he/she could not be identified. 13 % of the respondents were identified as category 1 (dimension 1) students. These students had weak skills/knowledge and they didn't recognise it. Four of these students got final grade 0. None of grade 0 students with category 1 watched videos. In fact, category 1 students were the most passive video viewers. Also category 5 students (good skills/knowledge and recognises it), viewed only a few videos. However, by considering the nature of videos, it was assumed that the students with better subject matter knowledge do not benefit significantly from short educational video lectures.

Table 13. Identified dimensions and viewing activity

Identified Dimension	Amount of Identified Students	Average Video Views/Students
1	7	8 %
2	16	83 %
3A	2	46 %
3B	15	59 %
4	7	81 %
5	6	16 %

By comparing students viewing activity and identified dimensions, the most active video viewers were the students with category 'weak skills/knowledge and recognises it'. Almost as active students were the ones that were identified as 'good skills/knowledge and does not recognise it'. This category included also the students that were insecure about their subject related competence.

4.3.2.4 Discussion

The study was carried out with 129 students during eight weeks Differential Calculus course. Seventy students represented the test groups and fifty-nine the control group. In terms of background studies, mathematical prerequisites for Differential Calculus was averagely weaker among the test groups' students. A part of the results has already reported in Kinnari-Korpela & Korpela (2015). This study reports results by using self-regulated learning as theoretical framework.

Dunlosky et al. (2013) discussed ten effective learning techniques for students' self-regulated learning. Practice testing was one of the techniques that received high utility assessments. According to Dunlosky et al. (2013), practice testing is e.g. making self-testing over to the topics that have been learnt and it seems to improve learning. Practice testing also works in various learning conditions and benefits learners for different proficiency. In this study, practice testing was provided in a form of short educational video lectures and self-assessment form.

The in-class teaching was organised for all the study groups. However, additional short educational video lectures were provided only for the test groups students. Even though, the videos were one element for promoting students' self-regulated learning, they were provided for increasing learning outcomes. The control group participated in classroom teaching but they didn't have any short educational video content available. To support self-regulation of the test groups' students more intensively, they were able to test and recognise their course related knowledge with self-assessment form. Research has shown that self-regulative learning can increase academic achievement, students' engagement and motivation (Schunk & Zimmerman, 1998, 2012). Utilising the self-assessment form was not mandatory for the students.

The original publication (Kinnari-Korpela & Korpela, 2015) reported that a total of 560 video views were recorded during the eight-week course. The detected viewing activity was quite high, as almost 90 % of the test groups' students watched the videos. The short educational video lecturing seems to be one method to activate students, even though the viewing activity varies between the students.

From the perspective of learning regulation, a self-regulated learner actively monitors and modifies behavior while obtaining personal learning goals (Schunk, 1989). For monitoring, controlling and modifying behavior, feedback from learning process is more than relevant. During this study, students got feedback about their performance i.e. from self-assessment form and short educational video lectures. 89 % of the students that utilised self-assessment form felt that, they were able to reflect their skills and knowledge with the form.

Based on viewing activity figures, short educational video lectures have a potential to promote self-regulation by providing elements for self-monitoring and self-evaluation. Thus, they give instant feedback about students' performance such as, what do I need to practice more or what topics I already manage at the level that I am pursuing.

The results in original publication also indicated that the students with satisfactory/good mathematical knowledge (final grades 2 or 3) are the most active video watchers. On the contrary, the students with the grade 0 had watched only few videos. Combining the original publication results and students self-assessment (from this study), the most active video viewers were the students that had weak skills/knowledge of mathematics and who recognises it. Almost as active students were the ones that were identified as 'good skills/knowledge and does not recognise it'. The students that had weak skills/knowledge and they didn't recognise it, were the most passive video viewers. Over the half of these passive students got final grade 0.

From the perspective of self-regulation, students with 'weak skills/knowledge and does not recognise it', can't regulate their mathematics learning process. One major lack is that they do not recognise their competence. Instead of being active, these students were the most passive video viewers. It would have been interesting to find out, why this group was passive. Did they have a lack of motivation or didn't they know how to study?

During the experiment, it was detected that the test groups performed significantly better than the control group; both the passing rates as well as the average final scores of students were higher in the test groups. The results are consistent with the literature. In engineering studies, it has been identified that the students who utilised more screencasts achieved significantly higher course grades (Green et al., 2011) and increasing competency due to their utilisation of screencasts (Green et al., 2012).

Based on these study results, short educational video lectures have a potential to effect positively on students' performance. The results indicated that short educational video lectures seem to be one method to activate students. From the self-regulated learning perspective, such video lectures provide elements for promoting regulation.

Based on the experiences and results of the studies 1-3, short educational video lectures appears to have a positive role in UAS-level engineering mathematics teaching and learning. As an intervention of early studies, it was decided to develop the framework of mathematics teaching and learning in the next direction. Study 1 had provided experiences of utilising CAA but the issues regarding to implementing CAA more systematically and using CAA as a part of students learning process were not explored. Hence, CAA was taken as an integral part of engineering mathematics courses during the study 4.

4.4 Developing the framework for engineering mathematics learning (Study 4)

4.4.1 Purpose of the study 4

Previous studies 1-3 have shown that short educational video lectures have a place in UAS-level mathematics teaching and learning. The next step in this design-based research was to develop the overall framework for mathematics learning in UAS-level. This phase was implemented between spring semesters 2014-2017. This phase included exploring and developing the overall teaching and learning process, developing instruments for promoting self-regulated learning and developing evaluation of students. Educational technology had a central role for development work.

In the study 1, the forthcoming curriculum reform at TAMK was described. After curriculum reform was implemented, the financial resources available for mathematics teaching have decreased by 25 %. This has challenged the instructional design. As the amount of contact teaching has decreased, motivating, activating and engaging students into learning process have become increasingly important. Studying must take a place outside the classroom to an increasing extent.

Early research on self-regulated learning encouraged putting emphasis on developing instruments that promote self-regulated learning (Zimmerman, 2002). In fact, strategic self-regulation can be considered as a vital skill in the 21st century (Järvenoja, Järvelä & Malmberg, 2015). In the most theories and models of self-regulative learning, the learning is considered as a cyclical process and learning is seen as a student proactive activity rather than a reaction caused by teaching (Zimmerman, 2000).

Studies have indicated that self-regulative learning can increase students' academic achievement, engagement and motivation (Schunk & Zimmerman, 1998; Zimmerman, 2000, Zimmerman & Schunk, 2001; Schunk & Zimmerman, 2012). Student's self-regulation is not any mental ability but rather it can be learnt to self-regulate own learning (Schunk & Zimmerman, 1998; Zimmerman, 2000; Zimmerman & Schunk, 2001).

Dunlosky et al. (2013) contemplated effective learning techniques for self-regulated learning. So-called practice testing and distributed practice were two of the selected techniques. These concepts were presented in the section 2.3.1. Technology can contribute practice testing and distributed practice for example in a form of online self-testing (Dunlosky et al., 2013).

The first step of developing framework for mathematics teaching and learning was to explore, how to utilise educational technology for assessment purposes in UAS-level mathematical engineering studies. Practice has shown that the reasons for poor performance in mathematics are for example lacks of effort and practicing. According to the objectives of the research, developing assessment focused on promoting activity and practicing of students. For example, Budé et al. (2011) suggested using distributed practice as a learning technique, after they noticed that a group of statistics students performed better when using distributed practice during their course.

At the beginning of this study, mathematics learning during in-class sessions was still largely teacher-led instruction. The problems related to that are discussed in the section 1.3. However, when promoting self-regulated learning, the emphasis should be on students' own activity. Consequently, overall instructional design needed to remodel. This encapsulated making new types of learning materials, changing classroom practices to activate the students and changing assessment process.

The research results on flipped model of instruction have been encouraging. In a traditional mathematics classroom settings a lecturer has a central role for lecturing and giving instruction. Hence, the traditional classroom setting is largely teacher centered and the students are making exercises as a homework. The flipped model of instruction flips this common practice. Hence, in a flipped model of instruction, the students are learning theory and instructions at home and the time in the classrooms is used for making different types of assignments and exercises in pairs, groups or individually. Flipped model of instruction can increase students' engagement and activity, self-paced learning and course participation (Vaughan, 2014; Clark, 2015). Flipped model of instruction can make in-class sessions more effective (Clark, 2015).

On the other hand, a meta-analysis carried out by US Department of Education (Means et al., 2009) reviewed more than a thousand empirical studies related to e-learning. They found positive effects on learning with instructional design that emphasis blended or online learning. The flipped model of instruction can be considered as one type of blended learning setting. Blended learning setting refers instructions that take place in both classrooms and online.

The goal of the study was to develop the framework for mathematics teaching and learning in UAS-level, that promotes active learning of the students. Based on the previous studies and overall research goal, the following steps were set for the development of the framework:

- Central for the framework is to promote active learning and utilise instruments to support self-regulation of students. Hence, instruments for self-regulated learning need to be discussed and explored.
- Different types of assessment in mathematics learning by utilising CAA need to be tested and implemented.
- The students activity of making online assignments needs to be explored.

Even though during the study 1, a computer-aided assessment had been tested during Discrete Mathematics course, its utilisation has not been systematically tested. The emphasis of this study was to develop CAA as an integral part of engineering mathematics courses and to develop assessment related to that. Overall, this study deals with the following research questions:

- (Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?
- (Q2) How can technology contribute to the organisation of engineering mathematics courses, including course content and assessment? (This research question is closely connected to Q4 and Q5.)
- (Q4) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning activity in an engineering mathematics context? (This research question is closely connected to Q8.)
- (Q8) How can active learning of engineering mathematics with an emphasis on self-regulated learning be promoted?

4.4.2 Method

4.4.2.1 Participants

The participants of the study were 171 engineering students at TAMK from five different study groups. The research process involved a total of sixteen engineering mathematics courses for the target study groups. The author taught all these courses. During these courses, 539 course completions were registered for the participants. Depending on the study group, this figure encapsulates one to four course completions for each of the participants. In addition to the above figures, one group of students from the other lecturer was used as a control group for comparing the learning activity between the study groups.

4.4.2.2 Procedure

As one sub-goal of the study was to test CAA in different types of assignments, the first step was to explore, how to utilise educational technology for assessment purposes in mathematics. CAA is one tool for assessing mathematics learning (Sangwin, 2012). Mathematical online exercises were already tested with a small group in the study 1. This type of automatically assessed exercises were selected for the target of review. There were various reasons for that. Nowadays, it is possible to automatically assess 'significant proportion of existing Mathematics questions' (Sangwin, 2015). For example, Aalto University in Finland utilises CAA in all Bachelor's level mathematics courses (Rasila et al., 2015).

From student's self-regulation perspective, CAA can foster engagement of students (Henderson et al., 2015). A learner that self-regulates his/her learning needs feedback to monitor and modify behavior while obtaining his/her personal educational goals. CAA enables instant feedback of students' performance, thus it can help students to self-regulate. Instant feedback from learning progress can also promote students' motivation (Sousa, 2016).

The study started with testing two sets of online exercises during Function and Matrices (abbreviation FM) course for one study group in the spring 2014. After the experiment, the lecturer evaluated experiment and collected feedback from the students. After the feedback from student and experiences of lecturer had been analysed, these types of online exercises were decided to use also in the other mathematics courses of the author. The experiences and the feedback from FM course were taking into account of while designing the next set of exercises and developing the instructional design for the courses.

In the next phase, automatically assessed online exercises were put into practice for all first year engineering mathematics courses of the author step-by-step. Hence, the online exercises were utilised in Geometry and Vector Algebra (abbreviation GV), Function and Matrices (FM), Differential Calculus (DC) and Integral Calculus (IC) courses. In these courses, three sets of online exercises were released averagely every second week for the courses GV and FM and two sets of online exercises for the courses DC and IC. However, the exercises were not mandatory for the students.

The feedback and experiences were collected and analysed again after two GV courses. After that i.e. online exam was implemented in DC courses. Again feedback was collected and analysed. As a final phase of this study, the students learning activity related to the online exercises were explored for 16 mathematics courses. The design based research process is described more detailed in the results section.

Alongside with implementing online exercises as a part of course work, the overall instructional design and evaluation criteria needed to review and develop to promote self-regulation and students' own activity. Hence, various instruments to promote self-regulation and students activity were tested and implemented.

Overall, within the development process, the following methods and instruments were tested and put into practice:

- Theory as homework: Students' familiarisation with the topic and subject matter of the next lesson as homework from i.e. short educational video lectures or lecture notes
- The emphasis of in-class sessions was on students own activity. In-class sessions typically followed following protocol:
    - The lecturer highlighted the key elements of theory and the most important exercises shortly. Alternatively a discussion of the read content.
    - Exercise session started (paper and pencil exercises)
    - The lecturer taught and guided the students individually during exercise session
    - The lecturer highlighted occasionally typical mistakes from the exercises
    - Checking correctness of the exercises
- All paper and pencil exercises were put into activation list
- Occasionally short online polls were used to monitor students proficiency (e.g. testing the familiarisation of concepts)

- Automatically assessed online exercises were a part of course work (2-3 exercise sets/course)
- A part of the exam was organised online
- Smaller emphasis on the final exam that was organised at the end of the course

During the research process, the feedback with slightly different emphasis was collected from the students after the first FM course (spring 2014), after two GV courses (autumn 2014) and after DC courses (spring 2016 and spring 2017). As a part of the students participated in all of these courses, the feedback was collected only from selected courses. In addition, Moodle log data was taken into account of for reviewing learning activity of the students. A part of the results has been reported in Kinnari-Korpela and Yli-Rämi (2016) and Kinnari-Korpela and Suhonen (2017). This study reviews the results from the perspective of self-regulated learning.

The next, some of the tested methods and instruments are described in more detail.

Theory as homework

During this research process, the emphasis of instructional design was on blended and flipped model of instruction. To support students activity and to get more time on helping students during the in-class sessions, the students needed to familiarise themselves with the topic and subject matter for the next lesson as homework. All the theory materials were released through the Moodle learning environment in a form of short educational video lectures and theory notes. After every contact lesson, a lecturer evaluated the key issues of the next lesson, occasionally produced some extra materials and gave students the topics of the next lesson as homework. The more detailed instructions for reading/watching the topics of next lesson were given in Moodle. Students were instructed to take notes, when preparing to the next lesson. For example, if the students watched the short educational video lectures about basics of vectors, they were instructed to take notes and put up things that they do not understand.

Online polls

During the in-class sessions, the activity of students was occasionally monitored with polls. The polls were implemented especially in the first mathematics courses, when the students were still learning, how to effectively learn with this new method of instructions. The tool used for polls was Socrative. The purpose of the polls was to activate students to learn as a homework the subject matter theory. Thus, the lecturer occasionally tested central concepts and students' understanding of the subject concerned. The results of polls were not utilised for overall assessment, but rather, the intent was to activate the students and encourage them to study the topics concerned as a homework. On the other hand, from the perspective of self-regulation the polls helped the students to recognise their skills and knowledge and monitor their progress.

The in-class sessions and activation list

The in-class sessions typically started with discussion related to the content that students had familiarised themselves with as a homework. Usually, the lecturer highlighted some key elements of the theory or rehearsed some part of the theory. For selecting these parts for review, the lecturer needed a proper pedagogical content knowledge. Moreover, the lecturer presented and explained some central exercises based on the topics concerned. Although this session was typically short and interactive, occasionally, the lecturer spent more time trying to explain the difficult parts of the content.

After the discussion session, the lecturer marked the in-class exercises down to the so-called activation list. At this stage, the exercise session started. Typically, the in-class exercises included both basic exercises, as well as advanced ones. All students had an opportunity to calculate all provided exercises. The emphasis of in-class sessions was on students' own activity and calculating exercises. The students were encouraged to interact and work in pairs or small groups. The advanced students were instructed to explain difficult content and help other one whenever needed. This was also mentioned in the competence-based evaluation criteria.

During the exercise session, the lecturer gave individual teaching and guidance to the students. If it seemed that some theory part had not been learnt as required, the lecturer taught the theory for a smaller group, or alternatively, briefed it to the whole group. Practically, during the exercise sessions, students were able to proceed at their own pace. If students were proficient, they were able to accomplish almost all the given exercises during the in-class session. If not, they were able to continue with the exercises at home.

All the accomplished exercises were marked on the activation list with the 'x' mark. Each student constantly updated the table with mobile phones or tablet computers during the in-class sessions. Based on the ‘x’ marks on the activation list, the lecturer was able to reflect on which one of the exercises seemed to be the most challenging, as well as to monitor the total activity of the students.

During the exercise sessions, some of the exercises were checked together. The lecturer used pedagogical content knowledge for selecting the exercises for review. The lecturer mostly selected the exercises that were typically misunderstood, or where the students’ proficiency varied the most. Usually, these exercises were solved on the whiteboard by some student or the lecturer made model solutions and presented them in Moodle. The lecturer provided also other solutions of the exercises through Moodle. Hence, checking the most solutions of the exercises was depending on the students’ own activity.

Online exercises

One key element for engagement, activation and assessment was online exercises provided to the students two to three times per the course. These online exercises included the most important content of the current course. Online exercises encapsulated multiple choice questions, numerical questions and due to the installation of STACK (at the beginning of 2015), questions that required symbolic answers. To be able to successfully complete the exercises, students were required not only the basic skills but also more advanced as well. These questions were designed to test the ability to carry out the routines and to display deeper mathematical thinking.

One example of STACK exercise is given in the Figure 6. From the figure, it can be seen that the system interprets the students’ response. Hence, the system is visual and helps students to give correct syntax. To the STACK exercises it is possible to code the correct solution. Thus, STACK enables giving instant feedback from students’ performance.

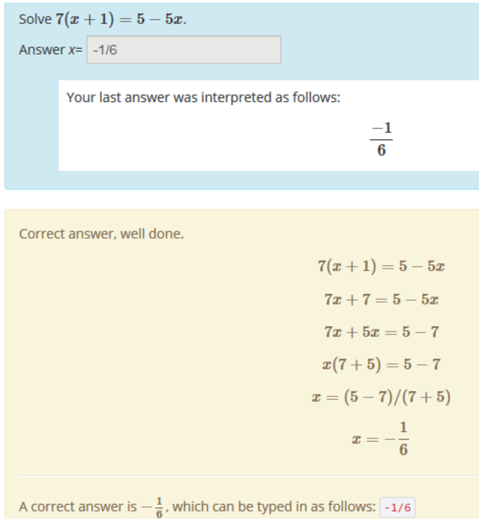

Figure 10. An example of STACK exercise including feedback

The online exercises were not compulsory, but students were awarded for high-quality work. The aim of these exercises was not only to activate students, but also to guide them to review the previous content in the course. The students were able to monitor their achieved knowledge based on the feedback and points from exercises.

The content for each online exercise was determined from the core of the current topic. The lecturer asked herself, 'what are the most central concepts of the current topic that students should learn?' These topics were selected for online exercises.

Course exam and total grade

To promote active learning, students were given points based on their total activity and performance during the course implementation. Thus, the total course grade was based on the exercise points (activation list), the online exercise points and the final exam. Practically, about 30 % of the overall points were earned from tasks besides the final exam. Moreover, to pass the course, a student needed to get at least two points from the activation list and the online exercises. Through these methods, students were encouraged to apply a steady effort to learning throughout the entire study period.

4.4.2.3 Strategies for promoting self-regulation

The subject of the study was a framework for engineering mathematics learning at UAS-level of studies. Hence, alongside with developing online exercises, the overall instructional design and evaluation criteria were reviewed. Designing learning activities and instructional design that promote stimulation of self-regulated learning can foster higher learning outcomes (Rowe & Rafferty, 2013).

The previous section presented the developed and used instruments and methods. This section discusses the instruments and methods from the point of view of self-regulation.

The research on self-regulated learning suggest putting emphasis on promoting self-regulated learning to foster learning outcomes. Zimmerman (2000) describes self-regulation as cyclical process that includes forethought, performance/volitional control and self-reflection phases. In this cyclical model, the feedback from previous performance is used to regulate and control own learning behavior during the learning tasks in progress. The forethought phase includes task analysis and self-motivation classes. These occur before learning efforts and provide the foundation for learning. The performance/volitional control phase includes self-control and self-observation classes. These occur during a student is executing the learning task and monitoring his/her performance. The self-reflection phase consists of self-judgement and self-reaction classes. This phase occurs after students' learning efforts and includes examining and assessing performance of the learning task.

Following introduces the developed and used instruments/methods for promoting students' self-regulation during each of these three phases.

Forethought phase

The forethought phase provides the foundation for learning of specific learning task and it occurs before students' learning efforts. This phase consists of task analysis and self-motivation. The phase under consideration is shown in the Figure 11.

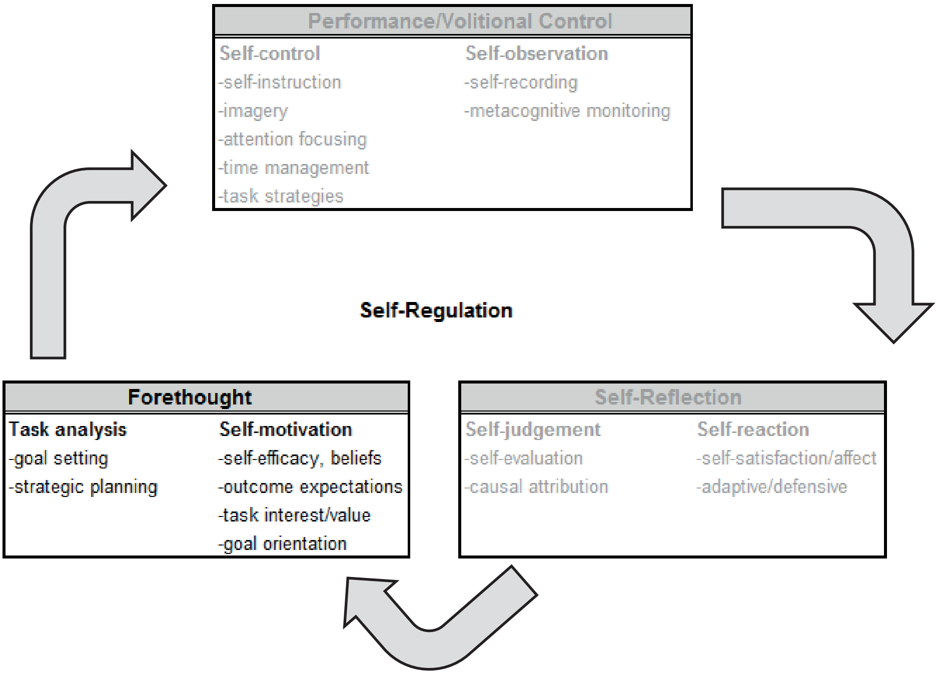

Figure 11. Forethought phase in Zimmerman's (2000) cyclical model

Task analysis includes goal setting and strategic planning classes. Goal setting refers to the specific goals that the student sets for the learning task. The student that self-regulates his/her learning selects appropriate strategies that are needed to achieve the goals. Setting explicit goals can promote academic success (Zimmerman, 2002).

Self-efficacy beliefs, value/interest of the task and personal goals (include in self-motivation class) are factors that affect motivation towards completing a specific learning task (Bandura, 1997; Zimmerman, 2002). Self-efficacy beliefs about personal capability to perform a specific task influence on motivation (Bandura, 1997). Experiencing the learning task as useful promotes the motivation towards the task and can contribute to use more abundant strategies for learning (Wigfield, Hoa, & Lutz Klauda, 2008).

To help students' goal setting and strategic planning, the critical issue is setting clear learning goals for the course. To be able to set goals for learning, students need to know, what are the exact outcome expectations set by the lecturer (Panadero & Alonso-Tapia, 2014). Hence, before students started any coursework, the lecturer introduces the course, the course syllabus, the working tasks of the course, the overall timetables and the clear learning goals for the course. In many cases this included the specific timelines (if possible) and the competence-based evaluation criterias for the grades 1-2, 3-4 and 5 (learning goals for the grades 1-2, 3-4 and 5). For example the specific learning goals for the grades 1-2 were set in GV course as follows:

'The student is able to solve basic level exercises related to vectors and calculation of areas and volumes of two- and three-dimensional objects. The student is able to solve simple applications that are similar to those exercises solved in the course. The student has shortages in the reasoning of solutions and using mathematical language. The student takes responsibility for his/her own performance and performs the tasks with the support of the study group.'

Even though the evaluation criteria enable monitoring and comparing expected learning goals and achieved learning goals, the explicit assessment criteria for each learning tasks are important as they have founded to have positive effect on students' learning (Panadero & Jonsson, 2013). The explicit assessment criteria help students to set more personalised strategies for performance. Students' outcome expectations also interact with the assessment criteria (Pintrich & de Groot, 1990; Panadero & Alonso-Tapia, 2014).

Hence, bringing explicitly out the assessment criterias and scores of different learning tasks were emphasised during the research process. At the beginning of the course, the lecturer introduced the available scores for different learning tasks. For example in GV course, the total score of the course was 32 points and it was divided as follows: final exam 22 points, three sets of online exercises 6 points (2 points/each) and activation list (exercises) 4 points. At least 2 points from online exercises and activation list were required in order to take the final exam. During the study, slightly different variations for points were tested.

In addition to overall points, the lecturer announced, how many precent of the exercises should be made to get a certain amount of points. The students were able to monitor their exercise points in real time during the course work. In addition, students were also able to monitor their online exercise performance based on instant feedback and points they got from each of the online exercise.

The activation list and the online exercises included vast variety of exercises. By providing exercises from easy to demanding, it is possible to increase students' self-efficacy beliefs. The purpose was to provide abundant amount of exercises that everyone could get routine for calculating but also experience that they really know, how to calculate or solve mathematical problems.

Performance phase

During the performance or volitional control phase, a student executes the learning task and regulates learning performance and concentration. This phase includes self-control and self-observation classes. Maintaining attention and motivation during the performance phase, different metacognitive and motivational methods or strategies are required (Panadero & Alonso-Tapia, 2014). In general, self-control is putting into action the methods and strategies that the student has selected in the forethought phase (Zimmerman, 2002). The types of self-control methods/strategies are i.e. self-instruction, imagery, attention focusing, time management and task strategies (Zimmerman, 2000).

The other class, self-observation, refers to students' recording and monitoring of their own performance systematically (Zimmerman, 2000). By observing one's own performance, a student get information about learning progress. According to some research (Winne & Hadwin, 1998; Panadero & Alonso-Tapia, 2013), self-monitoring is similar process to self-assessment. However, monitoring takes place during the performance and assessment after learning task has been executed. The phase under consideration is shown in the Figure 12.

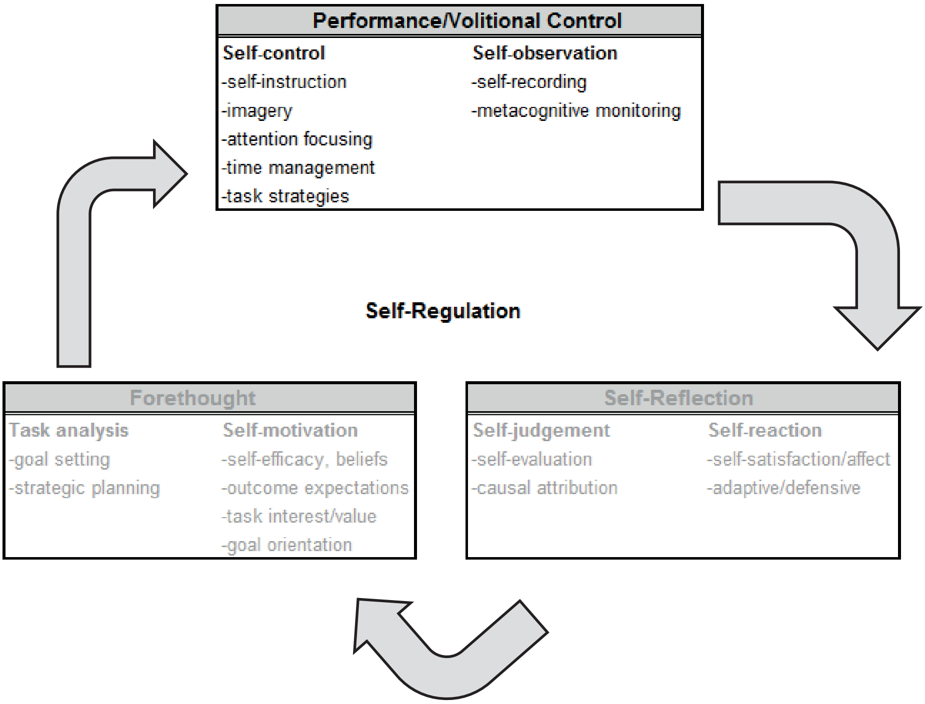

Figure 12. Performance or Volitional Control phase in Zimmerman's (2000) cyclical model

To support performance phase, several instruments and methods were tested and implemented. In the following, the instruments and methods are separated in self-control and self-observation classes.

Instruments for promoting self-control

In many cases, there were available content for the next lesson a week or couple of days before in-class session. The lecturer had instructed the students to take notes, when preparing to the next in-class session. For example, if the students watched the short educational video lectures about basics of vectors, they were instructed to take notes and mark down things that they did not understand. Being able to use task specific strategies for completing the learning task at hand, the students need to have clear understanding of task (Panadero & Alonso-Tapia, 2014). Taking notes and marking down the difficult things may help to remind the most difficult part of the content (Panadero & Alonso-Tapia, 2014).

The emphasis of in-class sessions was on calculating mathematical exercises. The lecturer had encouraged the students to interact and work in pairs or small groups. For example, if a low proficient student had some difficulty with solving an exercise, the advanced students had been instructed to explain and help others whenever needed. This was one requirement for grade 5 and it was also mentioned in the competence-based evaluation criteria. These types of actions can be paralleled to self-instruction and verbalisation that appear to improve students learning (Panadero & Alonso-Tapia, 2014; Schunk, 1982).

The students that regulate their learning manage effectively their time. Setting intermediate steps with timetables, for example, helps overall time management (Panadero & Alonso-Tapia, 2014). During this research, the lecturer had set intermediate steps (online exercises and activation list) for learning and used timetables for tasks. For example the students typically had one week time to accomplish the weekly exercises. After that they were not able to mark exercises on the activation list. Also, the online exercises were timed and available only for a certain time period.

Instruments for promoting self-observation

To activate students before the in-class sessions and to give them instruments to monitor their performance, online polls were occasionally utilised during the in-class session. The online polls typically tested conceptual understanding of the students. The lecturer used real-time results to visualise students' progress. The results didn't affect the course evaluation. Rather, the polls were a tool for students' self-observation.

Some studies (Winne & Hadwin, 1998; Panadero & Alonso-Tapia, 2013) consider self-monitoring and self-evaluation as parallel processes. Self-monitoring takes places during the student performance and self-evaluation after performance. From this point of view, the short educational video lectures and online exercises can be consider to support both self-monitoring and self-evaluation. The students got instant feedback from both of these methods. For example, the short educational video lectures included step-by-step solutions of exercises. By watching this type of videos, students can make observations about their current performance, thus they can become aware of their progress. Also, the activation list can be considered as an instrument to promote self-observations. During the courses, students were able to review the number of completed exercises versus total amount of exercises at all the time. Hence, the activation list gave them information about their progress versus their goals.

Metacognitive monitoring (self-monitoring) refers to adequacy of learning and it is student's subjective monitoring (Winne & Hadwin, 1998). For metacognitive monitoring, the student needs to become aware of time use, effort, comprehension, cognition and motivation (Rowe & Rafferty, 2013). Hence, previously presented instruments offer students the opportunity to become and increase such awareness required for metacognitive monitoring.

Self-Reflection phase

The self-reflection phase includes self-judgement and self-reaction classes. This phase occurs after students' learning efforts. The self-reflection encapsulates effective evaluation of performance in the learning task and reasons for their result (Panadero & Alonso-Tapia, 2014; Zimmerman, 2000, 2002). The phase under consideration is shown in the Figure 13.

Self-judgement includes two classes, self-evaluation and causal attribution (Zimmerman, 2002). Self-evaluation refers evaluation of student's own performance against some standard evaluation criteria and personal goals (Zimmerman, 2002). Causal attributions 'refer to beliefs about the cause of one's errors or successes (Zimmerman, 2002)'. Depending on students' attribution styles, they experience negative or positive emotions that may influence on their future motivation (Zimmerman, 2000; Panadero & Alonso-Tapia, 2014).

In order to help the students to self-evaluate, they need to reflect on their mistakes. Short educational video lectures and online exercises can be considered as instruments for reflecting learning. For example, from model solution of exercise (video), the students can reflect their mistakes and learn to correct i.e. wrong mental models. Additionally, the personal feedback from online exercises as well as activation list can increase students' understanding of their progress. All these instruments serve students' self-evaluation.

Attributions can lead to positive or negative self-reactions (Zimmerman, 2000, 2002). Positive self-satisfaction and affect related to student's own performance can promote future motivation, whereas negative self-satisfaction can dilute future motivation and learning efforts (Zimmerman, 2002). Self-reactions includes also adaptive/defensive reactions. Adaptive reactions occur when the student modify learning strategy in order to achieve better results. On the contrary, defensive reactions refer to avoiding performing task again to evade failure again (Zimmerman, 2000; Zimmerman, 2002).

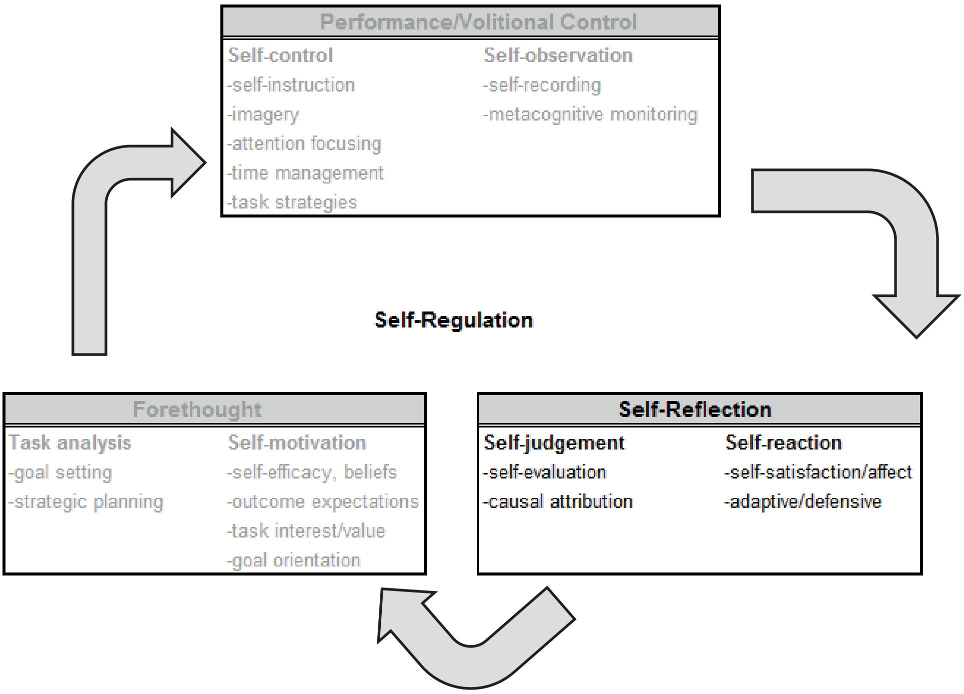

Figure 13. Self-Reflection phase in Zimmerman's (2000) cyclical model

4.4.2.4 Results

A total of 171 engineering students participated in this study. The research process involved a total of sixteen engineering mathematics courses for the target study groups. These courses encapsulated 539 course completions. Hence, one participant completed from one to four courses. A part of the results has been reported in Kinnari-Korpela and Yli-Rämi (2016) and Kinnari-Korpela and Suhonen (2017). This study includes more study groups (see Kinnari-Korpela & Yli-Rämi, 2016) and reflects results from the perspective of self-regulation.

Collecting oral and written feedback and making observation were important in order to be able to develop teaching and learning process. The feedback with slightly different emphasis was collected from the participant students after the first FM course (spring 2014), after two GV courses (autumn 2014) and after DL courses (spring 2016 and spring 2017). These courses had students from different study groups. In addition, log data from Moodle was utilised in making analysis.

The feedback and experiences from the first FM course (spring 2014) were used when designing the next set of exercises and developing the teaching and learning process. This was a first time, when online exercises were a part of assessment. As an intervention of FM course, the online exercises were implemented for all engineering mathematics courses of the author since autumn 2014. Also, assessment criteria were changed.

In the next stage, three sets of online exercises were implemented as a part of GV courses (autumn 2014). Again, the feedback and experiences were collected and analysed. As an intervention, online exercises were taken as a regular instrument to learn mathematics in the author's mathematics courses. Additionally the assessment criteria were modified, more video examples were provided and one part of the exam was implemented in a form of STACK-exercises. These changes were tested in two DL courses (spring 2016 and spring 2017). Again, the feedback and experiences were collected and analysed.

The results from students' questionnaires and log data have been presented separately in the following. The results have been categorized according to the phase of the development process. As during the FM and GV courses were concentrated on developing the online exercises, continuous assessment and overall assessment criteria, the results of this phase are combined. On the other hand, as the students made the online exams at the first time during DC courses, these courses were examined together.

The students experiences of developed process

A total of 104 students gave feedback during the research process. The feedback was collected with the online questionnaires. The questionnaires included the qualitative and quantitative questions. 5-point Likert scale was used in most of the quantitative statements. Additionally, the quantitative log data from Moodle was also examined. The data utilised was related to online exercises, log events and the students' time spend on activities.

A total of 71 students gave feedback from the FM (20 students) and GV (51 students) courses during 2014 regarding to online exercises and changed practices. Based on the feedback, it appears that students experienced the online exercises meaningful. Overall, three-quarters of the respondents experienced that this type of assignments are meaningful in mathematics learning. Additionally, about 70 % of respondents experienced that with this type of online exercises their mathematical competence can be reliably evaluated.

As an intervention of the first FM course, the framework of mathematics learning were developed and the assessment criteria were changed. Hence, it was important to explore students' experience about the new methods and framework. The students of GV courses were asked, how they experience the new framework for mathematics learning. 98 % of respondents (n = 51) experienced that it was a good practice to be able to get points during the course. In addition, almost 90 % agreed that it was good that the emphasis of final exam was decreased.

The lecturer provided theory of the next lesson before the in-class sessions and the students were able to prepare themselves for the lesson. During the in-class sessions the emphasis was on calculating exercises. Based on the survey results, the students experienced this as a good practice. Three-quarters of the respondents felt that it was a good practice to be able to concentrate on calculating exercises during the in-class sessions. However, one-third of the respondents prepared for the lessons always or almost always, one-third prepared sometimes and one-third prepared rarely or never. However, 96 % of the respondents agreed that 'In my opinion, the course practices are working'. These results indicated that the new methods and framework for mathematics learning are working from the students point of view. As an intervention of GV courses, i.e. online exam was desided to put into practice in DC courses.

A total of 33 students gave feedback from DC courses after compliting the course. About 80 % of the respondent experienced that online exam was easy to make and that they didn't had problems with the syntax (entering the responses). About 60 % of the respondents felt that more automatic assessment could be utilised in mathematics exams. As students were able to return assignments online, their experience related to that was asked. About 80 % of the respondents experienced that 'It was useful for me that to be able to make online assignments'.

Activity of students

As a final phase of this study, the students learning activity related to online exercises were explored between 2014-2017. The Moodle log data was used to examine the activity. Table 14 shows students' activity of making online exercises. Table includes average percentages of completed online exercises from 16 different mathematics courses. These courses included two to three sets of online exercises that were not mandatory but the students were awarded of high quality work.

The students were active to make online exercises as they completed an average of 87 % of online exercises. This figure was higher than expected. The activity of making the online exercises varied between the study groups.

Table 14. Activity of making online exercises

Course	Group	Number of Participants	Percentage of Completed Exe 1	Percentage of Completed Exe 2	Percentage of Completed Exe 3
GV	14A	37	100 %	97 %	87 %
GV	14B	30	90 %	97 %	90 %
GV	15A	39	92 %	77 %	79 %
GV	16A	33	94 %	82 %	91 %
FM	13B	27	78 %	56 %	-
FM	14A	37	97 %	97 %	95 %
FM	14B	31	90 %	87 %	94 %
FM	15A	36	83 %	86 %	69 %
FM	16A	33	73 %	79 %	91 %
DC	14A	40	100 %	93 %	-
DC	14B	29	100 %	90 %	-
DC	15A	32	78 %	88 %	-
DC	16A	34	83 %	83 %	-
IC	14A	38	89 %	87 %	-
IC	14B	30	87 %	87 %	-
IC	16A	33	82 %	91 %	91 %

The Moodle log data was also examined to explore, how much time students spent on making the online exercises. For example in DC courses (groups 14A, 14B, 15A and 16A), the students averagely spent 72 minutes for making 7 exercises in the online exercises 2. However, the variation of time spend occurred between the students in abundance (std = 55 min, median = 59 min).

The students overall learning activity was also compared between two study groups during GV courses in the spring 2017. The groups were 16A and a control group from other the lecturer. Both of these courses included three sets of automatically assessed online exercises (abbreviation E1, E2 and E3) and short educational video lectures. The course materials were almost same but the groups had different assignments' timings. The emphasis of assessment was continuous for the group 16A, and more traditional for the control group. In this case, the more traditional assessment means that the emphasis of assessment was on the final exam. A part of the results has been presented in Kinnari-Korpela and Suhonen (2017).

Both groups had three sets of online exercises but with the different deadlines for assignments (see Table 15. , Figure 14. and Figure 15.). Group 16A had three separate deadlines for all online exercises. Instead, for the control group the deadlines of E2 and E3 were the same. The lecturers used slightly different technique for making the online exercises. Hence, Moodle recorded more log events for the students of control group. The Figure 14 and the Figure 15. show daily activity of the students.

Table 15. Timings of online exercises for the group 16A and the control group

	E1	E2	E3
16A	9.9.-18.9.	3.10.-11.10.	12.10.-26.10.
Control	7.9.-20.9.	3.10.-12.10.	3.10.-12.10.

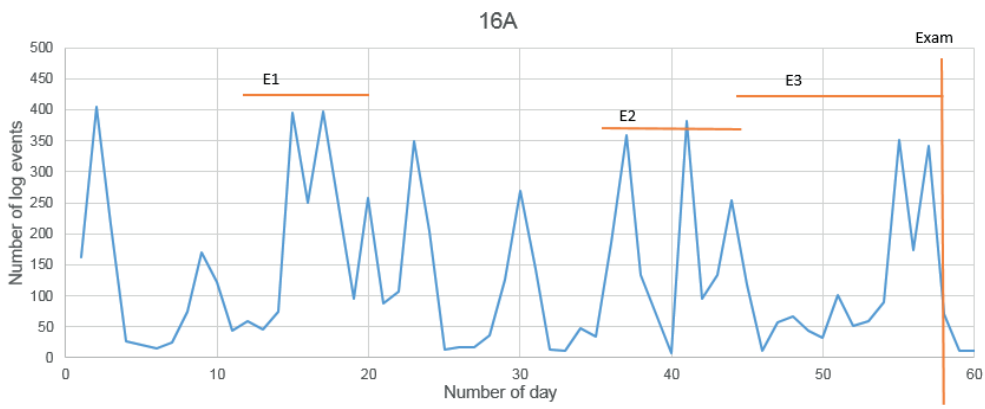

Figure 14. Total number of log events per day among the group 16A

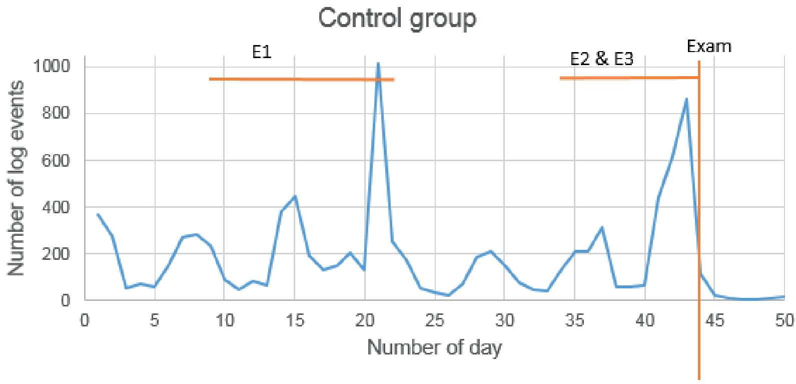

Figure 15. Total number of log events per day among the control group

The figures show that the activity peaks appeared right before the deadlines of assignments. These figures indicate that the deadlines guide the learning activity of the students. When comparing activity between the group 16A and the control group, the learning activity is evenly distributed when separated deadlines are used for different assignments. The results indicate that the students are studying nearby the deadlines of assignments.

Table 16. compares the total activity of making online exercises. Table includes average percentages of completed online exercises from the group 16A and control group. The control group students' activity of making online exercises decreased significantly as the course proceed. The reason for that could not be initiated but one reason can be the lack of proper deadlines for assignments.

Table 16. Activity of making online exercises

	E1	E2	E3
16A	91 %	79 %	79 %
Control	100 %	58 %	50 %

4.4.2.5 Discussion

The study was carried out between the spring semesters 2014 and 2017 for 16 different study groups (plus one control group). The goal of the study was to develop the framework for mathematics teaching and learning in UAS-level, that has the features of flipped model of instruction. The process included several sub-goals such as promoting students' self-regulation. Some utilised instruments were already tested and implement in previous studies. This study combines the whole research process.

Appropriate and meaningful learning activities and instructional design can promote stimulation of self-regulated learning, which can foster higher learning outcomes (Rowe & Rafferty, 2013). This study presents several instruments and methods that can promote stimulation of self-regulated learning. The results indicated that the used methods are working. To name a few instruments/methods, setting explicite goals can promote academic success (Zimmerman, 2002) and setting intermediate steps with timetables will help time management (Panadero & Alonso-Tapia, 2014). On the other hand using instruments such online exercises and short educational video lectures can support e.g. students' self-evaluation.

CAA had a central role for developing the framework for mathematics teaching and learning. From self-regulation perspective, CAA can foster students' overall engagement on learning (Henderson et al., 2015). A student that self-regulates his/her own learning needs feedback to monitor and modify behavior while obtaining the personal educational goals. CAA enables giving the instant feedback of performance. Hence, it can foster self-regulated learning. The results also indicated that the students experienced CAA as a good pedagogical method. Overall, if a student experience some learning task as useful, it promotes the motivation towards the task and can contribute to use more abundant strategies for learning (Wigfield, Hoa, & Lutz Klauda, 2008).

5 CONCLUSIONS

This dissertation contributes to the discussion on how engineering mathematics can be taught at UAS-level with a particular focus on promoting active learning with selected educational technology. Hence, the overall goal of the research was to contribute to the development of engineering mathematics education from two different but interwoven perspectives:

1) to explore the possibilities to enhance engineering mathematics teaching and learning with the help of educational technology, and
2) to promote active learning of students.

Next, the main findings of the research are presented. The first and second sections describe the findings from perspective 1 and perspective 2, respectively.

5.1 Enhancing mathematics learning with technology

Exploring possibilities to enhance students' learning with technology focused on short educational video lectures and CAA. During the research process, short videos and CAA were implemented as an integral part of the author's engineering mathematics courses in UAS-level studies. This work was concentrated not merely on developing and implementing separate methods but also (more so) on developing teaching/learning strategies and materials and advancing knowledge about their utilisation and effects. As no suitable materials were available for implementation in UAS-level mathematics courses (more details are given in the section 4.2.2.), the author designed, recorded and tested all the learning materials herself. The studies were part of a design-based research process, and the results aimed to provide knowledge for changing instructional design.

5.1.1 Short educational video lectures

Study 1 (n = 18 in the posttest) was a preparatory study whose results indicated that the short educational video lecturing method (and online exercises) can be implemented as a part of engineering mathematics teaching and learning. In that study, the students' learning outcomes were tested with a pre- and posttest design, and the test items were designed using Bloom's taxonomy. Between the tests, students studied propositional logic, and the learning materials included videos and online exercises. The students performed significantly better in the posttest by comparing either total points or each test item separately. However, the students were not monitored between the tests. Hence, the method did not determine how the students had achieved increased competence or which strategies they had used during their learning process. That said, the results indicated that videos and online exercises are indeed useful for UAS-level mathematics learning purposes.

The following section categorises the focal themes that arose during the research process.

Designing short educational video lectures

Based on the experiences of this research, the central idea behind short educational video lectures is to concisely present the key content of a topic, keeping the videos as short as possible. To design the content of short videos, the author relied on her pedagogical content knowledge to identify 'what makes learning of specific topics easy or difficult' (Shulman, 1986, p. 9).

The literature suggested that shorter videos might engage students, as they are more meticulously planned (Guo, Kim, & Rubin, 2014). In addition, personal experiences and observations supported this. Hence, the researcher asked herself questions such as: 'What is the most relevant and important content in the current topic?', 'How can the content be presented in a simple way without losing any important content?', 'Which topics will most likely cause problems for the students?' and 'What are the students' prerequisites for the topics?'. These questions were addressed before designing and recording the videos. In that sense, the content of short educational videos and the manner in which it was presented were carefully planned and scripted before recording. This kept the produced and utilised videos as compact and concise as possible, thereby presenting only the most appropriate content to learners, which was identified to increase its pedagogical usability (Nokelainen, 2006).

Using short educational video lectures for different learning purposes

During this research process, a versatile set of short educational video lectures were designed, produced and tested in an engineering mathematics learning context. During the tests, the videos were used for the following learning purposes:

- as an introduction to a new topic,
- as a revision of a topic,
- as a supplementary example,
- as a supplementary material for a challenging topic, and
- as a step-by-step solution for the exercise.

Via these practices, it was possible to change the traditional teacher-led teaching process to a more student-centered learning process. Based on the students' video-viewing activity, explored in study 3, and the students' learning experiences, identified in study 2 and study 4, videos were demonstrated to be effective for mathematics learning purposes. As the videos were provided to different study groups during different engineering mathematics courses, the practices tested students with heterogeneous mathematical backgrounds.

Interpreting the observations made during the research process, it may be possible to develop and improve course content and also facilitate self-regulated learning with short educational video lectures (study 4). Clearly, using short educational video lectures increased flexibility of learning. This was also highlighted in the students' responses.

Furthermore, the videos helped provide supplementary materials for the students for, e.g., challenging topics, and made learning more flexible. On the other hand, based on experiences, during in-class sessions, there is no time to present supplementary examples to those students who need extra resources for their learning purposes. As students' prerequisites vary in UAS-level engineering mathematics courses, not all students have the same level of proficiency. Therefore, to facilitate learning, it is important to provide the most appropriate learning materials for each learner (Wilson & Myers, 2000). Short educational video lectures achieve this goal by providing, e.g., supplementary materials for learners with different prerequisites. For example, during study 2, students who did not have any earlier experience with basic derivatives were able to learn differentiation rules from the videos at their own pace. Hence, they were able to use the time they required for understanding the topics concerned.

Experiences of students regarding short educational video lectures

Students' experiences with short educational video lectures were explored in study 2, and their overall experiences were assessed in study 4. Most notably, the results suggest that it is valuable to learn mathematics from short videos. About three-quarters of the study 2 respondents (n = 140) regarded mathematics learning from videos as valuable. Some of the students also expressed that viewing video materials was similar to listening to classroom teaching.

The students' open-ended responses (in study 2) regarding the importance and benefits of videos were analysed, and the following features emerged:

- Repeatability of videos. Being able to pause and replay the content
- Step-by-step solution for exercises explained by the lecturer
- Independence from time and place
- Video includes audio

The repeatability of videos was especially valued in terms of learning. A clear benefit expressed across the open responses was that, with the help of the videos, students had more time to think about and understand the tasks they were assigned. They expressed that when viewing videos, they had more solitude for learning, could pause the videos whenever they chose, and had sufficient time to consider a given topic. The open responses highlighted that some students tried to calculate exercises at their own pace first; if they were struggling, they were able to watch the step-by-step solution from the video, which was audio-narrated by the lecturer. According to the responses, this method helped the students to understand their mistakes. The students also appreciated the freedom to watch the videos whenever and wherever they wanted. Overall, it appears that the short educational video lectures assisted the students in completing exercises and personalising learning.

One noteworthy detail was that some of the study 2 students claimed to learn better from the videos that included audio than from reading the exact same content from a book.

Study 2 students also ranked different learning methods based on which practices they learned from the best (see Table 8.). The ranked methods comprised doing exercises during the in-class sessions, listening teaching, doing homework exercises on my own time (excluding videos), learning from short educational video lectures, and learning theory materials on my own time (excluding videos). In this ranking, the students identified 'doing exercises during in-class sessions' as the best learning method. Worth noting is that VET-backgrounded students considered 'learning from short educational video lectures' to be slightly more important than 'doing homework exercises on my own time'. The respondents also identified 'learning theory materials on my own time' as the worst method for learn engineering mathematics.

Students' viewing activity with short educational video lectures

In study 3, students' viewing activity with short educational video lectures was explored. The original publication reported students' viewing activity (Kinnari-Korpela & Korpela, 2015) and the study 3 reports the key results of original publication and reviews results from the perspective of self-regulation. In total, 129 students participated in this study during their mathematics classes: 70 students comprised the test group and 59 students comprised the control group. Both groups were educated by the same lecturer and with the same course materials. However, the supplementary short educational video lectures were provided only to the test group. The short videos covered topics considered challenging by the participants or for which the students' prerequisites varied the most.

The original publication (Kinnari-Korpela & Korpela, 2015) determined that students' video-viewing activity levels were quite high, as almost 90 % of the test group students watched the short videos. A total of 560 video views occurred during the eight-week course, although the viewing activity varied between the students. The average score on the final exam and the passing rate were both higher in the test group than in the control group, which indicates that the test group performed better than control group.

To encourage the test group students' self-regulated learning and identify their course-related knowledge, they were provided a self-assessment form that was based on Bloom's taxonomy: 78 % (n = 70) of the test group's students completed this form. The completed self-assessment forms were analysed and compared to performances on the final exam. Based on this comparison, the following dimensions were identified:

(1) weak skills/knowledge and does not recognise it,

(2) weak skills/knowledge and recognises it,

(3A) average skills/knowledge and does not recognise it,

(3B) average skills/knowledge and recognises it,

(4) good skills/knowledge and does not recognise it,

(5) good skills/knowledge and recognises it.

The weakest viewing activity was observed among students who had 'weak skills/knowledge and did not recognise it'; 60 % of these dimension (1) students received a final grade of 0, and none of the grade 0 students with dimension (1) watched the videos. Although only 13 % of the respondents were identified as dimension (1) students, further research is needed to provide more robust conclusions.

On the other hand, the most active video viewers were the students who had 'weak skills/knowledge and recognises it'. Students who had 'good skills/knowledge and does not recognise it' were also active viewers.

5.1.2 Computer-aided assessment

As the results of study 1 indicated that CAA can be used in UAS-level engineering mathematics courses, it needed to investigate, how to best use educational technology for assessment purposes in that context. For this reason, CAA was tested and implemented more systematically in study 4.

Activity of completing online exercises

CAA was used in study 4 in the form of mathematical online exercises. The online exercises were conducted through TAMK's Moodle using Moodle quizzes. To evaluate the usability of CAA and students' activity on calculating the online exercises, Moodle log files were monitored and students' experiences were collected with electronic questionnaire. The data in this study were derived from the online activity of 171 engineering students among 16 engineering mathematics courses. These courses included 539 course completions. During the seven-to-eight week courses, two-to-three sets of online exercises were provided for the participants. One set of exercises included several randomised exercises. The online exercises were not mandatory, but the students were awarded for high-quality work.

The results of study 4 showed that the students were active in taking online exercises, as they completed an average of 87 % of exercises provided. This percentage was higher than expected. However, students' actual completion of the online exercises varied between different individuals.

The study 4 also compared students' learning activity between two similar mathematics courses. The test group was named '16A' (see Table 14.) and the other group, 'control group'. Both groups had three sets of automatically assessed online exercises and short educational video lectures. The course materials were almost the same for both groups, but the timings of assignments were different. The emphasis of assessment was continuous for the test group, and more traditional (emphasis on final exam) for the control group. The test group had distinct deadlines for the online exercises, but the control group had the same deadline for two sets of online exercises. The deadline was the same day the final exam was held.

The learning activity figures showed that the students' activity peaked right before the deadlines. Hence, the results indicate that deadlines for assignments strongly guide learning activity, and that students mostly study close to deadlines. When comparing the activity of taking online exercises between the test group and the control group, the test group students were more active, and their activity was evenly distributed when separate deadlines for assignments were used. On the other hand, the control group's activity of making online exercises decreased significantly during the course. One reason for this could be the lack of proper deadlines for assignments. However, clarifying the reason behind the decreased activity requires more research.

5.2 Promoting active learning

Meaningfulness is one component of mathematics interest (Mitchell, 1993), and individual interest promotes self-regulated learning (Lee et al., 2014). From the point of view of pedagogical usability, learning materials that are interesting can encourage students' activity (Nokelainen, 2006), which is closely connected to self-regulated learning (Zimmerman, 2000). Study 2 (n = 184) explored the students' experiences regarding short educational video lectures from different mathematics courses. Almost 75 % of the study 2 respondents (n = 140) experienced learning from short educational video lectures as meaningful, and only 10 % felt the opposite. These findings indicate that short educational videos have the potential to motivate students and promote self-regulated learning.

Study 2 also investigated motivation aspects, such as students' motivation factors (intrinsic and extrinsic) and motivation towards mathematics learning. Motivation is one component of self-regulated learning, and motivated students are more likely to self-regulate their learning (Pintrich & De Groot, 1990).

About one-half of the study 2 respondents agreed with statement, 'using videos as a teaching method increased my motivation towards the course'. One interesting detail is that 40 % of the respondents who were not intrinsically motivated experienced short educational videos as a teaching method as increasing their motivation towards the mathematics course.

One part of study 2 (Mathematics 2 course; n = 45) compared the students' learning experiences and course grades. The results indicated that well-performing students had high intrinsic and medium extrinsic motivation. Actually, all the students who received a grade of 4 or 5 had high intrinsic motivation. However, since only some of the study 2 participants' learning experiences and course grades were identified, more research should be done to increase the validity of this result.

The data from study 3 indicated that short educational videos can motivate students to learn. During study 3, a total of 560 video views were detected during the eight-week Differential Calculus course, although the videos were only supplementary resources. During that study, it was also found that the test group, which used the short videos, performed significantly better than the control group, which did not have video resources. These results, including the students' increased competence in study 1, support the use of short educational video lectures as engineering mathematics learning resources.

On the other hand, the data collected during study 4 indicated that online exercises can motivate students. However, the online activities require deadlines, and the findings revealed that students tend to study closer to deadlines. Therefore, the results indicate that proper and distinct deadlines for assignments are more likely to motivate students.

5.3 Guidelines for using educational technology in a similar educational setting

Typically, the outcomes of design-based research are some design principles or guidelines for an educational setting that has been researched. At the beginning of this research process, there were no guidelines on how to use educational technology for UAS-level engineering mathematics education to motivate students. Hence, design-based research provides an approach to exploring the complex educational task at hand.

This research tested different elements to support students' self-regulated learning. Before giving instructional design guidelines for a similar educational setting, students' motivation experiences are discussed and perspectives for the exploitation of Bloom's taxonomy are given.

Students' motivation

To develop a practical framework for mathematics learning that facilitates learning regulation, students' experiences were explored. In study 2, 184 engineering students participated, of whom 140 responded to the questionnaire exploring, e.g., experiences of mathematics learning.

The following factors that impact students' motivation were highlighted in many of the students' open responses (classified from the highest occurrence to the lowest):

- More classroom time for calculating an abundant number of exercises, including individual support from the lecturer,
- Supporting mathematics learning with different types of examples: step-by-step calculation examples, video examples and model solutions for homework exercises,
- Teaching methods and pedagogy, and
- Nice and good lecturer.

Based on the students' experiences, more classroom time was preferred, especially for calculating different types of exercises. They experienced that step-by-step calculations examples, i.e., in the form of videos, supported their learning. Overall, they preferred to have model step-by-step solutions for as many exercises as possible; i.e., that the correct answer was not enough for their learning purposes. Some of the respondents regarded teaching methods as influencing their learning motivation, as well as having a 'nice and good teacher'.

Bloom's taxonomy for designing test items

During the research process, Bloom's taxonomy was used to design items for the pre- and posttests (study 1) and for the self-assessment form (study 3). Both these instruments were for students and lecturers. For the students, the instruments facilitated and promoted self-regulation. On the other hand, when designing the instrument items, Bloom's taxonomy provided a foundation for reviewing in more detail the expected learning outcomes. Hence, Bloom's taxonomy appears to be a useful instrument for an instructor when designing test items and reviewing students' mathematical proficiency in more detail.

Students' experiences of the developed mathematics teaching and learning framework

In study 4, students' experiences regarding the developed mathematics learning framework were explored. A total of 104 students provided feedback during this study. As the mathematics teaching and learning framework was developed in cycles, the emphasis of development was different in separate cycles. Hence, the feedback was collected step by step during different mathematics courses.

The lecturer provided theory materials for the next lesson before the in-class sessions. The students were guided to take notes and mark down the difficult part of the theory. Hence, the students were able to prepare themselves for the lesson. When students came prepared to the in-class sessions, they could place emphasis on calculating exercises. Based on the results, the students considered this to be a good practice. However, not all students prepared themselves for the lessons. Based on the survey results, one-third of the respondents prepared for the lessons always or almost always, one-third prepared sometimes, and one-third prepared rarely or never.

One part of the new framework was to change assessment practices. Hence, the emphasis of final exam was decreased and students were able to collect points from the activation list and online exercises during the course. Of the GV course respondents, 98 % (n = 51) experienced collecting points during the course as useful, and about 90 % preferred emphasis be placed on continuous assessment (emphasis of final exam was decreased). Almost every respondent (96 %) agreed that 'In my opinion, the course practices are working'.

Guidelines for instructional design

During the research process, several instruments for promoting self-regulated learning were tested and implemented as a part of the mathematics teaching and learning framework. The Figure 16. summarises the instruments that were used for promoting self-regulated learning. These instruments are justified and discussed in more detail in study 4.

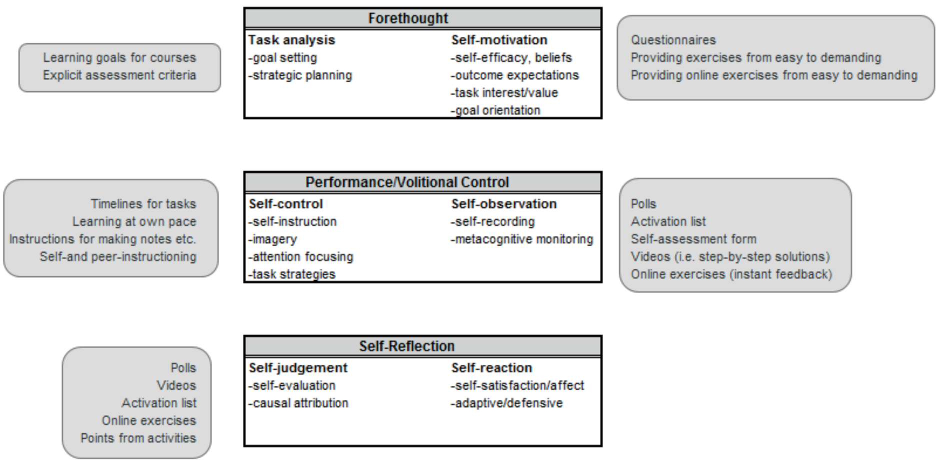

Figure 16. Instruments for promoting self-regulated learning

As an overall conclusion of this research process, the following guidelines for instructional design in a similar educational setting are recommended:

- make clear learning goals,

- try to make/use/provide the most appropriate learning materials for students' learning purposes,
    - try to make/use/provide meaningful learning materials,
    - students are taking advantage only for the selected part of e.g. videos,
- motivate and activate students before, during and after in-class sessions,
- put more emphasis on flipped and blended learning possibilities,
    - emphasis of in-class sessions can be on calculating exercises,
- if you record videos, keep them as short as possible,
- use your pedagogical content knowledge and subject matter knowledge when planning the learning materials and instructional design,
- provide learning materials that promote self-regulated learning
    - using an assessment framework, such as Bloom's taxonomy, helps to review the students' proficiency in a detailed manner,
    - promote phases of self-regulation with different methods and instruments,
- put emphasis on continuous assessment,
- enable instant feedback, and use timelines for assignments, as they guide the students' activity.

6 DISCUSSION

This thesis has concentrated on the development of UAS-level engineering mathematics education from different perspectives to determine the suitable educational technology to be used and to motivate students in their learning process. The findings of the studies do not only represent separate methods for enhancing teaching and learning; they also reveal the development of the teaching and learning process more comprehensively. The studies provide perspectives for promoting students' self-regulated learning and examples of the utilisation and effects of educational technology and how these connect to the theoretical framework in the engineering mathematics context. Hence, this thesis provides guidelines for developing an instructional design that facilitates active learning.

In this chapter, the results of the studies and their implications are discussed in connection with the theoretical framework. The validity, reliability and exploitability of the results are also explained.

6.1 Discussion of the research problem

The need for this research arose from concrete problems encountered at the Tampere University of Applied Sciences. Problems with the mathematical proficiency of students together with inactivity were noted to cause difficulties in engineering studies. In fact, various studies (i.e., Hawkes & Savage, 2000; Heck & Van Gastel, 2006; James, Montelle, & Williams, 2008; Lawson, 2003; London Mathematical Society, 1995) have universally highlighted problems with the mathematical proficiencies of incoming students at the tertiary level. Lack of necessary mathematical skills and knowledge appears as, e.g., poor algebraic routines, inadequate quality of writing mathematics, poor understanding of mathematical concepts, etc. Thus, the problems observed in the research setting were not only local.

On the other hand, universities and UAS have faced financial problems during the current millennium (Moody, 2013; Teferra & Altbachl, 2004; Yang & McCall, 2014). This situation is new in Finland and, according to the national government, improvements are not expected in the near future. Practically in UAS education, there are insufficient time resources for teaching, traditionally, all the necessary content or for concentrating on those students who may need the most help. Thus, there is a clear need for a shift in a pedagogy. The literature supports emphasising active learning as the pedagogical approach of this research. The research has indicated that active learning methods can increase students' learning outcomes and decrease failure rates in STEM subjects (Freeman et al., 2014). Implementing proper educational technology, changing classroom practices and promoting self-regulated learning have been seen as key methods for activating students in their learning process. Using educational technologies, especially in higher education, can promote learners' self-regulative processes (Kitsantas & Dabbagh, 2010), which may in turn improve learning outcomes (Dabbagh & Kitsantas, 2004).

The US Department of Education (Means et al., 2009) carried out a meta-analysis of empirical studies of e-learning and found positive effects on learning outcomes with instructional designs that emphasised blended or online learning. The intention in this research process was not to design purely online courses but rather to increase the possibilities of blended and online learning. Taking into account the context of this research (UAS-level engineering education) and heterogeneous cohorts, it was deemed valuable to increase blended and online learning possibilities but also to maintain in-class activities. Employing educational technology that promotes students' own activity and self-regulated learning while allowing for its personalisation was also valuable. For changing towards these actions, instructional design needed to be done.

Although technology itself does not generate learning outcomes, it can improve students' learning when it facilitates active learning (McLoughlin & Loch, 2013). Dunlosky (2013) named practice testing and distributed practice as highly effective learning techniques whose effects were robust and could be widely generalized. CAA enables practice testing and distributed practice, and it supports students' own activity and practicing. Short educational video lectures mainly support distributed practice and students' own activity and practicing. From the perspective of developing mathematical proficiency, both of these technologies mainly influence conceptual understanding, strategic competence and procedural fluency (see Kilpatrick, Swafford, & Findell, 2001, p. 116). Considering the research context, the premises of the research and the target groups, it was justified to use short educational video lectures and CAA as technologies. However, it should be noted that these are not the only possible technologies. For example, graphical calculators, mathematical software and GeoGebra visualisations could also have been used.

Even though the literature provides examples of the utilisation of educational technology, there is an evident lack of empirical research on how to enhance students' learning with educational technology, motivate students for educational technology, reorganise the instructional design and understand how students and lecturers experience using the selected technology. Accordingly, there is also a clear lack of design principles for applying educational technology to mathematics teaching and learning at UAS-level that would activate students. This dissertation aimed to provide such design principles to instructional design and the use of educational technology in UAS-level engineering mathematics education. At universities of applied sciences especially, scientific research on the utilisation of educational technology in mathematics studies has been very limited.

On the other hand, the overall theme of this research has been the active learning of students. The focus of cognitive learning theories is on learners who actively seek, process and construct information. Metacognition, self-regulation and self-regulated learning are the core types of cognitive control processes (Schunk, 2008). Hence, active learning strategies require the self-regulatory skills of the learner, which are in fact considered a vital skill in the twenty-first century (Järvenoja, Järvelä, & Malmberg, 2015). To promote students' active learning, developing and implementing elements and instruments for facilitating self-regulated learning are vital.

6.2 Implications of research

Since this study constituted educational design-based research, its value should be measured by its ability to improve educational practice (Design-Based Research Collective, 2003). This section discusses the implications of this study through the research questions, which are presented in section 1.1. As the research questions are partly intertwined, they are jointly discussed.

(Q1) How can engineering mathematics courses be taught with the help of technology, especially with short educational video lectures and computer-aided assessment?

(Q2) How can technology contribute to the organisation of courses including course content and assessment? (This research question is closely connected to Q4 and Q5.)

(Q3) How is the utilisation of educational technology, such as short educational video lectures and computer-aided assessment, experienced by UAS students in the learning and teaching of engineering mathematics?

(Q8) How can active learning of engineering mathematics with an emphasis on self-regulated learning be promoted?

Studying the possibilities to teach and facilitate engineering students' learning with technology focused on short educational video lectures and CAA. At the beginning of this research process, there were neither guidelines nor instructional materials on how to use educational technology for UAS-level engineering mathematics education to motivate students or on students' experiences with such technology. Hence, this research has both practical and theoretical implications.

When conducting design-based research, the focus is typically on building a connection between an authentic learning context and theoretical research with interventions that aim to improve local educational practices (Amiel & Reeves, 2008; Design-Based Research Collective, 2003). This approach was followed in this study. During the research process, a framework for mathematics teaching and learning was built that utilised selected educational technology and promoted students' active learning. The developed framework has improved local practices. This can be justified via, e.g., different study results (studies 1-4), students' learning experiences, learning outcomes and observations. The results of this dissertation can be applied especially to UAS-level engineering mathematics education. However, the results can also be applied in other contexts.

It is typical that a design-based research process includes cycles of development, testing and refinement (e.g., Reeves, 2006; Van den Akker et al., 2006; Wang & Hannafin, 2005). Developing a framework for mathematics teaching and learning during the four studies included 25 UAS-level engineering mathematics course implementations. The different studies had different emphases, and the research questions varied between the studies. The studies and interventions are presented in Table 5.

As an outcome of educational design-based research, guidelines or design principles for exploring educational settings are typically given (Amiel & Reeves, 2008; Reeves, 2006). The guidelines for instructional design in similar educational settings beyond the local context (Design-Based Research Collective, 2003) were given in section 5.3. These guidelines aim to provide knowledge for developing instructional design in similar settings.

When evaluating students' experiences using the selected educational technology, different issues can be highlighted. Based on the students' learning experience (study 2), high value was placed on self-paced learning and self-regulation. Dunlosky et al. (2013) named distributed practice as one of the most effective learning techniques for students' self-regulated learning. In mathematics learning, distributed practice has the potential to benefit learners (Dunlosky et al., 2013). Budé, Imbos, van de Wiel, and Berger (2011) determined that students who used distributed practice performed better on conceptual tests and on the final exam than those who did not use it. Educational screencast videos mainly support distributed practice.

It appears that short educational videos can be used for different learning purposes (study 2–4). Students reported using the videos especially while completing homework. The students emphasised that while struggling to make exercises, they could check the step-by-step video solution for the exercise, which in turn helped them understand their mistakes and find the correct exercise solutions.

On the other hand, CAA was used for activating students and assessing their learning (study 4). Based on the results, students' learning can be evaluated rather reliably with CAA (study 4). Instant feedback from CAA was also perceived as beneficial. Therefore, it appears that CAA is a useful method for supporting learning in student-centered learning process.

When considering promoting self-regulated learning, short educational videos and online exercises may serve that purpose. Figure 17. illustrates the phases of self-regulation (Zimmerman, 2000). Self-observation refers to students' recording and monitoring of their current performance systematically (2000), and self-evaluation refers to a student's evaluation of his or her current performance against standard evaluation criteria and personal goals (Zimmerman, 2002). That said, self-observation and self-evaluation have been considered similar processes in some research (Panadero & Alonso-Tapia, 2013; Winne & Hadwin, 1998).

From this point of view, the short educational videos and online exercises are feasible instruments for promoting students' self-observation and self-evaluation. Both these instruments provide instant feedback to students. Students use this feedback to, for example, understand their mistakes in exercises (study 2). This inevitably increases their awareness regarding their learning progress.

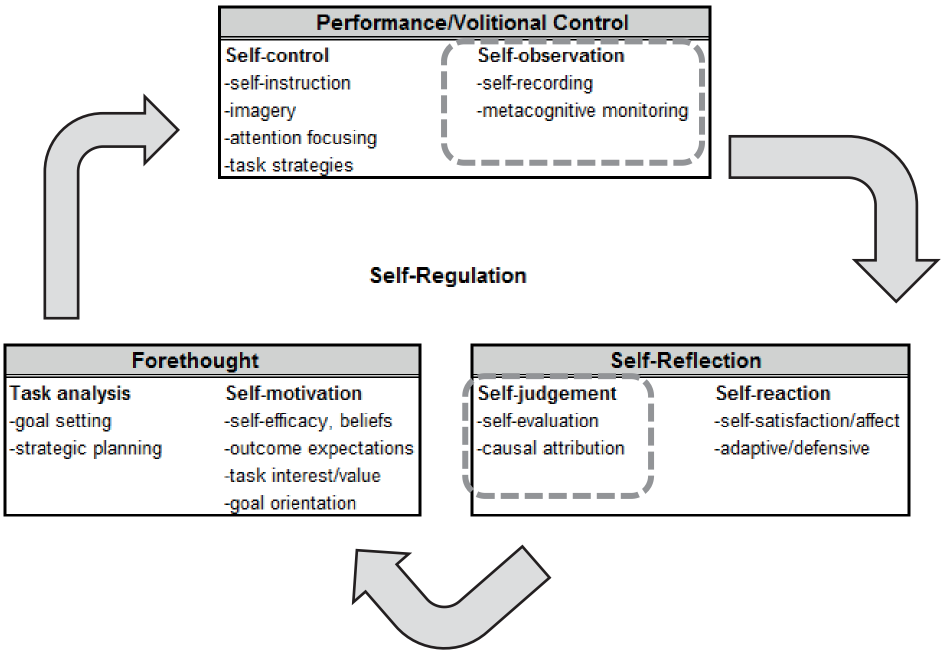

Figure 17. Supporting phases of self-regulated learning with videos and CAA

Altogether, the results of the different studies indicate that students experience the use of short educational video lectures and CAA positively. For future research, it would be interesting to determine long-term student experiences. On the other hand, it would also be interesting to explore, how students experience other types of educational technology. For example, developing the students' step-by-step exercise solutions with GeoGebra.

(Q4) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning activity in an engineering mathematics context? (This research question is closely connected to Q8.)

(Q5) Does the utilisation of technology, such as short educational video lectures and computer-aided assessment, affect students' learning outcomes in an engineering mathematics context?

Learning occurs less frequently in controlled conditions. Hence, measuring the activities and attributes that influence students' activity or learning is difficult. However, these issues can be discussed from the point of view of both theory and study results.

Self-regulated learning can increase students' academic achievement, engagement and motivation (Schunk & Zimmerman, 1998, 2012; Zimmerman, 2000; Zimmerman & Schunk, 2001). Designing learning activities that are experienced as meaningful can promote the stimulation of self-regulation (Rowe & Rafferty, 2013), which is closely connected to students' activity. The results of study 2 highlight that most of the students (about three-quarters of the respondents) experienced mathematics learning from short educational videos as meaningful. In the same study, almost one-half of the students expressed that as a teaching method, the videos had increased their motivation towards the current mathematics course. These results were consistent regardless of the explored motivation orientation (intrinsic/extrinsic). As promoting students' interests can facilitate self-regulated learning (Lee et al., 2014), these results indicate that videos have the potential to promote self-regulated learning and students' learning activity.

On the other hand, if educational technology is to be useful, it must be integrated meaningfully (Niess et al., 2009). Meaningful and interesting learning activities can promote learners' activity, but so too can digital learning material (Nokelainen, 2006). For example, presenting digital learning material in a meaningful and suitable package (Wilson & Myers, 2000) can be helpful for learning and promoting self-regulation (Rowe & Rafferty, 2013). The research has indicated that when designing learning materials, attention should be paid to learners' subject-related prerequisites and the topics that would most likely cause problems for learners (Nokelainen, 2006; Wilson & Myers, 2000). This attention was given in this research. For example, short educational video lectures were pre-designed before recording, and each video was as short as possible to increase its pedagogical usability. Earlier research highlighted how pre-designed short videos may engage students more in learning than longer videos (Guo, Kim, & Rubin, 2014). Further, the meticulous planning of short educational videos inevitably increases their quality, which consequently affects students' learning indirectly.

The studies undertaken in this research indicated, in several ways, that using the selected educational technology has an effect on students' activity and learning. In study 3, the students' viewing activity of short educational video lectures was examined. In that study, a total of 560 video views were recorded during the eight-week course, even though the videos were only supplementary resources. This illustrated that the short videos had activated the students. In study 3, the test group (which used the short educational videos) performed significantly better than the control group (without the videos) when considering the average course scores and passing rates. Related research provides similar results in an engineering education context. The students who used actively screencast videos achieved significantly higher course grades (Green et al., 2011) and increased competency (Green et al., 2012). The use of screencast videos may also provide a deeper understanding of course concepts (2012), which naturally can affect learning in engineering subjects.

From a cognitive learning perspective, short educational video lectures allow communication through different channels (see multimedia learning, in Mayer, 2003), such as narration and visual aids (Mullamphy et al., 2010). Due to these different channels, it appears that short videos, which naturally include visual and audio elements, might be more effective for students' learning than learning from text or narration alone (Dunn et al., 2015). This effectiveness is based on cognitive theories about human learning and especially on multimedia learning (Mayer, 2003). According to this theory, students can gain a deeper understanding of content from a combination of narration, text and pictures than from narration, text or pictures alone (2003). This viewpoint also arose in this research, as some of the study 2 students experienced better learning from the short videos that included audio narration than from reading the exact same content in a book.

On the other hand, when comparing the students' experiences (study 2) related to the different learning method, VET-backgrounded students ranked 'learning from short educational video lectures' slightly higher than 'doing homework exercises on my own time' (see Table 8.). VET students' lower mathematical proficiency may explain this. This result indicates that especially students who have lower mathematical proficiency may benefit most from the videos.

Worth noting is that study 3 compared the video-viewing activity of the test group students, their self-assessment form responses and the final grades. The most active video viewers were those students identified as having weak subject-related skills/knowledge and who recognised it. On the contrary, the most passive video viewers were those students who had weak skills/knowledge and did not recognise it by themselves. From this point of view, it would have been interesting to investigate whether support for passive students' self-regulation effectively influences their learning-related activity. It has been mentioned that prompting may be an effective tool when promoting self-regulated learning (Hadwin & Oshige, 2011). This may represent one direction for future research.

In study 4, which was related to online exercises, a high completion rate of online exercises was recorded. Almost 90 % of the students completed the exercises, even though the exercises were not compulsory. The students received automatic feedback about their performance, and they were rewarded for high-quality work. The students' activity indicates that the CAA has the potential to motivate students and to engage more with the learning process. The results are consistent with the literature (e.g., Armbruster et al., 2009; Henderson et al., 2015). Armbruster et al. (2009) noticed that weekly quizzes were helpful to students' learning. Studies have also shown that providing clear feedback about students' performance can help them to achieve better learning outcomes (Hattie, 2012). Furthermore, formative assessments, such as quizzes, appear to enhance students' learning more effectively than summative assessments (Sousa, 2016).

(Q6) Is Bloom's taxonomy suitable for designing test items to recognise students' level of subject-related knowledge in an engineering mathematics context?

Various frameworks have been provided to recognise and assess the depth of substance-related knowledge – for example, Bloom's taxonomy of educational objectives (1956). In the mathematics education context, e.g. Brändström (2005), Highley and Edlin (2009), Kastberg (2003), Thompson (2008, 2011) and Vidakovic et al. (2003) have all provided useful examples regarding the use of Bloom's taxonomy. Despite its longevity, Bloom's taxonomy remains, according to research, a useful framework. In this research, Bloom's taxonomy was used for designing items for the pre-/posttests (study 1) and self-assessment form (study 3). In addition, the students' mathematical proficiency was examined through the items. However, Bloom's taxonomy was not directly used for assessing students' learning, such as course grading.

Bloom's taxonomy was demonstrated to be a feasible method for the purposes of this research. When using Bloom's taxonomy, more attention was placed on designing the items for the pre-/posttests and the self-evaluation form. In study 1, Bloom's taxonomy provided guidelines about students' substance-related proficiency in pre-/posttests. However, it is important to note that the method did not recognise how the students had achieved, for example, increased competence after the pretest. In study 3, the self-assessment form worked for the students as an instrument for recognising and monitoring their learning progress. Monitoring learning progress during performance is one sub-phase of self-regulated learning (Zimmerman, 2000, 2002). Hence, the results indicate that these instruments have the potential to promote self-regulated learning.

Based on the results and experiences of this research, Bloom's taxonomy appears to be a useful method when designing test items and reviewing students' mathematical proficiency in more detail (e.g., promoting students' self-regulated learning with pre-/posttests and the self-assessment form).

(Q7) Do components of self-regulation, such as intrinsic/extrinsic motivation, affect students' learning experience or performance in an engineering mathematics context?

Research has shown that promoting self-regulation activities improves students' learning (Hattie et al., 1996; Richardson et al., 2012) and increases their motivation towards learning and achievement (Schunk & Zimmerman, 1998). Self-regulation has been characterised as 'one of the main ways in which individuals translate motivation into achievement' (Wigfield & Eccles, 2002, p. 5). According to Zimmerman (1996, 1989), a student who regulates his/her learning is metacognitively, motivationally, and behaviourally active in the learning process.

Although it is known that self-regulation includes important constructs of student learning (Panadero, 2017), isolating and measuring those constructs which have an influence on learning are difficult. For this reason, the focus of study 2 was not on measuring students' overall motivation or self-regulatory processes but rather on promoting self-regulated learning and exploring about students' experiences related to short educational video lectures. Typically, students regulate their learning more effectively when they are motivated towards the learning task (Zimmerman, 2008; Zimmerman & Schunk, 2008). Hence, the aim of study 2 was to explore whether a relation existed between motivation factors (intrinsic/extrinsic) and students' experiences.

When considering students' performance in study 2, all the students with a grade of 4 or 5 had high intrinsic motivation, as well as 60 % of the students with a grade of 3. On the other hand, almost 90 % of the students with a grade of 0 or 1 had no intrinsic motivation. The results indicate that high intrinsic motivation is correlated with higher grades.

Lin et al. (2003) highlighted that students with a medium level of extrinsic goal orientation are more likely to perform better. Those students who have both high intrinsic and medium extrinsic motivation also typically perform well (Lin et al., 2003). This was the case in this research as well. The results of study 2 indicate that well-performing students had both high intrinsic and medium extrinsic motivation, as over 90 % of grade 3, 4 or 5 students had a medium-level extrinsic goal orientation. In that sense, it is valuable to promote students' motivation, as it may have a positive influence on learning outcomes.

When exploring students' learning experience, almost one-half of study 2 respondents believed that using short educational videos as a teaching method had increased their motivation towards the course. The results were nearly consistent regardless of the students' motivational orientation (intrinsic/extrinsic). Hence, also those students who were not intrinsically motivated experienced 'using videos as a teaching method increased my motivation towards the course'.

According to results, it appears that short videos have the potential to increase students' motivation. This result is in line with existing research which indicates that short educational videos may improve students' self-regulation (Kitsantas & Dabbagh, 2010) and have a positive influence on students' learning outcomes (Dabbagh & Kitsantas, 2004).

6.3 Validity and reliability

Slightly different interpretations of validity and reliability circulate among qualitative and quantitative research (Hirsjärvi, Remes, & Sajavaara, 1997). The reliability of research is typically associated with consistent and repeatable findings (Hirsjärvi et al., 1997). In design-based research, reliability can be increased by repeating the same design more than once (McKenney & Reeves, 2013). In this research, a design-based research approach was adopted.

During this research, a total of 25 mathematics courses were implemented. Thus, iterative cycles of development, testing and refinement in real-world contexts were accomplished (Reeves, 2006; Van den Akker et al., 2006; Wang & Hannafin, 2005). As there were many course implementations, the applicability and repeatability of the results were increased both locally and regionally. Moreover, as the research was conducted in an authentic learning environment, it increased the (external) validity of the study (McKenney & Reeves, 2013).

However, the validity of the research can be criticised, as only short educational video lectures and CAA were examined. At the beginning of the research process, literature provided examples of the utilisation of educational technology. However, there was a clear lack of empirical research on how to enhance students' learning with educational technology, how to reorganise instructional design and how to understand how students and lecturers experience the use of such technology. In universities of applied sciences, practically no scientific research has been carried out related to the topic. As the main idea behind the utilisation of educational technology was to motivate students and promote self-regulated learning, the selected educational technology was needed to facilitate active studying. This research provided four studies and overall analysis related to enhancing students' learning with the technology. It can be argued that more perspectives on technology would likely decrease the emphasis of short educational videos and CAA and, in that case, the results might be narrower.

To increase the validity and reliability of the study, different data collection sources were utilised. Therefore, both qualitative and quantitative research methods were used. In the surveys, open-ended questions were used to obtain genuine feedback from students. Typically, multiple methods are used to investigate authentic learning environments (McKenney & Reeves, 2013), as was the case in this research.

The core of the design-based research process was to develop a framework for mathematics teaching and learning during 2011–2017. Thus, it was natural that the author had a twofold role as a teacher and researcher. Being able to use the pedagogical content knowledge of a teacher during the research process added value for achieving the research objectives. Naturally, the twofold role can also cause problems. Sometimes, it was difficult to objectively state the questions in surveys or reflect on actions in the classroom and evaluate the results, as my role as a teacher had to be minimised. Also, a larger research group might have provided different perspectives and approaches to examine the research problem.

Despite the possible risks of the twofold role of teacher and researcher, this approach is mostly positive. Being both a teacher and a researcher gave me a deeper perspective on the research. An outside researcher might have brought a different perspective to the research process but would never have been able to dig as deeply as a teacher with extensive pedagogical content knowledge of the taught subject and who thoroughly knows the students and their backgrounds.

Since cultural contexts vary, it is often difficult to replicate the results of someone else's study (Barab & Squire, 2004). Actually, the case might be quite similar to this study. As the study groups in UAS are different and always consist of students with different backgrounds, variations in students' mathematical proficiencies, motivation and learning styles are unavoidable. This naturally affects the results and especially their generalisation. Thus, the more general goal of design-based research is to 'lay open and problematize the completed design and resultant implementation in a way that provides insight into the local dynamics' (2004), which is similar to the goal of this study. However, investigations related to the use of technology to change classroom practices have been concentrated on developing instructional practices. Thus, the emphasis has been on the applicability and transferability of the results into practice, not just locally but regionally.

The fact that a single teacher planned and implemented the research can be seen as both a benefit and a limitation. The benefit is that there was no need to interpret which issues were teacher-related and which were not. This increased the validity of the study.

6.4 Future directions

Summing up the research process, there is evidence that guidelines for changing instructional practices for mathematics teaching and learning (section 5.3) are feasible. Even though this kind of educational development process never reaches an endpoint, as there is always room for improvement, it can be concluded that the research has reached its goals.

While the design-based research process included several iterative cycles and took several years (2011–2018), open questions remain. The research implemented educational technology, such as short educational video lectures and CAA, as part of a mathematics teaching and learning framework. That said, it is good to know that these are not the only possible technologies. It would be valuable to investigate, for example, GeoGebra visualisations and their usability in a UAS-level engineering mathematics context. How do students experience visualisations made by GeoGebra, and how could the visualisations contribute to the organisation of course content? Also, long-term impacts of using educational technology – for example, during third or fourth year engineering studies or after graduation – would be interesting to explore. Does the use of educational technology have long-term impacts on students' learning experience? What degree of cognitive load would be created by using educational technology simultaneously in different engineering courses?

During this research process, the emphasis on final exams was decreased, while emphasis on continuous assessment and motivating students was increased. An interesting line for future research would be giving up final exams and developing reliable methods to recognise students' course-related mathematics knowledge without exams.

On the other hand, this research concentrated on self-regulated learning. It would be interesting to explore more deeply the mechanism for supporting engineering students' self-regulation in mathematics learning. Also, other forms of regulation, co-regulation and shared regulation, could be feasibly attached to a UAS-level mathematics education context.

6.5 Final words

The winds of change are blowing in many ways in the field of higher education in Finland. The University of Tampere and the Tampere University of Technology started a new foundation university at the beginning of 2019, and TAMK is a part of this university. How teaching between universities in Tampere will be organised remains to be seen. In any case, the challenges discussed in this thesis will continue to exist despite changes in university administration. Therefore, the value of this research will remain, despite potential administrative changes.

On the other hand, decreasing financial resources targeted for teaching has become an international-level challenge of higher education in recent years, particularly for maintaining a high level of learning outcomes for students. Thus, novel ways to organise education must be developed and implemented.

Besides structural changes in education, the organisation of teaching is also in transition. In this process, technology plays an important role. It could be said that currently, it is almost a necessity to use educational technology in higher education to achieve better learning outcomes. However, while developing the teaching and learning processes, the key focus should always be on building subject matter knowledge.

The educational sector has faced a variety of challenges in recent years. The most common problems have been due to decreasing financial resources. Thus, different methods to organise teaching and learning should be urgently developed and implemented.

In the twenty-first century, teaching requires more than the possession of robust content-related knowledge. In fact, working at UAS has become much more fragmented, and teachers must possess different types of knowledge and skills. For example, educational technology plays an important role in education now more than ever before. Thus, instructors must develop pedagogical and technological skills and knowledge to organise high-quality teaching and learning experiences.

However, in the midst of the digitalisation hype, instructors should remember that technology should only be implemented meaningfully. There should be clear needs and objectives for using such technology. There is no reason to implement technology if it is not effective in helping students in their learning.

This dissertation has been a personal development process for me. Without my curiosity and passion for constant development, I would not be here. Without my passion, I would not be here.

'Nothing is as important as passion. No matter what you want to do with your life, be passionate.' –Jon Bon Jovi

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APPENDIX

The pre-/posttest of the study 1 (in Finnish)

https://docs.google.com/document/d/1bzShhHBZuAP1G6qg5UytMviljt3GKsOJ2s1BJ5RFoA0/edit?usp=sharing

The online questionnaire of the study 2 (in Finnish)

https://lomake.tamk.fi/v3/lomakkeet/26537/lomake.html

The online questionnaire of the study 4 (in Finnish)

https://lomake.tamk.fi/v3/lomakkeet/26538/lomake.html