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LIST OF ABBREVIATIONS

CFA – Confirmatory factor analysis
CG – Control group
CI – Core idea
DCI – Disciplinary core idea
ICI – Interdisciplinary core idea
EFA – Exploratory factor analysis
EG – Experimental group
OECD – Organisation for Economic Co-operation and Development
STEM – Science, technology, engineering, and mathematics
QUAL – Qualitative data analysis
QUANT – Quantitative data analysis

LIST OF ORIGINAL PUBLICATIONS

This doctoral study is based on the following publications, which are referenced in the text by their Roman numerals.

Article I
Soobard, R., **Semilarski, H**., Holbrook, J., Rannikmäe, M. (2018). Grade 12 students' perceived self-efficacy towards working life skills and curriculum content promoted through science education. *Journal of Baltic Science Education,* 17 (5), 838–850.

Article II
Semilarski, H., Soobard, R., Rannikmäe, M. (2019). Modelling students' perceived self-efficacy and importance towards core ideas in science education. *Science Education International,* 30 (4), 261–273.

Article III
Semilarski, H., Soobard R., Holbrook, J., Rannikmäe, M. (2021). Exploring the complexity of student-created mind maps, based on science-related disciplinary and interdisciplinary core ideas. *Interdisciplinary Journal of Environmental and Science Education,* 17 (1), 1–13.

Article IV
Semilarski, H., Soobard, R., Rannikmäe, M. (2021). Promoting students' perceived self-efficacy towards 21st century skills through everyday life-related scenarios. *Education Sciences*, 11(10), 1–18.

Article V
Semilarski, H., Soobard, R., Holbrook, J., Rannikmäe, M. (accepted). Expanding disciplinary and interdisciplinary core idea maps by students to promote perceived self-efficacy in learning science. (accepted, *International Journal of STEM Education*).

The author contributed to the publications in the following way:

Article I: Participated in the creation of the study design, participated in the formulation of the research questions, planned and carried out the data analysis, contributed to the paper as the second author.

Article II: Designed the study, adapted the measurement instruments, formulated the research questions, planned and carried out the data collection and analysis, wrote the original manuscript, and performed the rewrites based on reviewers' suggestions. Wrote the paper as the main author in cooperation with co-authors.

Article III: Designed the study, adapted the measurement instruments, formulated the research questions, planned and carried out the data collection and analysis, wrote the original manuscript, and performed the rewrites based on reviewers' suggestions. Wrote the paper as the main author in cooperation with co-authors.

Article IV: Designed the study, adapted the measurement instruments, formulated the research questions, planned and carried out the data collection and analysis, wrote the original manuscript, and performed the rewrites based on reviewers' suggestions. Wrote the paper as the main author in cooperation with co-authors.

Article V: Designed the study, adapted the measurement instruments, formulated the research questions, planned and carried out the data collection and analysis, wrote the original manuscript, and performed the rewrites based on reviewers' suggestions. Wrote the paper as the main author in cooperation with co-authors.

1. INTRODUCTION

In recent years, considerable attention has been paid to how to support students' meaningful learning in science education [Life Science (biology), Earth Science (geography), Chemistry, and Physics], in such a way that the acquired material is meaningful and connections have been established enabling students' self-efficacy to be enhanced (Cañas & Novak, 2019; Heddy et al., 2017). Meaningful learning is seen as the process of interpreting situations in light of previous knowledge and experiences (Odden & Russ, 2019). In this way, emphasis is put on promoting students' independence, identifying their own world view and stimulating their willingness to succeed in life through developing self-efficacy (Estonian Government, 2011; McBride et al., 2019). Self-efficacy is taken to be an indicator of a person's belief in their ability to succeed in a specific situation, or accomplishment of a task, based on acquired situational connections (Bandura, 1986). Where the perception is weak, or self-efficacy not established, this can be expected to lead to concerns in science learning, for example students' acquisition of fragmented science knowledge (Harlen et al., 2015). Figure 1 indicates such concerns, potentially impacting on students' self-efficacy.

Learning in science education, increasingly focuses on seeking ways to integrate different science subjects [Life Science (Biology), Earth Science (Geography), Chemistry and Physics] to support students' meaningful conceptualisation about the world (Bretz et al., 2013; Heddy et al., 2017). This lack of meaningful learning has been exacerbated by the concern of emphasising students gaining fragmental knowledge in learning through science topics (Harlen et al., 2010; 2015). It has also led to situations where students cannot see the 'bigger picture' (complete overview of learned knowledge) of the learning and lack coherence of progression towards overarching disciplinary core ideas (the fundamental ideas that are necessary for conceptualising science) (Harlen et al., 2015; Semilarski et al., 2020). Also, it is important to develop interdisciplinary core ideas which are transferrable across science fields, e.g. models and systems, and which are much broader in scope and are not solely rooted in science (Harlen et al., 2015). One approach to mitigate against fragmental knowledge has been to place emphasis on identifying disciplinary and interdisciplinary core ideas, which serve as a conceptual framework, allowing students to make sense of critical knowledge about the world in which they live (Cooper et al., 2017; Harlen et al., 2010;15). Not only is it important to support students in linking everything they know, but also how to use the knowledge in their everyday life and, based on this, the way they act (e.g., ask questions, design and perform investigations and inquiries, construct explanations, etc.) (Holley & Park, 2020).

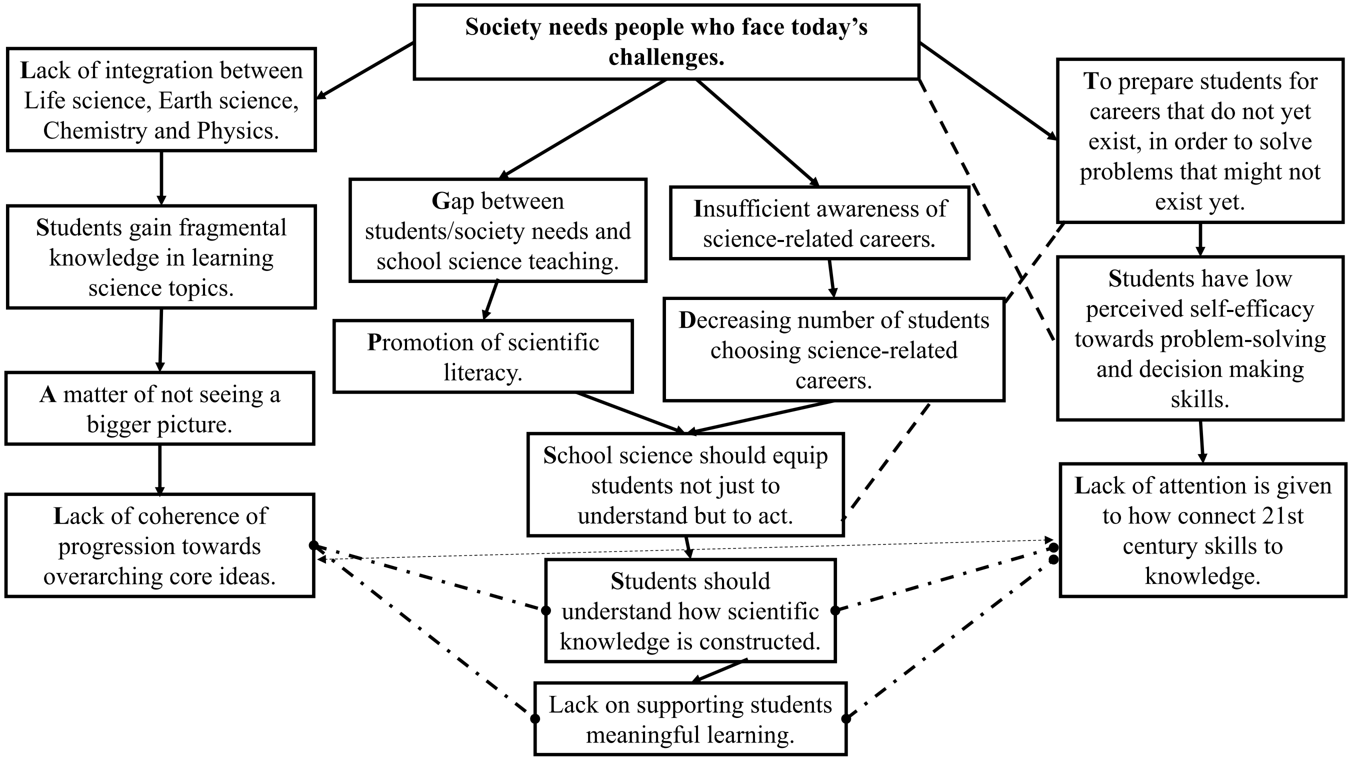


Figure 1. Concerns in school science education associated with the society's perceptions of science education

Another concern in science education is that students tend to have low self-efficacy towards acquiring problem-solving and decision-making skills (Evans et al., 2020). The reasons cited have been the lack of attention given to how to connect skills, often referred to as 21st century skills, to knowledge (Harlen et al., 2015; Joynes, 2019). Following Krathwohl's (2002) knowledge model it is important – besides the students' factual knowledge – to develop students' conceptualisation of information gained and knowledge related to utilising skills and methods. This suggests that it is advantageous for students to develop the desired 21st century skills (Evans et al., 2020; OECD, 2019), seen as critically important for student success in the future (Evans et al., 2020). A further area of concern for science educators and teachers is the preparation of students for careers that, as yet, do not exist (OECD, 2019).

According to research over the decades, students' lack of interest in science learning – suggested to relate to a decreasing number of students choosing science-related careers – is still a continuing concern (DeWitt & Archer, 2015; Drymiotou et al., 2021; Osborne et al., 2003). Researchers have raised concerns on ways to link the needs of society with science education (Choi et al., 2011; Pleasants et al., 2021). Today's society needs specialists who are prepared to face today's challenges and are ready to deal with multiple science-related problems and decision-making situations in the real world (Lambert et al., 2020; OECD, 2019). Further concerns put forward are that students' awareness of science-related careers is lacking (Darling-Hammond et al., 2020; Schleicher, 2020), and there is a recognised gap between students'/society's needs and school science teaching (Choi et al., 2011; Pleasants et al., 2021).

A goal for science education today is promoting scientific literacy (Estonian Government, 2011). This suggests school science studies should pay more attention to equipping students, not just to conceptualise science ideas, but also to be able to put forward actions to take in both scientific and socio-scientific situations (OECD, 2019; Steward, 2019). For students to solve problems, or make justified decisions, it is crucial that they make sense of how scientific knowledge is constructed (Holley & Park, 2020; Rudolph, 2005), as well as being provided with opportunities to create and construct new knowledge through their own experiences (Pegg et al., 2012).

With the above concerns in mind, researchers have sought ways to promote students' meaningful learning in the science education learning process. Meaningful learning entails that learned knowledge is completely acquired and can be used to make connections with other previously known knowledge, aiding further conceptualisation (Bressington et al., 2018). One key aspect in this regard is seen as involving learners in actively integrating new learning with their prior knowledge (Cañas & Novak, 2019; Novak, 2010) through methods of knowledge integration (e.g. using mind maps and concept maps), thus developing coherent, transferrable conceptual frameworks of the learning (Ambrose et al*.,* 2010; Buzan 2009a; Novak, 2010).

In Estonia, the science curriculum is divided into four branch subjects: Biology (Life Science), Geography (Earth Science), Chemistry, and Physics.

However, this has led to the problem that although science teachers in Estonia are subjects specific and have a very good knowledge of their subject, it is often problematic that their subject is not associated with other branches of science. Several studies (OECD, 2019; 2016) show that Estonian students have good levels of knowledge but modest creative, problem-solving and entrepreneurial skills. However, these skills are essential in today's society and economy.

The aim of this study is to determine the impact of student-led expansion of disciplinary core idea (DCI) and interdisciplinary core idea (ICI) maps which can contribute to promoting students' meaningful learning.

Based on this aim, the following research questions are proposed:
1. What is the students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills? (Articles I and II)
2. Which essential characteristics need to be included in deriving interventions which promote students' meaningful learning? (Articles I, II, and III)
3. In what ways can changes in upper secondary school students' self-efficacy towards acquiring meaningful learning be enhanced by guiding and engaging students in expanding upon DCI and ICI maps? (Articles IV and V)

The research questions have been addressed in one (or more) of the following original publications:

Articles I and II address research questions 1 and 2 by investigating students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills, using a newly developed instrument. **Article III** further addresses research question 2 and explores the complexity of student-created mind maps, on disciplinary and interdisciplinary core ideas.

Articles IV and V address research question 3 by investigating the impact of an intervention carried out in schools using students expanding upon DCI and ICI maps in support of students' meaningful learning. While **Article IV** focuses on how the conducted intervention facilitates the promotion of students' self-efficacy towards acquiring disciplinary and interdisciplinary core ideas. Finally, **Article V** focuses on how students' self-efficacy towards acquiring 21st century skills changes after the implemented intervention.

2. THEORETICAL BACKGROUND

In the following sections, the theoretical outline of the dissertation is presented. First, relevant theoretical literature regarding meaningful learning is given. Then overviews are presented regarding disciplinary and interdisciplinary core ideas in science education and 21st century skills and research developments in these areas. This is followed by a short overview of self-efficacy and dimensions of knowledge and knowledge construction. Following this, meaningful learning through mapping is explored. Finally, an overview of the constructivist theory is given.

2.1. Meaningful learning

Ausubel's (1963) meaningful learning theory states that students learn through a meaningful process of relating new knowledge to that which is already existing, this being seen as an effective way for students to engage in learning.

There are three main characteristics of Ausubel's theory (Ausubel et al., 1978):

a) *Relevant prior knowledge* – meaningful learning is supported by previous experiences and knowledge, through the ability to draw connections between the two;
b) *Meaningful material* – logic and meaningful activities as part of teaching materials seek to engage students and arouse their interest;
c) *The learner must choose to learn meaningfully* – the learning experience, thoughts, and arguments are willingly explored and expressed by students.

Research indicates that students need to actively seek out ways to integrate new knowledge with prior knowledge in their cognitive structure in order to construct and reconstruct meaning (Apodaca et al., 2019; Heddy et al., 2017; Novak, 1993; 2002). Novak (2010) also indicates that such meaningful learning can take place when prior knowledge is conceptualised and well-structured by students. The promotion of meaningful learning is based on a constructivist approach in which the learning becomes meaningful when it is fully assimilated by the students thus making connections between their prior and new knowledge (Gromley et al., 2022; Novak, 1993; 2002). Knowledge is the sum of what is known – the body of truth, information, principles, and theories that the learner receives by experience or study, either known by one person or by people generally (Ericson, 2002; Howell et al., 2014; Jonassen et al., 2003). Meaningful learning also takes place when the students are given the opportunity to internalise the meaning, and based on this, to be able to ask questions (Freedman, 1994; Mayer et al., 1996; Tasker, 1992; Thompson, 2000).

Teachers can influence students' meaningful learning both directly and in-directly, such as by creating materials that motivate students to be interested in the gaining of new knowledge, while also providing opportunities to link this knowledge to prior knowledge (Bretz et al., 2013; DeKorver & Towns, 2015; Merriam & Clark, 1993). Consequently, relevant prior knowledge can become more and more meaningful over time, becoming richer and refined, serving as a platform for learning that which is perceived as new (Ausubel, 1968; Hailikari et al., 2007; Tobias, 1994). Researchers also indicate that learning depends on so-called "anchor points" based on which new knowledge can be constructed and integrated (Bretz et al., 2013; Donald, 2002).

Conceptualising a particular phenomenon can be achieved through the process of integrating knowledge into meaningful dimensions and principles, with the aim of gaining a deeper appreciation of the subject matter (Anderson & Krathwohl, 2001; Gupte et al., 2021). In enabling learned knowledge to become meaningful for the students, science educators need to concentrate on facilitation, as well as enabling and the conceptualisation of science learning (Alavi & Leidner, 2001; Ausubel, 1968; Bransford et al., 2000; Heddy et al., 2017). As Chapman (1999) suggests, knowledge is constructed through the interactions of an individual and their social contexts. Thus, to deeply engage students in science learning, self-efficacy is seen to be of great importance (Lin, 2021). Students with higher self-efficacy set higher goals and expend more effort towards their achievement and show a higher level of thinking about conseptualising science (Smit et al., 2019). Students' self-efficacy is seen as the key to promoting students' engagement and learning (Wu & Fan, 2017).

This research seeks to find ways to support meaningful learning for students in science education. For this, it is important to support students in interconnecting different science subjects. Various authors have outlined that disciplinary and interdisciplinary core ideas are fundamental for conceptualising science (Krajcik & Delen, 2017; Kubsch et al., 2020; NRC, 2012).

2.2. Disciplinary and interdisciplinary core ideas in science education

Core ideas can be defined as fundamental ideas that are necessary for understanding a given science discipline (NRC, 2012). Disciplinary and interdisciplinary core ideas have been seen as a key perspective for conceptualising knowledge such as that in the field of science, regarding genetics, models, climate and weather, etc., which can help to develop a better and more accurate perception of how scientific ideas enable a picture of how the world works (Alonzo & Gotwals, 2012; NRC, 2012). These have been suggested as being critical for comprehending the overall picture and for enabling the relating of a variety of science learning disciplines (Roche Allred et al., 2020). They have been seen as essential for exploring connections across scientific disciplines and for solving problems, explaining complex knowledge and making important decisions (Flaherty, 2020; Pleasants et al., 2021). The promotion offers the conceptualisation of knowledge and skills, enhancing the raising of scientific career awareness, and forming a foundation for preparing students for more in-depth deeper scientific inquiry (Krajcik & Delen, 2017; Kubsch et al., 2020; NRC, 2012). For example, to tackle the problem effectively, it is important to know the content and to make sense of what the problem actually entails. Each disciplinary and interdisciplinary core idea represents a conceptual whole that guides student thinking, and links to other DCIs and ICIs to help develop a deep and meaningful conceptualisation of the world (Kubsch et al., 2020). By building years of learned material, the DCI and ICI subcomponents cultivate a foundation of knowledge on which students can build (Harlen et al., 2015). While students learn new, increasingly advanced, material in every school grade (from grade 1 to grade 12), each new knowledge component can be expected to follow a logical progression from the material they have mastered from previous years (Kubsch et al., 2020).

In many studies, it has been demonstrated that students can learn science from conceptualising their immediate surroundings themselves, relating to different science fields (e.g. Life Science, Physics, etc.) (Article II, Harlen et al., 2015;10; Krajcik & Delen, 2017). Science curricula have been criticised for a lack of coherence and knowledge integration between different science disciplines, e.g. Physics and Chemistry, showing a lack of progression between primary to secondary school education (Duschl et al., 2011; Schmidt et al., 2002), which causes students to fail to make sense of what they are learning, as well as to lose interest in science (Harlen et al., 2015). School science teaching often focuses on teaching factual knowledge in a way that reduces the content to mere trivia instead of learning how to apply it to something useful (Oslon, 2007). Generally, students tend to show little interest in learning things that seem disconnected to them (Harlen et al., 2015), and this is seen as a major concern raised during the distance learning period, related to the COVID-19 pandemic (Page et al., 2021).

Disciplinary core ideas (DCIs) and interdisciplinary core ideas (ICIs) are key (learning) components and include ideas that are important across one or multiple disciplines (NRC, 2012). These are necessary for students to know in order to be able to conceptualise the world around them (Krajcik & Delen, 2017). The DCIs and ICIs form a conceptual framework through which students can conceptualise the disciplines. The following aspects are criteria which identify the DCIs and ICIs (Article, III; NGSS, 2012):

- Have broad importance across multiple disciplines or be a key organising concept of a single discipline;
- Provide a key tool for conceptualising or investigating more complex ideas and solving problems;
- Relate to interests and life experiences of students or be connected to societal or personal concerns that require knowledge;
- Be teachable and learnable over multiple grades at increasing levels of depth and sophistication.

It has been suggested we live in a world where disciplinary and interdisciplinary core ideas are critical, where both science and society agree on similar DCIs or ICIs (Cooper et al., 2017; Harlen et al., 2010;15). For conceptualising science, Arnold et al (2021) suggest it is a fundamental necessity to develop DCIs and ICIs within science education and teaching, while Holley and Park (2020) recognise that disciplinary and interdisciplinary core ideas acquired in school, related to societal or individual needs, have wide significance (Holley & Park, 2020). In this regard, it is noted that the Estonian science curriculum includes a variety of topics which can be interrelated by a logical system (scientific framework) (Article, II) such that school science learning can be built on disciplinary core ideas, enabling meaningful conceptualisation of various scientific phenomena and processes (Krajcik et al., 2012). Furthermore, conceptualising disciplinary and interdisciplinary core ideas facilitates solving scientific problems which interrelate with science learning (Article, II; Krajcik & Delen, 2017; NRC, 2012). In summary, irrespective of the career a student chooses, DCIs and ICIs are applicable in their learning process, throughout the various school levels (Arnold et al., 2021). The learning experiences provided for students (e.g. conducting experiments in the laboratory) should engage them with questions and inquiries about the world and by how scientists have investigated and found answers to these questions. Throughout their grades, students should have the opportunity to carry out scientific investigations and design projects related to the DCIs and ICIs (Kubsch et al., 2020; NRC, 2012). These can support students' meaningful learning because students are motivated to deepen their conceptualisation of science in order to solve a problem that is meaningful to them (Kubsch et al., 2020; Odden & Russ, 2019).

DCIs and ICIs are viewed as building a framework (Borda et al., 2020; Wang & Song, 2021) for supporting students' meaningful learning (NRC, 2012; Stevens et al., 2009). Based on research (Article II; Krajcik & Delen, 2017; NRC, 2012), such core ideas have been considered in two different orientations:

a) Disciplinary core ideas are the science content that students must know and be able to apply and that are specific to a science field, such as core ideas in Life Science (hereditary, genetic variation), Earth Science (relief formation; climate and weather), Chemistry (atoms and molecules; chemical reactions) and Physics (energy conversion; movement: waves), and;
b) Interdisciplinary core ideas that are transferrable across different science fields, e.g. models, systems, etc., yet are central for learning. These are much broader in scope and are not necessarily solely rooted in science. These support how students think like scientists, focusing on a specific aspect of the observations.

In order for our students to be prepared for their future careers, it is crucial to help them connect knowledge across disciplines (Borda et al., 2020). It is therefore essential for students to integrate disciplinary and interdisciplinary core ideas (Article III). This knowledge integration focuses on making connections for students, allowing them to engage in relevant, meaningful activities that can be connected to real life (Wang et al., 2019). When students can conceptualise the DCIs and ICIs, they are more likely and more confident to develop skills such as how science and careers are interconnected, and thus be better prepared to think about science and careers in a broader context (Borda et al., 2020; Wang et al., 2019). For example, a conceptualisation of genetic variability and DNA (both relevant to the field of Life Science) can aid in the treatment of interdisciplinary medical issues related to hereditary diseases, reasons for their occurrences, and the treatments needed for them (Holley & Park, 2020). Additionally, conceptualising climate change (a disciplinary core idea involving globalisation, the economy, and the environment) allows for better interdisciplinary conceptualising interdisciplinary of the causes and solutions for combating this phenomenon (Darling-Hammond et al., 2020; Harlen et al., 2015).

It is important to emphasise how the DCIs and ICIs are linked to 21st century skills (NRC, 2012). This doctoral study seeks ways in which to increase students' acquisition of DCIs, ICIs, and 21st century skills.

2.3. 21st century skills

The term 21st century skills is generally used by researchers as an umbrella term for describing a range of skills and subcategories of skills (Binkley et al., 2012; Choi et al., 2011). The literature, however, reveals that other concepts can be associated with 21st century skills, for example, working and life skills, transversal skills, critical skills, and digital skills, despite some significant diversity across a range of personal and practical attributes (Chalkiadaki, 2018). This diversity indicates that no clear and unique definition of such attributes is evident and adopted internationally.

In today's society, science and science-related careers require 21st century skills (Binkley et al., 2012; P21, 2009; Short & Keller-Bell, 2021) particularly involving (Article IV):

- *Cognitive and problem-solving skills* – needed in the acquisition of knowledge, manipulation of information, and reasoning;
- *Critical thinking* – mode of thinking about any subject, content, or problem in which the thinker improves the quality of their thinking by skilfully analysis, reasoning, synthesising, etc.;
- *The changeability of scientific knowledge* – understanding how scientific knowledge is constructed;
- *Responsible citizenship* – having knowledge about his/her role in the community, and in the world;
- *Mindset for scientific research* – organised mindset that ensures thinking (considering evidence, flexibility, methodological approaches, accuracy).

The literature shows that Estonian students' problem-solving skills and decision-making skills are not generally at the level expected by the end of upper secondary school (Article I and II). Youths can become more competitive in the job market by acquiring different attributes that empower them to become more skilled and prepared for today's world (van Laar et al., 2020; Wagner, 2010). Numerous researchers have identified a number of such attributes that are essential to prepare tomorrow's workforce, such as critical thinking, responsibility, problem-solving, and decision-making (Binkley et al., 2012; Choi et al., 2011; Krskova et al., 2020; P21, 2009; OECD, 2019). Different authors have named these key attributes differently – 21st century skills (Binkley et al., 2012; Choi, 2011; Haug & Mork, 2021), global competence (Chong et al., 2021; OECD, 2019; 2016), self-leadership (Estonian Education and Research Strategy, 2021–2035) or work/working and life skills (Salonen et al., 2017; Semilarski et al., 2019; Soobard et al., 2018).

These 21st century skills play a major role in the process of relating science education to everyday life (Rios et al., 2020). Hence, it is desirable that educational systems seek to develop such skills in students, even though they may not recognise the link between knowledge acquisition and acquiring the skills essential for being attracted to science-related, career-oriented choices (Sarkar et al., 2019). The acquisition of skills needed for different careers, (Kashefpakdel et al., 2021; Potvin & Hasni, 2014), points to the need for future education endeavours to be seen as shaping students to 'learn for life'. One way to address this situation is to create a new teaching-learning approach for students, especially at the upper secondary school level. As it is important to develop, through science lessons, students' disciplinary and interdisciplinary core ideas as well as 21st century skills, all of these are seen as important for the future workforce (Kashefpakdel et al., 2021).

In this study, determining students' self-efficacy is considered as a measure to identify the impact of the carried-out intervention on the development of DCIs, ICIs, and the acquisition of 21st century skills.

2.4. Self-efficacy

Bandura (1986), described how self-efficacy affected people's perception of difficult tasks as something to be mastered rather than avoided. Moreover, students with high self-efficacy tend to work harder, pursue more ambitious goals, and persevere in the face of challenges (Bandura, 1997; Pajares, 2003). According to several studies, beliefs about one's competence can have an important role to play in motivating and enhancing performance in science classes (Pajares, 2003; Schunk, 1991).

Self-efficacy is also correlated with academic motivation, learning, and even achievement, although it is independent of actual ability (Pajares 2003). Bandura (1986) has argued that self-efficacy is one of the more accurate indicators of future performance as opposed to people's actual competency, because self-efficacy is seen as determining what people do with their knowledge and skills, thus allowing them to be successful. Researchers have also shown that self-efficacy correlates with actual capabilities: students who report increasing self-efficacy over time are more likely to succeed academically (Jamil & Mahmud, 2019; Phan, 2011; Stewart et al., 2020). The opposite is also true: negative self-efficacy (inactivity and non-performance) may lead to demotivation and dropout (Bandura 1997).

Research suggests that students' self-efficacy affects their choice of activities related to science lessons or activities (Bandura, 1997; Usher & Pajares, 2008). When students believe strongly in their abilities and choose specific activities in which they put more effort to accomplishe, they are more likely to succeed (Stewart et al., 2020). Furthermore, teachers' beliefs and values can affect students' self-efficacy (Fisher & Hänze, 2019; Zlatkin-Troitschanskaia et al., 2020). Research suggests that it plays a role in students' self-efficacy based on teacher competence and teacher respect (Miller et al., 2017). Moreover, different research studies show that both teachers' and students' beliefs can affect student achievement (Berebitsky & Salloum, 2017; Kikas et al., 2021; Mowafaq et al., 2019). Research shows that the type of learning environment and teaching method can improve students' self-efficacy in the classroom (Bandura, 1997). A similar result was reported by Fencl and Sheel (2005), who concluded that if students make sense of learned material and can-do collaboration to ask questions, solving problems, and inquiry have a positive effect on students' self-efficacy. Moreover, enhancing students' collaboration and self-efficacy can support students' meaningful learning (Bressington et al., 2018; Johannsen et al., 2012). Furthermore, as indicated in the previous research, encouraging students to relate their previous knowledge to new knowledge can have a positive influence on their self-efficacy and can promote students' meaningful learning (Baltaoğlu & Güven, 2019; Zang & Soergel, 2014).

Novak (2002) found that meaningful learning results in a modification of students' knowledge structures. In keeping this in mind for this doctoral study it was important to research which dimensions of knowledge students could develop and in which areas they needed more support.

2.5. Dimensions of knowledge and knowledge construction

Krathwohl (2002) categorised the dimensions of knowledge as:

- Factual – basic elements that include isolated bits of information, or knowledge about specific details;
- Conceptual – the interrelationships between the basic elements within a larger structure that enable them to function together, such as knowledge of models, classifications, etc.;
- Procedural – how to do something including methods, specific skills, or techniques.

Within this framework, conceptual knowledge tends to indicate an order for teaching so that students can reach higher levels of thinking, rather than just recalling some facts (factual knowledge) (Anderson & Krathwohl, 2001; Bloom & Krathwohl, 1956; Krathwohl, 2002). This is seen as important to support students' meaningful learning (Mayer, 2002; Odden & Russ, 2019). While factual and conceptual knowledge are often taught at school lessons, putting more emphasis on procedural and conceptual dimensions of knowledge can lead to a stronger and deeper conceptualisation and supports students' meaningful learning

(Alavi & Leidner, 2001; Saks et al., 2021). Deconstructing subject content to dimensions of knowledge identifies how students conceptualise their prior and new knowledge and can be important in assisting students to develop meaningful knowledge (Chi, 2008; Cho et al., 1985; Krathwohl, 2002).

Knowledge construction can be interpreted as a learning process of how knowledge is formed (Chang, 2018; Vygotsky, 1986). Knowledge construction is the effort of a student to interconnect new knowledge with the prior knowledge and is more than just remembering facts (Stahl, 2004). Researchers have identified that a lack of meaningful interconnections made by students can lead to misconceptions, which are seen as obstacles to supporting students' meaningful learning (Cho et al., 1985; Gafoor & Akhilesh, 2008). This indicates that it is necessary that the correct interconnections between prior and new knowledge are formed during the learning process (Chi, 2008).

The theory of knowledge construction highlights that students gain knowledge effectively when they are engaged in the learning process (Thompson, 2000; Wilson, 2001). In this regard, mind mapping and concept mapping are well-recognised methods which can help students to organise their knowledge construction and are beneficial to students' clarification of the relationship between concepts, assisting students in connecting prior and new knowledge (Liu et al., 2010).

Learning entails to construct knowledge on the learner's interpretations of experiences in the world. Instruction involves engaging the learners in meaning making (knowledge construction). Mind and concept mapping are used for researching more in-depth students' dimensions of knowledge in greater depth (Bressington et al., 2018; Novak, 2010). Mapping has been used effectively to aid meaningful learning with resulting modifications in students' dimensions of knowledge (Novak 2002). In this current doctoral study, students constructed knowledge when they expanded their DCI and ICI maps. The students expanded the DCI and ICI maps with different dimensions of knowledge, while the intervention sought to support students' conceptual and procedural knowledge rather than factual knowledge. In this doctoral study, mind and concept mapping are seen as ways to support students' knowledge integration and for supporting their meaningful learning in science education.

2.6. Meaningful learning through mapping

Meaningful learning can be promoted through students' knowledge integration (Howland et al., 2011; Mystakidis, 2019; Weick et al., 2005). Knowledge integration involves how the new knowledge and the existing knowledge interact, enabling the support of interdisciplinary learning (Huntley, 1998; Shen et al., 2016; Wicklein & Shell, 1995). When learners integrate their knowledge, meaningful learning is facilitated because the prior and new knowledge are interrelated (Cañas & Novak, 2014; Novak, 2010).

Research indicates that mind mapping and concept mapping help to integrate knowledge and this can promote students' meaningful learning (Bressington et al., 2018). While mind maps have been seen as a method of linking imagination with structure, via reasoning (Ausubel, 1968; Brinkmann, 2003), the technique has been further developed to examine students' capacity for planning and co-ordinating their learning (Buzan, 2009a; 2009b). Concept maps are usually rectangularly framed and connected with labelled arrows, which create a unique connection (Cañas & Novak, 2019; Cañas et al., 2017; Kinchin et al., 2019). Today, integrating knowledge through mind maps and concept maps is a common feature of education and training (Bressington et al., 2018), the purpose being to facilitate meaningful learning through the examination of prior and new knowledge (Cañas & Novak, 2019).

In the 1960s, Buzan developed the mind mapping technique to visualise meaningful connections between students' previous and new knowledge (Bressington et al., 2018), whilst Astriani et al. (2020) and Novak (2010) showed that students were able to achieve meaningful learning by viewing their knowledge in a concept map by using a hierarchy and hierarchical presentation. Furthermore, research also found that students who were proficient at connecting knowledge were significantly more successful in standard knowledge-based school tasks and assessments (Nordine et al., 2019; Kubsch et al., 2020). Thus students' prior knowledge could be identified by teachers through the use of a mind map or concept map, both allowing the use of more appropriate teaching materials and strategies to facilitate their learning (Ausubel et al., 1978; Novak, 2010; Heddy et al., 2017; Kalyuga & Sweller, 2004).

Developing coherent, transferrable conceptual learning frameworks can help students to develop mind maps and concept maps (Ambrose et al*.,* 2010; Buzan 2009a; Novak, 2010). In a study by Jena (2012), it was found that students' hierarchical mind maps and concept maps provide more meaningful science learning the more hierarchical they become. Thus, mind mapping and concept mapping have been shown to be effective in the teaching process. For example, student learning is more extensive and organised in a more thematic fashion, and their interconnected knowledge is portrayed more vividly (Dhindsa et al., 2010). As a result, mind mapping and concept mapping offer a means to assess learning – both by indicating how well the presented knowledge is integrated and related to the mind maps as well as by ensuring long-term memory (Astriani et al., 2020; Buzan, 2009b).

In this current study the developed DCI and ICI maps used some elements (such as connecting knowledge) from the mind mapping (arrows, radial structure) and concept mapping method (labelled arrows). Moreover, during the intervention students had several tasks where they were required to make mind maps or concept maps, related to the DCIs or ICIs, to support students' meaningful learning. Accordingly, meaningful learning was the constructive process of making meaning of the world, enabling the students to use knowledge in new and also unfamiliar situations (Mayer, 2002; Odden & Russ, 2019). However, this does not emphasise the hierarchical nature of knowledge and did not explain how students' conceptualisations were developing and changing over time (Jena, 2012). In this it is important to support students' knowledge integration and to support constructivism. For this doctoral study one of the theories chosen is constructivism. Knowledge not connected with a students' prior experiences will quickly be forgotten. Students must actively construct new knowledge into their existing framework for meaningful learning to occur.

2.7. Constructivist approach

Researchers state that current teaching practices tend to focus too strongly on learning content and need to move towards more constructivist approaches in which students' owning of the construction of knowledge is central (Biggs, 2014; Prosser, 2013). The constructivist theory is based on the idea that learners are active participants in their learning; knowledge is constructed based on experiences (Philips, 2000; Piaget, 1972; Vygotsky, 1978; Thompson, 2000). As events occur, each person reflects on their experience and incorporates the new knowledge with their prior knowledge (Wilson, 2001; White, 2001). This model has been entrenched in learning theories by Dewey, Piaget, Vygotsky, Gagne, and Bruner. Researchers have found that constructivist teaching engages the students' interest, fosters collaboration and inspires active experimentation (DeVries and Zan, 1994).

A constructivist approach provides opportunities for each student to create and construct new knowledge and to conceptualise the existing reality through their own experiences (Pande & Bharathi, 2020; Pegg et al., 2012). According to the constructivist approach, student learning becomes a concrete experience in which students can search for patterns, formulate questions and structure their own models, concepts and strategies – this process is seen as resulting in meaningful learning (Coffield et al., 2004; Pegg et al., 2012). Of importance, a constructivist approach to learning places the student at the centre (Bada & Olusegun, 2015; Wilson, 2001; White, 2001). The constructivist approach is based on a philosophy that forms the backbone for this doctoral study. In a constructivist approach, the learning is an activity of construction and it posits that knowledge involves acquisition and learning and is transformative through self-involvement. Such knowledge construction and interconnecting, prior to gained new knowledge, can support students' meaningful learning.

2.8. Estonian science curriculum as the research context

The Estonian science curriculum is competence-based, with a stated purpose to promote scientific literacy and initiate a paradigm shift from memorisation of knowledge to the acquisition of competences (Estonian Government, 2011). For this, there is a recognised need to develop interdisciplinary understanding about science, moving away from a concentration on a single science subject related to isolated knowledge and skills and focussing on wider learning outcomes. The Estonian science curriculum indicates key competences to be promoted throughout all school science subjects, all of which, as components of scientific literacy, are intended to be promoted in science lessons. The goals for science education are specified as fostering scientific literacy through: problem-solving, reasoning, decision-making and creative thinking skills.

The Estonian science curriculum topics are presented via a traditional syllabus, meaning that the science content is divided between four subjects: Life Science, Chemistry, Earth Science, and Physics. All the science subjects seek to enhance scientific competence, which is expressed in terms of science and technology literacy, and includes the development of the ability to observe, understand and speak in the natural, artificial and social environment, to analyse the environment as a whole, to identify problems within it, make informed resolving decisions, and use scientific methods. It seeks the using of knowledge gained from Life Science, Earth Science, Chemistry and Physics purposefully for developing students' problem-solving and decision-making skills.

3. RESEARCH METHODOLOGY

This research study was carried out in three stages. This section details the research methodology involving the three stages. The context in which the three stages are undertaken is described, including ethical benchmarks before identifying the samples involved, instrument development, data collection, data analysis methods plus the validity and reliability of the research.

3.1. The 3-stage research design

This study is described as having a mixed-methods design, combining both quantitative and qualitative methods in order to provide conclusions that supplement each other, while benefiting from the strengths of both methods (Ivankova, Creswell, & Stick, 2006; Niglas et al., 2018; Niglas, 2008). Utilising a three-stage approach, each stage is of equal priority involving data integration during interpretation. The research design is shown in Figure 2. A triangulation technique, incorporating quantitative and qualitative research, was employed, involving both methodological and data triangulation. The collected data were triangulated from different sources, including students and teachers from different schools.

Stage I was a quantitative study to determine students' current self-efficacy towards acquiring DCIs, ICIs, and 21st century skills. The stage I findings were presented in Articles I and II. Stage II was undertaken to develop an intervention, which included student-led expansion of DCI and ICI maps which can contribute to promote students' meaningful learning. Before and after the intervention pre- and post-questionnaires were conducted. Stage II was largely quantitative; however, in order to gain more insight into the students' conceptualisation of the disciplinary and interdisciplinary core ideas, a qualitative approach was added when analysing students' expanded mind maps about disciplinary and interdisciplinary core ideas. The findings from stage II were presented in Articles I, II, and III.

The goal in undertaking stage III was to determine the degree of students' meaningful learning, through determining students' self-efficacy, based on the carrying out of an intervention in a meaningful sample of schools. The research approach in stage III used mixed-methods, relying on the same framework as used in the data collection instrument within stages I and II. The findings from undertaking stage III were presented in Articles IV and V.

In stage I the aim was concentrating to determine students' current self-efficacy towards acquiring DCIs, ICIs, and 21st century skills. Thus, from the findings from stage I, general conclusions were drawn from which the intervention could be planned and later carried out in the selected schools, forming the sample I size N=1475 and sample II size N=311 students.

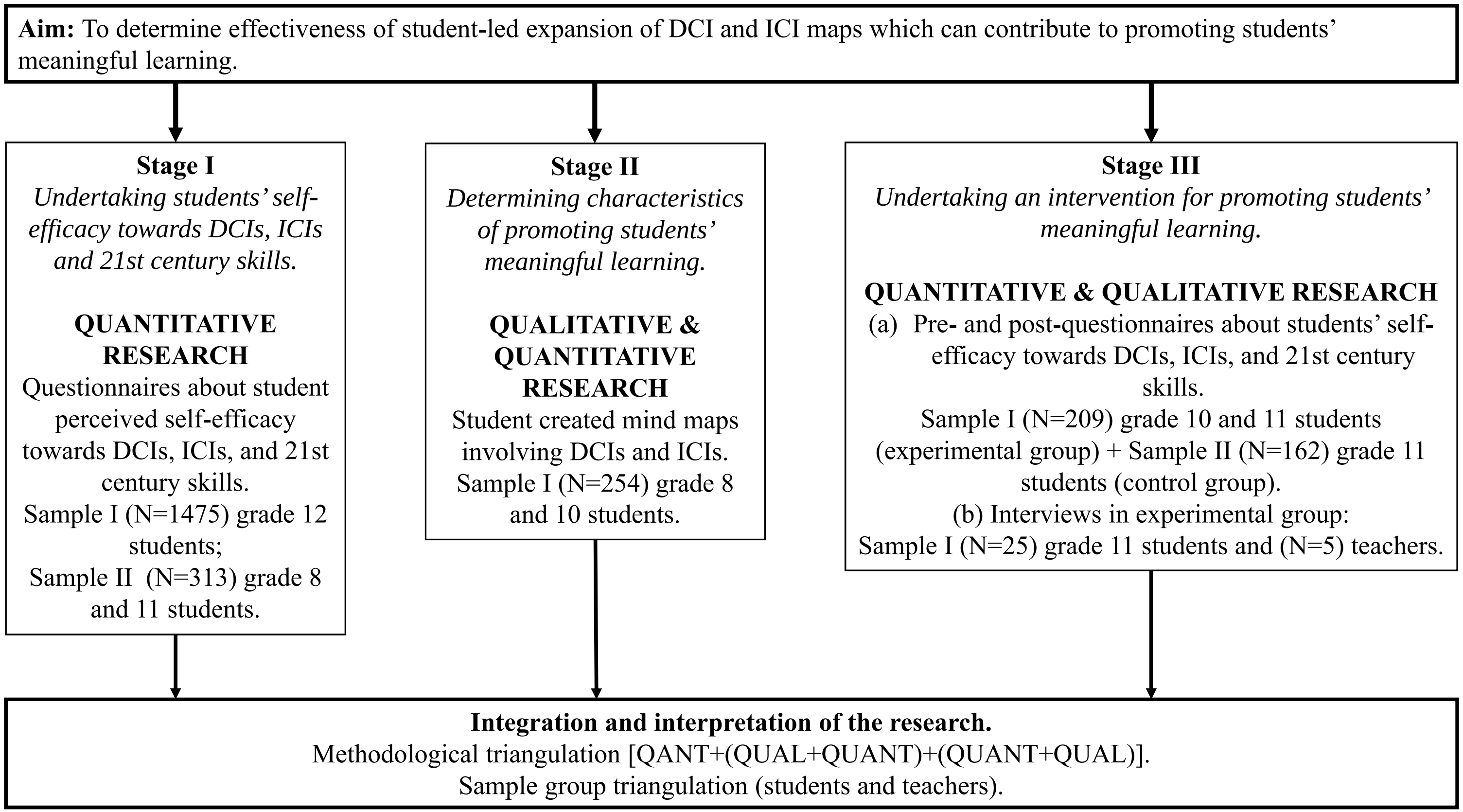


Figure 2. Flowchart showing a mixed-methods model and triangulation

The intervention in stages II and in III were narrowed down to the current study and included fewer schools but in both stages II and III included the same schools as a sample, N=254 students. The schools were selected on the basis that their teachers took part in in-service training, which provided a thorough overview of the DCIs, ICIs, 21st century skills, and later the planned intervention was introduced. A smaller sample size, N=162, was selected as this ensured the impact of the intervention and better cooperation between different schools.

3.2. Ethical benchmarks in the study

The current research was conducted within the Estonian Code of Conduct for Research Integrity (2017). As the research activities to achieve the aims were set by the Estonian National Curriculum for upper secondary schools (2011) no ethics committee approval was required.

To achieve the aim of this research, the following ethical considerations were identified – student and school confidentiality and participation was voluntary for students and teachers. After obtaining their permission, teachers and students were contacted personally by the researcher and given a detailed description of the aims of the research, the data collection methods, the data to be collected from them, how the data would be used, stored and their confidentiality guaranteed. Informed consent was collected from all the participants.

Implementation of the ethical aspects was undertaken by codenames used to protect students' confidentiality, which were kept separate from their data files. Data were analysed based on code names. A password-protected computer was used to store all collected data and the data files were only accessible to the author of this thesis, or to other involved researchers upon request. The research data obtained within the current thesis were analysed and interpreted critically and objectively as possible.

In order to become aware of the possible influences that the researcher might have had in the research process, and the minor alterations that were implemented during the data collection and analysis, the researcher kept a log.

The intervention (stage III) included experimental (EG) and control (CG) groups. The teachers for both groups were provided with information about the purpose of their participation. The teachers who led the EG were aware that the programme was part of the intervention.

3.3. Determining students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills

Stage I (Articles I and II) addressed research question 1 by investigating students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills, using a devised instrument. As the literature revealed that working and life skills (which were used in the Articles I and II) and 21st century skills are interconnected then, in the dissertation, by using one terminology continuously, it emphasises the 21st century skills, which also included the working and life skills.

The literature, however, reveals that other concepts can be associated with 21st century skills, for example, working and life skills, transversal skills, critical skills, and digital skills, despite some significant diversity across a range of personal and practical attributes (Chalkiadaki, 2018). This diversity indicates that no clear and unique definition of such attributes is evident and adopted internationally.

3.3.1. Sample

Two separate student samples were involved. The first sample involving upper secondary school students consisted of grade 12 students (N=1375) from 44 representative Estonian schools, as described by Soobard et al. (2018). All grade 12 students, from all selected schools, participated.

The second sample consisted of grade 8 (n=218) and grade 11 (n=95) students, from rural and urban schools, this being taken as a convenience sample. The total sample was 313 students.

3.3.2. Instrument

To undertake the research within stage I, data were obtained using two instruments.

Instrument I

An initial questionnaire was used in the LoteGym study (Rannikmäe et al., 2017; Soobard & Rannikmäe, 2014) and was later modified for this study. This was a 4-point Likert scale-type questionnaire, compiled and administered as a two-part measure of students' self-efficacy towards acquiring disciplinary core ideas and 21st century skills within the LoteGym study (Article I). All statements which the questionnaire included measured students' self-efficacy and began with an emphasis on "I believe that".

Instrument II

This instrument was a slightly modified version of instrument I. Items that were previously found to have a low factor weight were removed and additional items added relating to interdisciplinary core ideas (including models and systems). The modified instrument (questionnaire) was used to determine students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills. Details of items removed and added are as shown in Article II.

3.3.3. Data collection using instruments I and II

Students were given 45 minutes to answer instrument I within LoteGym and instrument II was administered within the same timeframe during one science lesson using a paper and pencil method. In each case, the instrument was administered by the class science teacher.

3.3.4. Data analysis

For the instrument I, data analysis was conducted using SPSS version 24. Descriptive statistics (mean, standard deviation) were determined for all statements. Categorisation of the statements was achieved by using Principal Component Analysis so as to reduce the dimensionality of the dataset by removing interrelated variables, while retaining as much relevant information from the dataset as possible (Jolliffe et al., 2002).

For the instrument II, SPSS Statistics 24 and Mplus (Version 7) (Muthén & Muthén, 1998-2015) were used for data analysis. At first, descriptive statistics (mean, standard deviation) of items were calculated. In order to investigate the internal structure of the instrument factor analysis was applied. First exploratory factor analysis (EFA) was carried out to determine the factor structure. To increase the interpretation of the instrument outcomes and to test the factorial structure, confirmatory factor analysis (CFA) was used. CFA and the related models were created to raise the interpretability of the entire questionnaire and findings with respect to the internal structure (Lewis, 2017).

To evaluate the goodness of fit models, well established indices and their criteria were used as follows: Root mean square error of approximation (RMSEA): Close fit: ≤ 0.05, reasonable fit: 0.05–0.08, poor fit: ≥ 0.10, Bentler's comparative fit index (CFI): ≥ 0.95, the Tucker-Lewis fit index (TLI): $0 \geq 0.95$ (Bowen & Guo, 2012).

3.3.5. Validity and reliability

The validity and reliability of the created instruments (Article I and II) and the methodology used for validation are shown in Table 1. For the compiled instruments, both content and construct validity were checked and reliability determined.

Table 1. Validation and reliability of the created instruments (Article I and II)

Instrument/method	Validity/ reliability	Used validation/reliability method
Students' self-efficacy towards acquiring disciplinary core ideas and 21st century skills by using a 4-point Likert-type scale questionnaire (Article I).	Content validity	Expert opinion method: four independent experts (from Estonia) in the field of science education, and also international experts for categorisation of statements.
	Construct validity	Analysis of Estonian middle and secondary science curriculum and syllabus to ensure that items are valid in terms of expected learning outcomes.
	Reliability	Cronbach alpha with each factor over 0.60.
Students' self-efficacy towards acquiring disciplinary and interdisciplinary core ideas and 21st century skills by using a 4-point Likert-type scale questionnaire (Article II).	Content validity Construct validity	Expert opinion method: Agreement by 14 independent experts in the field of science education.
	Reliability	Analysis of Estonian middle and secondary science curriculum and syllabus to ensure that items are valid in terms of expected learning outcomes; Mplus confirmatory factor analysis models. Cronbach alpha with each factor over 0.60.
	Content validity Construct validity	Mplus confirmatory factor analysis and related models were used to determine the suitability of the internal structure (Lewis, 2017).

3.4. Determining characteristics of promoting students' meaningful learning

Articles I, II and III address research question 2 by determining the essential characteristics needed for an intervention to promote students' meaningful learning. The methodology for Articles I and II is described earlier in paragraph 3.3 and thus the following describes the methodology used in Article III.

3.4.1. Sample

The sample participating in the study consisted of students from grades 8 and 10 (forming a total sample of 254 students from 6 schools, this being taken as a convenience sample). Prior to data collection, all students followed the same curriculum for teaching and learning, which is based on the same competence-based science curriculum to promote scientific literacy (Estonian Government, 2011).

3.4.2. Instrument

In stage II, student-created mind maps involving disciplinary and interdisciplinary core ideas were used.

To develop the instrument used to enable students to create mind maps, appropriate disciplinary and interdisciplinary core ideas were determined as follows.

Four science educators and teachers (from the University of Tartu and Estonian science teachers) were asked to make their selection based on the following criteria:

(a) To choose 2 disciplinary core ideas (DCIs), within each science disciplines, (Life Science, Earth Science, Physics and Chemistry) which were interconnected and considered important for a future workforce;
(b) Across multiples science disciplines, the interdisciplinary core ideas (ICIs) were seen as important;
(c) The DCIs and ICIs were linked to the national curriculum of Estonia;
(d) DCIs and ICIs were applicable across many grades at increasingly deeper levels (important to understanding global issues).

The following DCIs were selected by the experts for exploration by students through the creation of expanded mind maps:

- DCIs in Life Science – (1) genetic variation and (2) heredity/DNA;
- DCIs in Chemistry – (1) characteristics of substances and (2) chemical reactions;
- DCIs in Earth Science – (1) weather/climate and (2) land surface changes;
- DCIs in Physics – (1) energy conversion and (2) motions/waves.

The following two ICIs were also identified: (1) models and (2) systems.

3.4.3. Data collection

Prior to being asked to create mind maps, each class was instructed on the methods of presenting a mind map by their science teachers. Students used a paper and pen method to create the mind maps. Following the instruction, each student practiced the creation of a mind map with the word sustainability, and were asked to include in their mind maps its explanation, various meanings, and associations. This sustainability mind mapping tasks enabled students to practise drawing arrows and making connections during a normal lesson, i.e. within 45 minutes.

For the main data collection, in a subsequent science lesson, each student was presented with one disciplinary or interdisciplinary core idea, selected randomly from a set of 10 provided by the researchers. The students were asked, "How do you conceptualise the given disciplinary or interdisciplinary core idea? By applying your knowledge and skills, expand an appropriate mind map similar to that previously demonstrated". This task was assigned during one science lesson, and students were given 45 minutes to expand their mind maps.

3.4.4. Data analysis

By integrating theory and empirical data, abductive thematic analysis was performed (Hammersley & Atkinson, 2019; Tavory & Timmermans, 2014). Theory and empirical facts were interpreted in the context of one another (Rinehart, 2021). Through using abductive analysis, similar data were brought together within the disciplinary or interdisciplinary core idea so that the findings could be interpreted in a way that was clear to the reader.

Students' mind maps were analysed in two ways (utilising two science educators as experts in the data analysis process to ensure the validity of the analysation):

1. To discover the degree to which students were able to integrate their subject learning (Kinchin & Hay 2000);
2. To demonstrate a coherent conceptualisation of the disciplinary and interdisciplinary core ideas.

The mind maps analysis was based on determining how much students were able to interconnect their learning. The analysis measured the complexity of student-created mind maps, indicating the degree to which students could conceptualise the DCIs or ICIs; the frequency (the number of times these occurred on the created map) of the dimensions of knowledge reflected in the map. The frequency showed how often knowledge dimensions were reflected by students in their mind maps. The numbers of interconnections (links) within each of the higher, more complex hierarchies were labelled as 1-4 (Article, III). This was done by hand and involved the determination of:

a) Vertical and horizontal interconnection of boxes, knowledge;
b) The complexity of the map: radial; linear-radial over more than one hierarchy; integrated but limited to one linearity; multiple integrated.

The students' dimensions of knowledge (Krathwohl, 2002) were analysed to identify different learning outcomes and to determine students' higher levels of thinking. For this, student-created mind maps were examined to determine whether the following were present:

- Factual knowledge – the basic elements include isolated knowledge (knowledge of terminology, specific details, and elements);
- Conceptual knowledge – the interrelationships among the basic knowledge within a larger structure (including categories, principles, theories, and structures);
- Procedural knowledge – describes how to do something, including the knowledge of subject-specific skills, methods and techniques;
- Central concepts – branches (or breakdown) into more specific dimensions of knowledge that may or may not be interconnected to the DCIs or ICIs.

All of these were presented in the student-created mind maps. After analysis it was possible to determine students' higher levels of thinking.

3.4.5. Validity and reliability

Validity was established by

As students were familiar with the mind maps method (i.e. they had a prior opportunity to practise mind mapping in their science lessons) this facilitated the validity of the task (students had to create mind maps about disciplinary and interdisciplinary core ideas). The task was given to students in a concrete and clear manner.

The following collected data analyses, determined hierarchies and dimensions of knowledge were validated through an expert opinion method (four scientists from the University of Tartu). Percentage of agreement was over 70%.

Relevance was established by

All DCIs and ICIs, used for mind mapping were selected by experts (science teachers and educators). All chosen DCIs and ICIs were taken from the Estonian science curriculum. The reliability of the student-created mind maps analysis was identified by expert opinion and by the abductive thematic analysis (including hierarchies and dimensions of knowledge). The reliability of the data analysis was determined by cross-checking (from four science educators).

3.5. Undertaking an intervention for promoting students' meaningful learning

Stage III (Articles IV and V) addresses research question 3 by determining how changes in upper secondary school students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills can be enhanced through the use of student-led expansion of DCI and ICI maps for supporting students' meaningful learning. In order to support students' meaningful learning, an intervention in schools using DCI and ICI maps was carried out (Figure 3, Article IV and V) in five schools.

3.5.1. Sample

The samples, as experimental and control groups, were as described in Articles IV and V. The students forming the experimental group (Table 2) were in grade 10 (pre-questionnaire) and grade 11 (post-questionnaire), while the control group (no intervention) comprised 162 students from five schools, grade 11. The control group was selected based on their similarities to the experimental group:

- School location, urban or rural schools;
- Number of students and their academic performance;
- Number of teachers and their participation in professional development courses held by the Centre of Science education.

Table 2. Overview of the intervention participants

School	N₀ of students	N₀ of teachers	Lessons taught
School 1	59	2	Biology and Chemistry
School 2	25	3	Biology, Chemistry, and Physics
School 3	54	2	Biology and Geography
School 4	36	2	Chemistry and Physics
School 5	35	3	Biology, Chemistry, and Geography

3.5.2. Intervention design

The conducted intervention and its impact are described in Article IV, related to the disciplinary and interdisciplinary core ideas and in Article V, related to the 21st century skills. The intervention was divided to three major steps, as illustrated in Figures 3,4 and 5, during which different DCI and ICI maps were given to schools for students to expand upon. The task given for students was to expand the DCI and ICI maps with appropriate knowledge, the teachers emphasised that students should make more connections between conceptual and procedural knowledge. In addition, students expanded the same DCI and ICI maps during their different science lessons, which provided the basis for interdisciplinary connections.

Figure 3 illustrates the intervention timescale and when and how many maps were given to the students. In March 2019 students also performed a group session where they created mind and concept maps about nutrition. In January 2020 students also yet again practised the mapping but the topic was psychologist.

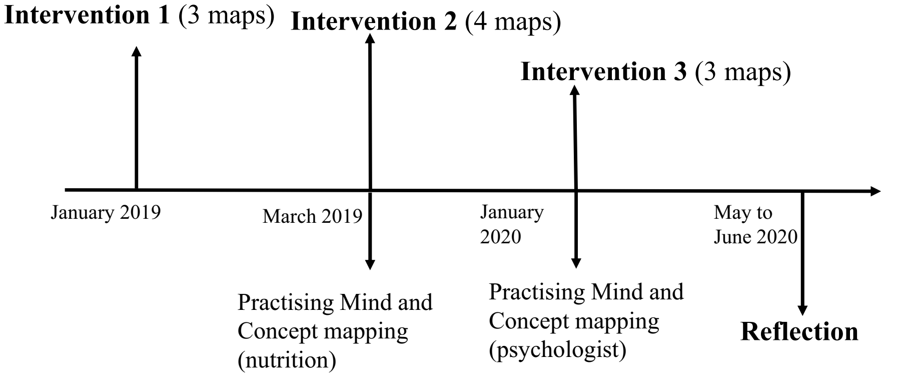


Figure 3. Intervention design, expanding DCI and ICI maps during teaching in schools

Figure 4 illustrates the overall design of the intervention (content, activities, and reflection about the used method). The intervention was divided into three steps, each step concentrating on a specific disciplinary and interdisciplinary core idea map. For each DCI and ICI map, the teaching encompassed at least 6 science lessons.

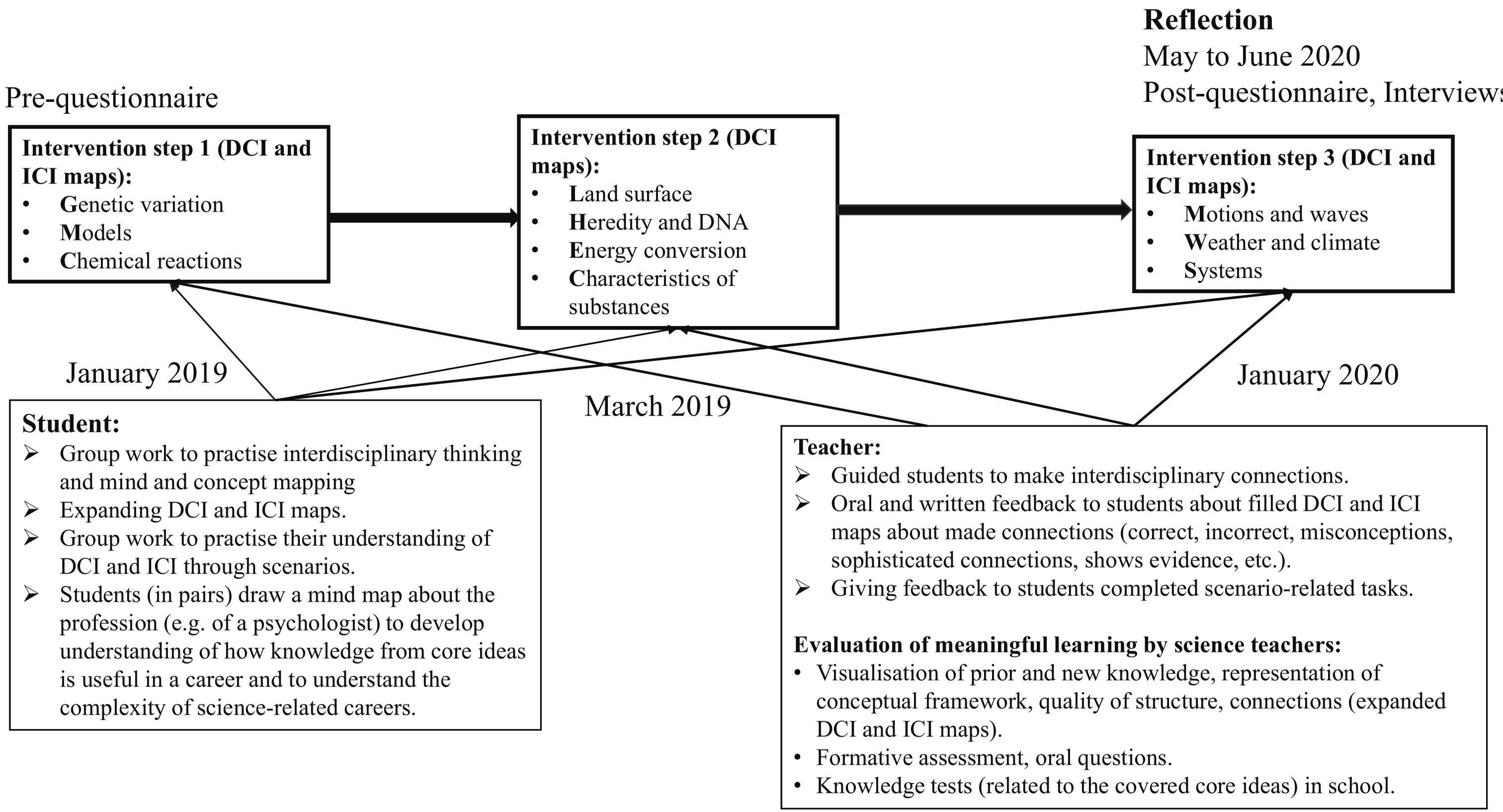


Figure 4. Intervention overall design

Figure 5 illustrates the task given to students where they had to expand the core idea map about genetic variation. During the intervention period students undertook tasks during their science lessons, which supported their meaningful learning (Figure, 5). During the intervention all students:

- Expanded DCI and ICI maps creating interdisciplinary connections between different dimensions of knowledge;
- Were given an opportunity to practise the mind mapping and concept mapping with different science content (for example, nutrition);
- Were given an opportunity to collaborate with their classmates to perform group work or to expand DCI and ICI maps;
- To connect the learning of science content with 21st century skills, everyday life-related scenarios (each involving students in expanding the DCI and ICI maps) were implemented in science lessons.

These tasks allowed students to construct their knowledge and thus to practise interconnecting their prior knowledge to the new knowledge more intensively. These activities were designed so as to support students' meaningful learning. Students used a paper and pen method to expand the disciplinary and interdisciplinary core idea maps.

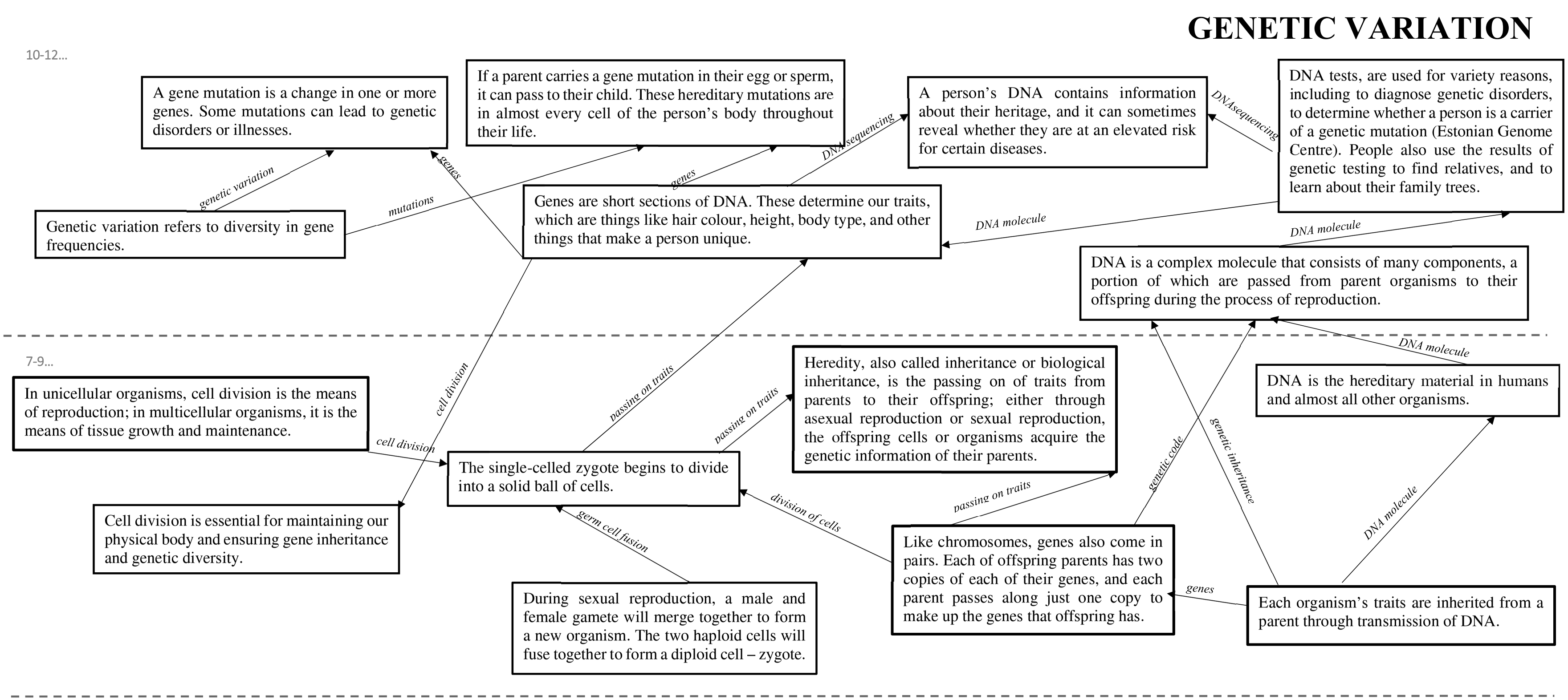


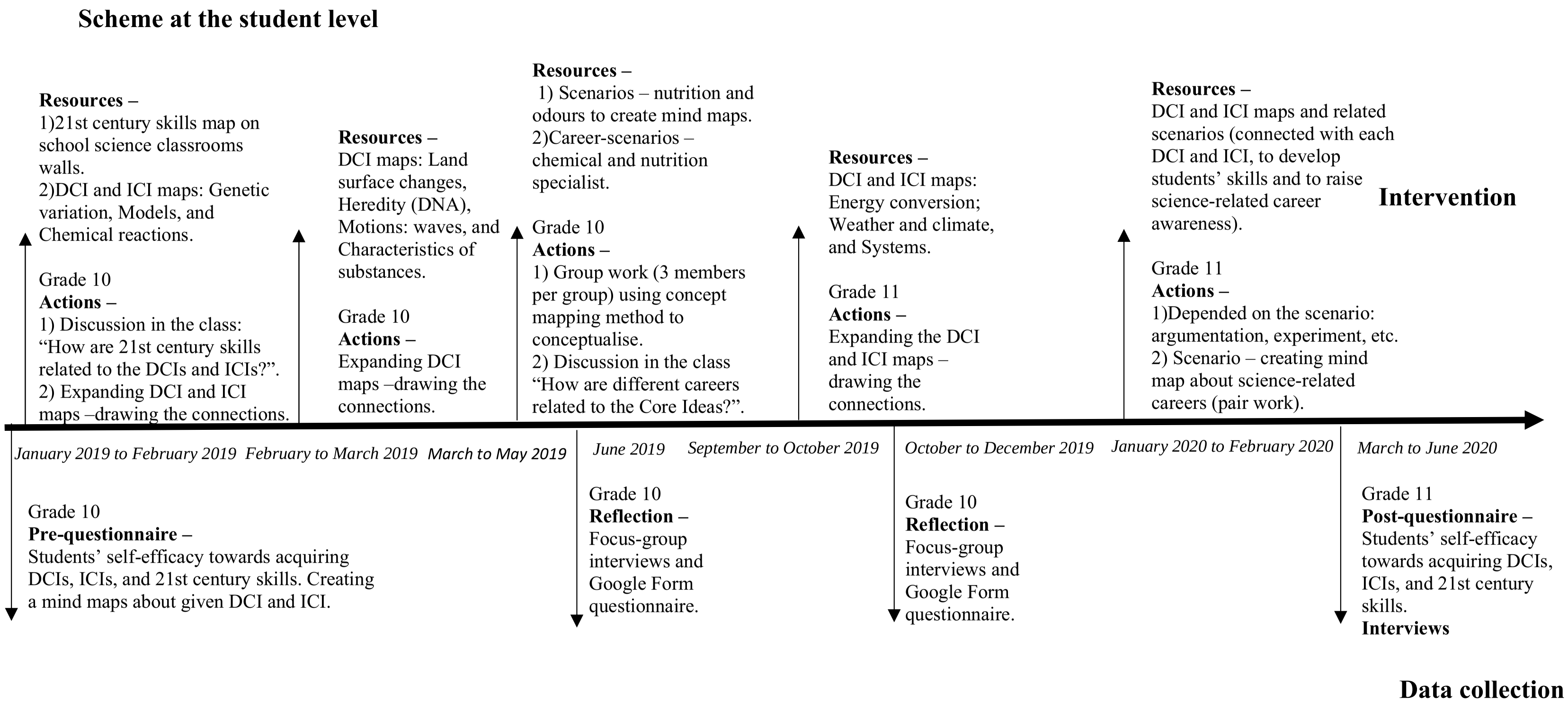
Figure 5. Illustration of the task where students had to expand the DCI and ICI map, based on AAAS, 2001

Figure 6 illustrates intervention design at the student level.

Also, Figure 6 shows what the students did during the intervention, i.e.:

- Discussions in the classroom on how are 21st century skills related to the disciplinary and interdisciplinary core ideas;
- Group work allowing students to understand DCIs and ICIs content through team discussion and group work (students listening, responding and considering their peer's differing thoughts in a collaborative environment);
- Expanding the DCI and ICI maps and drawing the connections and summarising their learning;
- Practising the mapping methods (including both mind mapping and concept mapping);
- Group work to practising interdisciplinary thinking;
- Discussions in the classroom on how different careers are related to the DCIs and ICIs;
- Practising 21st century skills including problem-solving, decision-making and critical thinking;
- Students (in pairs) drawing a mind map about the profession (e.g. of a psychologist) to develop understanding on how knowledge from DCIs and ICIs are useful in a career and to understand the complexity of science-related careers;
- Filling in the pre- and post-questionnaires (about self-efficacy towards acquiring DCIs, ICIs, and 21st century skills) and participating in the conducted interviews.

The illustration provides an overview of the intervention steps and also the resources that are used to support students' higher self-efficacy towards acquiring DCIs, ICIs, and 21st century skills.



***Resources**– used in the teaching process; **Actions**– what students exactly did in the classroom.

Figure 6. Intervention design applicable at the student level

Figure 7 illustrates the intervention design at the teacher level.

Also, Figure 7 shows directly what teachers did when carrying out the intervention.

During the intervention teachers:

- Participating in an in-service teachers' course where an in-depth overview was given about the DCIs, ICIs, and 21st century skills;
- Filling in questionnaires (the readiness for the carrying out the intervention and post-questionnaire) and participated in the conducted interviews and reflection seminars, which helped researchers to monitor the intervention process.
- Helping to carry out the intervention together with the researchers;
- Giving students the direct instructions i.e., to expand the DCI and ICI maps with interdisciplinary connections and to indicate the relevant conceptual and procedural knowledge on their expanded maps;
- Giving feedback (both oral and written) to students about their expanded DCI and ICI maps. The feedback included the suggestions for making the DCI and ICI maps more interdisciplinary, correct or incorrect interconnections, misconceptions, sophisticated connections, shows evidence, etc.;
- Giving feedback to students completed scenario-related tasks;
- Participating in the conducted interviews.

All of these steps were seen as important for supporting students' meaningful learning.

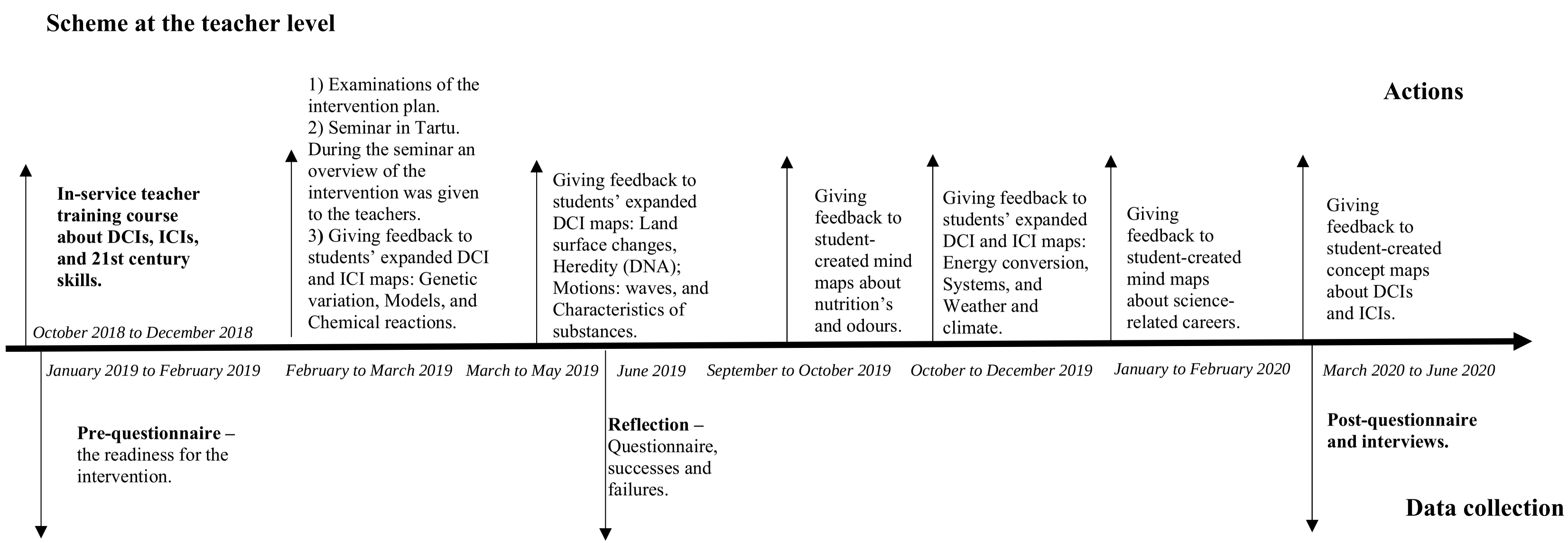


Figure 7. Intervention design applicable at the teacher level

3.5.3. Data collection

Two instruments were used for data collection:

(i) Student questionnaire (same for both the experimental and control group);

(ii) Student and teacher interview questions (utilised only with the experimental group).

Both of these instruments helped to measure the impact of the carried-out intervention and how it helped to increase students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills.

(i.) Questionnaire

The pre- and post-questionnaires are described in Table 3 and elaborated upon in Articles I and II. They were administered before and after the intervention, in order to determine whether the intervention was effective in soliciting students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills. Answers to each question ranged from 1 – "I do not agree at all" to 4 – "I definitely agree".

Table 3. Brief descriptions of the pre-, and post-questionnaires

<table>
<tr><th>Questionnaire</th><th>Questionnaire Parts</th><th>N$_o$ of questions</th><th>Data collection</th></tr>
<tr><td>Pre-questionnaire</td><td>Part 1: Students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills.</td><td>23</td><td>EG and CG</td></tr>
<tr><td rowspan="2">Post-questionnaire</td><td>Part 1: Students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills.</td><td>23</td><td rowspan="2">EG</td></tr>
<tr><td>Part 2: The usefulness (including the combination of like, interest, importance, etc.) of implemented student-led expansion of DCI and ICI maps in science lessons – 10 core ideas as part of the intervention.</td><td>10</td></tr>
</table>

*EG – experimental group; CG – control group

As many studies (Articles I and II), with different students, showed students' perceptions regarding their ability in certain core ideas were found to be similar, the control group questionnaire was administrated only at the end of grade 11 (Table 3).

(ii.) Interviews

Science educators interviewed the experimental group students and their teachers (separately) regarding their perceptions of the developed method (student-led expansion of DCI and ICI maps). The interviews were undertaken using the interview guide given in Table 4, validated by four science educators from University of Tartu. From the experimental group school, students were chosen by their science teachers to participate in the conducted focus group interviews. Individual interviews were conducted with all teachers who participated the in-service teachers course and initiated the intervention in their schools.

Students and teachers were asked for their consent before each interview was recorded on video and later transcribed. Interviews were conducted in the Zoom environment and were recorded on video. One-hour interviews were scheduled and conducted within the lockdown period (March to June 2020). As a precaution, written notes were taken during the interview. Oral consent to record the interview was requested from every participant as the first question with an explanation indicating that the recordings would only be used only for achieving the aims of the study and stored on a physical hard drive, access to which was only granted to the authors of the current study. All interviews were conducted in Estonian and the relevant quotes from participants were translated into English for publication.

Table 4. Interview guidelines (Article V)

Students' (N=25) interview questions	**Teachers' (N=5) interview questions**
Did you find it useful to expand DCI and ICI maps? Explain.	Did you find it useful for students to expand DCI and ICI maps? Explain.
Did you collaborate with your classmates when you expanded the DCI and ICI maps? Explain.	Did you collaborate with your teacher colleagues, when students expanded the DCI and ICI maps? Explain.
What feedback did you receive from teachers when you expanded the DCI and ICI maps?	What feedback did you give to students about their expanded DCI and ICI maps? Do you have any suggestions about how to give feedback to students expanded DCI and ICI maps?
Which DCI and ICI maps were most useful for you? Explain.	Which DCI and ICI maps were most useful for you as a teacher? Explain.
Did you think expanding DCI and ICI maps was useful for you in your science studies? Explain.	Did you think expanding DCI and ICI maps was useful for students in their science studies? Explain.
	With which DCIs and ICIs, did students indicated more prior and new knowledge and made more connections?

The data were gathered using a pre- and post-questionnaire, consisting of 24 statements obtaining data on students' self-efficacy towards acquiring 21st century skills. Answers to each question ranged from 1 – "I do not agree at all" to 4 – "I definitely agree".

As a prior validation (Articles I and II), the created questionnaire was divided into five 21st century skills factors giving factor names and example statements:

- Cognitive and problem-solving skills: "*I am motivated to solve challenging problems*".
- Critical thinking: "*I can distinguish scientific evidence from non-scientific*".
- The changeability of scientific knowledge: "*The usefulness of scientific knowledge depends on how and for what purpose they are used* ".
- Responsible citizenship: "*My personal well-being is connected to what happens in nature at a global level*".
- Mindset for scientific research: "*In my opinion, scientific models (like DNA) portray nature as it actually exists*".

All of these factors included several items, all related to 21st century skills, which provide a foundation for successful learning in school – these also help to ensure students were successful outside of the classroom.

The pre-questionnaire was completed using pencil and paper, while the post-questionnaire was completed via a Google Form template, making data collection possible during the COVID-19 epidemic. The procedure for collecting the data is shown in Table 5, along with the instruments used.

Table 5. Overview of the data collection per instrument used (Articles IV and V)

Group	Instrument	Time when carried out	Approximate duration (in minutes)
Experimental group	Pre-questionnaire	January 2019	20–25
	Post-questionnaire	May 2020	20–25
	Interviews (with students)	May-June 2020	25–45
	Interviews (with teachers)	June 2020	20–45
Control group	Post-questionnaire	May 2020	12–20

3.5.4. Data analysis

On the basis of the collected data (quantitative and qualitative), a mixed-method (Creswell, 2012) approach to data analysis for the Article IV was considered the most appropriate.

Questionnaire

SPSS Statistics 24 and Mplus (Version 7) (Muthén & Muthén, 1998–2015) were used for data analysis. At first, descriptive statistics (mean, standard deviation) of items and reliability were computed using the quantitative data obtained from questionnaires. A paired sample t-test was used to compare and analyse the mean scores from the students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills. In order to investigate the internal structure of the instrument factor analysis was applied. First exploratory factor analysis (EFA) was carried out to determine the factor structure. To increase the interpretation of the instrument outcomes and to test the factorial structure, confirmatory factor analysis (CFA) was used. CFA and the related models were created to raise the interpretability of the entire questionnaire and findings with respect to the internal structure (Lewis, 2017).

To evaluate the goodness of fit models, well established indices and their criteria were used as follows: Root mean square error of approximation (RMSEA): Close fit: ≤ 0.05, reasonable fit: 0.05–0.08, poor fit: ≥ 0.10, Bentler's comparative fit index (CFI): ≥ 0.95, the Tucker-Lewis fit index (TLI): ≥ 0.95 (Bowen & Guo, 2012).

Interviews

Following the approach proposed by Patton (1990), inductive thematic analysis was used to analyse the answers collected from students and teachers as a standard content analysis (Patton, 1990). Following the transcription of the conducted interviews, themes were identified based on the purpose of the research that were closely related to the data collected. In this study, coding themes were used as a method for the purpose of garnering a more in-depth understanding of what was occurring.

Descriptive statistics (means, standard deviations), statistical significance, and reliability were undertaken using SPSS version 23. The mean scores for students' self-efficacy towards acquiring 21st century skills were compared and analysed using paired sample t-test. The statistical program Mplus (Version 7) (Muthén & Muthén, 1998-2015) was used to conduct confirmatory factor analysis (CFA).

3.5.5. Validity and reliability

The questionnaire and interview data were triangulated (Patton, 2002) by comparing and analysing the findings. Identified experts (science teachers and educators) validated both the questionnaire and interview questions as clarified in Table 6 and further illustrated in Articles IV and V.

Table 6. Validation and reliability of the instruments created to measure the intervention impact

Instrument	Validity/ reliability	Used validation/reliability method
Pre- and post-questionnaire (DCIs and ICIs/4-point Likert-type scale)	Content validity	Expert opinion method: an agreement by 12 independent experts in the field of science education: whether the content of a measure covers the full domain of the content.
	Construct validity	Analysis of the Estonian secondary school science curriculum and syllabus to ensure items (disciplinary and interdisciplinary core ideas) are valid in terms of expected learning outcomes. For data analysis CFA was used.
	Reliability	Cronbach alpha with each factor over 0.60. CFA was used to test whether measures of the construct are consistent with a researcher's understanding of the nature of that construct (factors).
Pre- and post-questionnaire (21st century skills/4-point Likert-type scale)	Content validity	Expert opinion method; agreement of 14 independent experts in the field of science education.
	Construct validity	Analysis of Estonian science curriculum and syllabus to ensure that items (21st century skills) are valid in terms of expected learning outcomes; Mplus CFA.
	Reliability	Cronbach alpha with each factor over 0.60. CFA was used to test whether measures of the construct are consistent with a researcher's understanding of the nature of that construct (factors).
Interviews	Content validity	Inductive thematic analysis was used to analyse the transcripts of the interviewer's answers.
	Construct validity	Themes' identification and labelling.
	Inter-coder reliability	The percentage of agreement between two coders (science educators) was, with student interviews, 86% and teachers interviews, 78%.

4. FINDINGS

The following sections detail the important interpretations of the findings with regarding to the three research stages, i.e. determining, the current situation (stage I), analysing student-created mind maps (stage II), and undertaking the intervention (stage III).

4.1. Students' self-efficacy pre-intervention

4.1.1. Students' self-efficacy towards acquiring DCIs and ICIs

The findings from both conducted studies (Articles I and II) indicated that students' self-efficacy tends to be higher towards acquiring disciplinary core ideas related to Earth Science. For example, Table 7 indicated students' self-efficacy was higher towards acquiring DCIs and ICIs, which had a strong connection with everyday life situations (such as destroying the rainforests).

Table 7. Confirmatory factor analysis on students' self-efficacy towards acquiring DCIs and ICIs (Article II)

Factors (reliability) and measured items	**Factor loadings**	**M (SD)**
F1: DCIs related to Life Science and Chemistry (α = 0.89)		
Cell functions in various human tissues	0.67	2.30 (0.78)
Comparing the efficiency of aerobic and anaerobic respiration in the human muscle	0.59	2.29 (0.87)
Redox reactions in everyday life	0.55	2.03 (0.90)
Energy conversion from one form into another	0.55	2.31 (0.89)
Matter and energy exchange in living organisms	0.53	2.27 (0.76)
Development of the foetus	0.46	2.59 (0.85)
The basic hereditary process	0.40	2.29 (0.83)
Hereditary of genetic diseases	0.36	2.14 (0.83)
M	**0.51**	**2.28 (0.84)**
F2: DCIs related to Physics (α = 0.70)		
Working principle of an electricity generator	0.80	2.42 (0.91)
Newton's laws of motion	0.70	2.73 (0.85)
Sound transmission	0.62	2.60 (0.84)
Our solar system's planets and other small celestial bodies	0.56	2.97 (0.77)
Ideas that are controlled and tested by models	0.51	2.22 (0.89)
Perception of change in a moving elevator	0.46	2.41 (0.91)
Natural phenomena at the particulate level	0.40	2.40 (0.83)
The nature of interactions between bodies	0.35	2.68 (0.83)
M	**0.55**	**2.55 (0.85)**

Factors (reliability) and measured items	Factor loadings	M (SD)
F3: DCIs related to Earth Science (α = 0.90)		
The consequences of destroying rainforest on my own well-being	0.75	2.75 (0.91)
Relief deformation and climate change	0.67	2.48 (0.89)
Climate warming potential consequences for Estonia	0.59	2.78 (0.83)
Solar and lunar eclipse	0.54	2.89 (0.87)
M	**0.64**	**2.73 (0.86)**
F4: ICIs (α = 0.83)		
Systems creation	0.68	2.37 (0.86)
Causes and effects of events	0.62	2.64 (0.82)
Natural and human-made systems change over time	0.57	2.51 (0.85)
Structural properties of the objects and systems	0.53	2.33 (0.90)
M	**0.60**	**2.46 (0.86)**

Note: M–mean; SD–standard deviation, the results are indicated by the factors' mean values.

Students felt lower self-efficacy towards acquiring more abstract disciplinary core ideas such as those related to Physics and Chemistry and Life Science (Table 7). For example, students' self-efficacy was low towards acquiring DCIs related to the redox reactions, and the hereditary of genetic diseases. Students also had higher self-efficacy towards acquiring interdisciplinary core ideas such as models and systems (Table 7). Therefore, this was interpreted as being of value in different science lessons.

The four-factor model fit indices, for students' self-efficacy towards acquiring DCIs and ICIs is shown in Appendix 1. A statistically significant RMSEA value ensures the avoidance of issues of sample size and the RMSEA value, for students' self-efficacy towards acquiring DCIs and ICIs, showed reasonable fit (RMSEA=0.07). The CFI and TLI compare the fit of a target model to the fit of an independent model. CFI and TLI indices were lower than recommended (CFI=0.92, TLI=0.91) (Bowen & Guo, 2012).

4.1.2. Students' self-efficacy towards acquiring 21st century skills

In general, students perceived 21st century skills as important (M>2.50). The conducted research (Table 8) showed that students have higher self-efficacy towards acquiring 21st century skills related to the responsible citizenship and the changeability of scientific knowledge. Students had higher self-efficacy towards measured items such as Models explain natural phenomena's in everyday life (M=3.80) and Respect people regardless of their cultural backgrounds and nationalities (M=3.41).

Table 8. Confirmatory factor analysis on students' self-efficacy towards acquiring 21st century skills (Article II)

Factors (reliability) and measured items	Factor loadings	M (SD)
F1: Cognitive skills (α = 0.79)		
Creative thinking to solve scientific problems	0.73	2.93 (0.72)
Solve science problems	0.72	2.72 (0.68)
Explain that science and technology evolve together	0.53	2.59 (0.91)
Defend my standpoint using scientific evidence	0.52	2.46 (0.77)
Continue to solve a problem despite difficulties	0.51	2.63 (0.76)
M	**0.60**	**2.67 (0.77)**
F2: The roles of science lessons (α = 0.81)		
Develop useful skills for solving problems in everyday life	0.80	2.68 (0.91)
Develop skills needed to control thinking and action during the problem-solving process	0.75	2.82 (0.94)
Apply knowledge from science lessons in new situations	0.73	2.74 (0.81)
Develop values	0.62	2.98 (0.87)
M	**0.73**	**2.81 (0.88)**
F3: The changeability of scientific knowledge (α = 0.68)		
Understand other people's actions instead of judging them	0.71	3.16 (0.82)
Respect people regardless of their cultural backgrounds and nationalities	0.71	3.41 (0.90)
Scientific knowledge can change	0.67	3.38 (0.78)
Models explain natural phenomena's in everyday life	0.53	3.80 (0.73)
Usefulness of scientific knowledge	0.48	3.06 (0.59)
M	**0.62**	**3.36 (0.76)**
F4: Responsible citizenship (α = 0.73)		
Consider positive and negative consequences towards the environment	0.71	2.81 (0.89)
Responsibility for what happens to the environment	0.65	3.13 (0.86)
Well-being is connected to what happens in nature at a global level	0.52	2.94 (0.90)
Contribute to protecting the natural environment	0.37	2.32 (0.93)
In problem-solving, use ethical standards	0.70	2.66 (0.91)
M	**0.59**	**2.77 (0.90)**
F5: Critical thinking (α = 0.67)		
Efforts and the effectiveness of strategies	0.63	2.70 (0.77)
Critically evaluate the quality of information	0.50	2.91 (0.63)
Distinguish scientific evidence from non-scientific	0.49	3.00 (0.74)
Creativity and imagination are important for establishing scientific knowledge	0.70	2.87 (0.62)
M	**0.56**	**2.87 (0.69)**

Factors (reliability) and measured items	Factor loadings	M (SD)
F6: Mindset for scientific research (α = 0.79)		
Scientific models portray nature	0.74	2.69 (0.87)
Carefully collected data will give perfect knowledge	0.72	2.93 (0.87)
Scientific methods for creating scientific knowledge	0.54	2.23 (0.87)
M	**0.67**	**2.62 (0.87)**
F7: Problem-solving skills in everyday life situations (α = 0.67)		
Characteristics of scientific knowledge	0.47	2.98 (0.84)
Making sure whether the problem is within my level or if I need extra help	0.64	3.03 (0.74)
Efforts and effectiveness of not reaching the desired goal	0.62	2.93 (0.80)
Designing most appropriate strategy to solve problem	0.55	2.67 (0.77)
Finding alternative strategies if an initial method does not work	0.43	2.79 (0.77)
Motivated to solve challenging problems	0.83	2.48 (0.60)
M	**0.59**	**2.81 (0.75)**

Note: M–mean; SD–standard deviation, the results are indicated by the factors mean values.

The research also showed that students' self-efficacy towards acquiring the 21st century skills related to the mindset for scientific research and cognitive thinking and was among the lowest compared to the other factors (Table 8). Students had lower self-efficacy towards measured items such as Scientific methods for creating scientific knowledge (M=2.23) and Motivated to solve challenging problems (M=2.48).

The seven-factor model fit indices, for students' self-efficacy towards acquiring 21st century skills is shown in Appendix 2. The RMSEA value showed reasonable fit (RMSEA=0.07). Both CFI and TLI indices were lower than recommended (CFI=0.92, TLI=0.91) (Bowen & Guo, 2012).

4.2. Student-created Mind maps

Students found it hard to conceptualise the interlinking of dimensions of knowledge for different disciplinary and interdisciplinary core ideas in some cases. Table 9, showed the findings from student-created mind maps. Frequency (freq) indicated how many interconnections (links) students made in their created mind maps between the presented knowledge.

Table 9. Overall findings from student-created mind maps, indicating the number of mind maps per hierarchy, total links (interconnections) per core idea/per student (average) and central concepts per core idea/per student (average) (Article III)

Core idea	**1st *freq***	**2nd *freq***	**3rd *freq***	**4th *freq***	**Total links per DCI/ICI**	**Links per student**	**Central concepts per DCI/ICI**	**Central concepts per student**
Genetic variation (n=17)	208 (n1=17)	98 (n2=8)	38 (n3=2)	0 (n4=0)	344	20.24	60	3.53
Heredity: DNA (n=16)	160 (n1=16)	89 (n2=4)	51 (n3=3)	40 (n4=2)	340	21.25	56	3.50
Land surface changes (n=29)	272 (n1=29)	186 (n2=16)	71 (n3=3)	0 (n4=0)	529	18.24	87	3.00
Weather and climate (n=28)	255 (n1=28)	211 (n2=15)	99 (n3=6)	21 (n4=1)	596	21.29	105	3.75
Chemical reactions (n=30)	227 (n1=30)	95 (n2=17)	65 (n3=9)	0 (n4=0)	387	12.90	87	2.90
Characteristics of substances (n=34)	161 (n1=34)	97 (n2=16)	54 (n3=3)	0 (n4=0)	312	9.18	69	2.03
Energy conversion (n=24)	152 (n1=24)	104 (n2=9)	44 (n3=2)	0 (n4=0)	300	12.50	63	2.63
Motions: waves (n=24)	218 (n1=24)	119 (n2=10)	0 (n3=0)	0 (n4=0)	327	13.63	54	2.25
Models (n=31)	270 (n1=31)	142 (n2=13)	40 (n3=1)	0 (n4=0)	452	14.58	85	2.74
Systems (n=21)	216 (n1=21)	142 (n2=13)	56 (n3=4)	0 (n4=0)	414	19.71	64	3.05

Note: Frequency (freq); n indicates how many students created mind maps about DCI and ICI; n1 indicates how many students reached the 1st hierarchy, n2 the 2nd hierarchy, n3 the 3rd hierarchy and n4 the 4th hierarchy.

Table 9 showed averages for better comparability between DCIs and ICIs. Only in the case of DCIs, such as DNA and Weather and climate, were mind maps of hierarchy 4 created. Findings also indicated that fewer interconnections were formed with the DCIs, such as characteristics of substances and energy conversion. More interconnections were indicated with the DCIs, such as weather and climate, heredity, and genetic variation. Fewer central concepts were formed with the DCIs characteristics of substances and with motions: waves. Students formed more central concepts with the DCIs weather and climate and genetic variation. This showed that students made more interconnections with DCIs related to Life Science and Earth Science and fewer with Chemistry and Physics.

Table 10 showed more specifically how students conceptualised each DCI and ICI, in terms of dimensions of knowledge within their created mind maps. For each dimension of knowledge (factual, conceptual, and procedural), the frequency of number of times students indicated a specific dimension in their created DCI and ICI map were determined. Findings indicated that students needed more support (on how learned already acquired core ideas were interconnected) from their science teachers, especially how to interconnect procedural and conceptual knowledge to the core ideas.

Table 10. Students' frequency of inclusion of the dimensions of knowledge for each DCI and ICI (Article III)

	Core ideas	**No of students responding for each DCI or ICI**	**Dimensions of knowledge**		
			Factual ***frequency***	**Con-ceptual** ***frequency***	**Proce-dural** ***frequency***
DCIs in Life Science	Genetic variation Heredity: DNA	n=17 n=16	172 169	124 122	30 23
DCIs in Earth Science	Land surface changes Weather and climate	n=29 n=28	296 322	215 185	49 77
DCIs in Chemistry	Characteristics of substances Chemical reactions	n=30 n=34	169 188	114 145	19 33
DCIs in Physics	Energy conversion Motions: waves	n=24 n=24	176 213	50 157	25 28
ICIs	Models Systems	n=31 n=21	310 226	105 148	20 28
Total		**N=254**	**2241 55.1%**	**1365 33.6%**	**332 8.2%**

Table 10 showed that most interconnections were made with factual knowledge lacking the involvement of procedural and conceptual knowledge.

An example of student-created mind map about Genetic variation was as shown in Figure 8. This example shows that student put the DCI in the middle and two central concepts emerged (both of them indicated with dashes) – skills and genetic disorders.

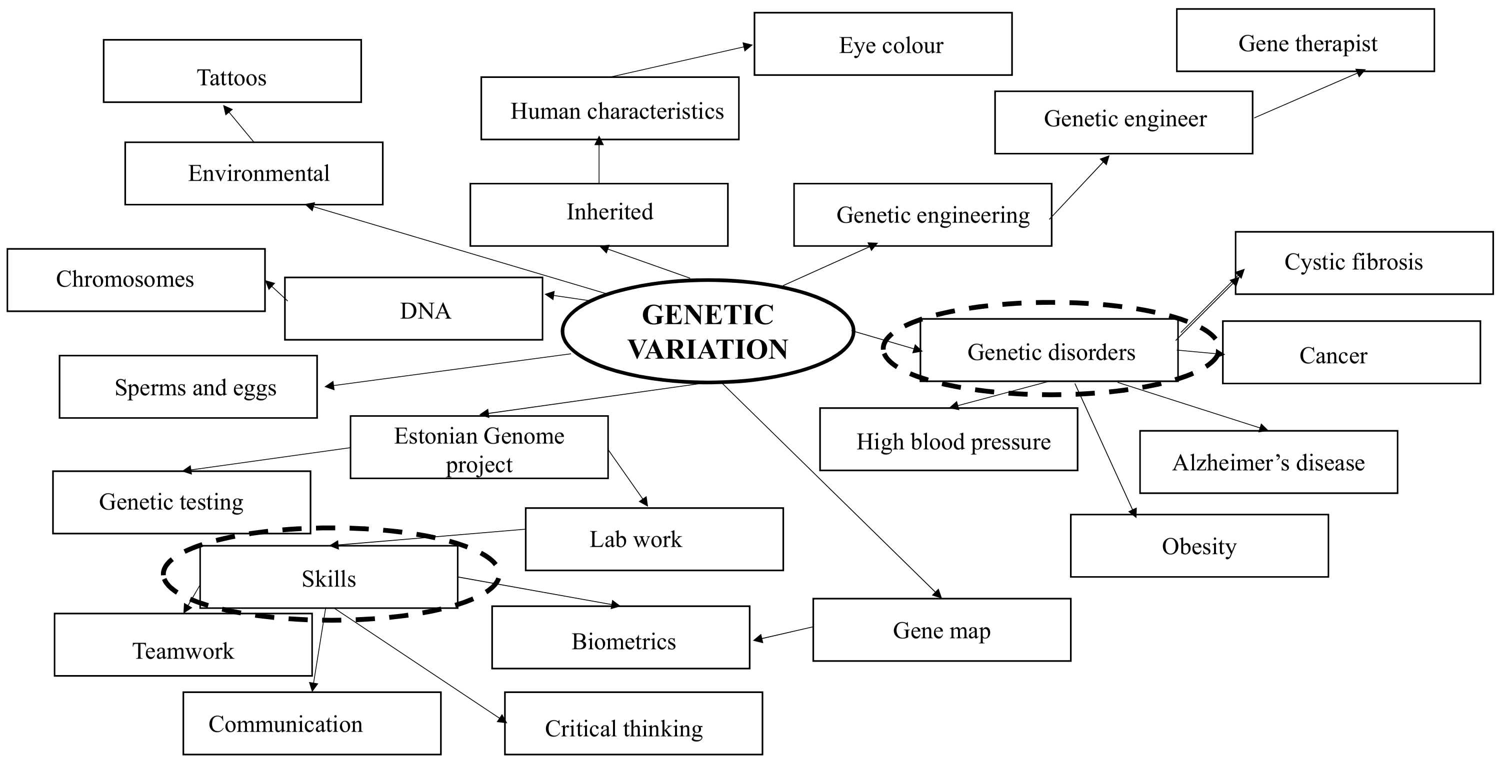


Figure 8. Illustrative sample of 4th level student-created mind map

The created mind map was 4th level, multiple integrated and hierarchical network, which demonstrated deep conceptualisation of the disciplinary core idea.

To determine the essential characteristics needed for the promotion of meaningful learning, findings were taken from Articles I, II and III. The findings of conducted research have shown that in order to support students' meaningful learning it is important to

- Provide a scientific framework for different curriculum topics and to pay attention to disciplinary and interdisciplinary core ideas for supporting students' conceptualisation of science learning (Articles, II and III);
- Together with knowledge to develop the 21st century skills for students which are needed to adapt and thrive in an ever-changing world (Articles I and II);
- Not only develop students' factual knowledge in the science lessons, but also to place more emphasis on procedural and conceptual knowledge. This is needed for students to deepen their conceptualisation of science or for solving problems for seeing important relationships (Article III). Introduce the mind mapping and concept mapping method to students in order to support students' meaningful learning;
- Support students so that they can relate their previous knowledge to the new forms of knowledge, to integrate knowledge through the use of mind mapping and concept mapping method in science lessons. This is seen as important for conceptualisation and knowledge construction (Article, III). Introduce to students mind mapping method in order to support students' meaningful learning;
- Develop and implement student-led expansion of disciplinary and interdisciplinary core idea maps in science lessons, which are methodological teaching and learning tools, which depict promotion of meaningful learning of important knowledge in sciences through different school levels. These maps pay attention to the related knowledge, skills and the development of career awareness.

Derived for the analysis of previous research findings, Figure 4 gives an overview of the characteristics needed for the intervention to support students' meaningful learning in science classes.

4.3. Identification of students' change of self-efficacy, post-intervention

4.3.1. Students' self-efficacy change towards acquiring DCIs and ICIs

Appendix 3 shows outcomes for the experimental group from conducting confirmatory factor analysis (CFA) on students' self-efficacy towards acquiring DCIs and ICIs for the pre-questionnaire (pre) and post-questionnaire (post). Table 14 indicated the descriptive statistics and t-test results comparing pre-and post-questionnaire results on students' self-efficacy towards acquiring DCIs and ICIs.

Table 11. t-test results comparing pre- and post-questionnaire results on students' self-efficacy towards acquiring DCIs and ICIs

DCIs and ICIs	M (SD) Pre	M (SD) Post	Paired sample t-test		
			t	df	SE
DCIs related to Life Science					
Cell functions in tissues	2.51 (0.78)	3.32 (0.80)	10.48**	416	0.08
Aerobic and anaerobic respiration	2.69 (0.68)	2.99 (0.88)	3.89**	416	0.08
Heredity and DNA*	2.77 (0.83)	3.57 (0.83)	9.85**	416	0.08
Genetic variation*	2.71 (0.73)	3.41 (0.79)	9.41**	416	0.07
M	**2.67 (0.76)**	**3.32 (0.83)**	**8.41****	**416**	**0.08**
DCIs related to Earth Science					
Rainforest deforestation	2.85 (0.91)	2.95 (0.80)	1.19	416	0.08
Land surface change*	2.60 (0.77)	3.00 (0.89)	4.91**	416	0.08
Weather and climate*	2.82 (0.76)	3.12 (0.70)	4.20**	416	0.07
Natural hazards	3.02 (0.68)	3.13 (0.65)	1.69	416	0.07
Climate warming	2.86 (0.83)	3.09 (0.83)	3.83**	416	0.08
Solar and lunar eclipse	2.82 (0.80)	3.00 (0.87)	2.20**	416	0.08
M	**2.83 (0.79)**	**3.05 (0.79)**	**3.00****	**416**	**0.08**
DCIs related to Chemistry					
Chemical reactions*	2.43 (0.92)	2.51 (0.93)	0.88	416	0.09
Natural phenomena at the particulate level	2.40 (0.85)	2.49 (0.89)	1.06	416	0.09
The nature of interactions between bodies	2.46 (0.87)	2.50 (0.90)	0.46	416	0.09
Characteristics of substances*	2.44 (0.87)	2.54 (0.97)	1.11	416	0.09
M	**2.43 (0.88)**	**2.51 (0.92)**	**0.88**	**416**	**0.09**
DCIs related to Physics					
Electricity generator	2.40 (0.91)	2.40 (0.71)	1.00	416	0.08
Motions and waves*	2.36 (0.86)	2.56 (0.86)	1.12	416	0.08
Energy conversion*	2.37 (0.89)	2.47 (0.84)	1.18	416	0.09
M	**2.38 (0.89)**	**2.48 (0.80)**	**1.10**	**416**	**0.08**
ICIs					
Systems*	2.37 (0.86)	3.25 (0.86)	10.46**	416	0.08
Cause and effect	2.64 (0.82)	3.13 (0.86)	5.96**	416	0.08
Natural and human-made systems	2.51 (0.85)	3.30 (0.95)	8.95**	416	0.09
Structural properties of the objects	2.33 (0.87)	3.25 (0.87)	10.81**	416	0.09
Models*	2.38 (0.85)	3.26 (0.85)	10.90**	416	0.08
M	**2.45 (0.85)**	**3.24 (0.88)**	**9.42****	**416**	**0.08**

Note: *DCIs and ICIs used in the intervention research; measured using a 4-point scale; M–mean; SD–standard deviation; t-statistics; ** p-level is < 0.05 and is considered significant**;** df–the degrees of freedom; SE–standard error of the difference.

Table 11 indicated that the developed and implemented intervention supported students' meaningful learning in disciplinary core ideas related to the Life Science, Earth Science, and with interdisciplinary core ideas such as Models and Systems. However, with the disciplinary core ideas related to the Chemistry and Physics the change was not statistically important which indicated that the intervention had little influence on students' meaningful learning in these subject areas.

The five-factor model fit indices, for students' self-efficacy towards acquiring DCIs and ICIs, are shown in Appendix 4. The RMSEA value showed reasonable fit for both CFA models. Both CFI and TLI indices were in the recommended level (CFI=0.96 and TLI=0.95) (Bowen & Guo, 2012).

Confirmatory Factor Analysis (CFA) revealed similar changes on students' self-efficacy towards acquiring DCIs and ICIs (Appendix 5).

- Life Science;
- Earth Science;
- Chemistry;
- Physics;
- Models and Systems.

The five-factor model fit indices, for students' self-efficacy towards acquiring DCIs and ICIs, are shown in Table 12. The RMSEA value showed reasonable fit for both CFA models. Both CFI and TLI indices were in the recommended level (Bowen & Guo, 2012).

Table 12. Summary of goodness fit indices for CFA models for showing students' self-efficacy towards acquiring DCIs and ICIs using a 4-point Likert-type scale, for the experimental and control group

Model fit indices	χ^2	df	p	RMSEA	CFI	TLI
5-factor model of students' self-efficacy towards acquiring DCIs and ICIs (experimental group)	832.14	369	<0.001	0.05	0.95	0.96
5-factor model of students' self-efficacy towards acquiring DCIs and ICIs (control group)	768.44	369	<0.001	0.04	0.95	0.96

Table 13 indicated the descriptive statistics and t-test results comparing experimental and control group results on students' self-efficacy towards acquiring DCIs and ICIs.

Table 13. t-test results comparing experimental and control group results on students' self-efficacy towards acquiring DCIs and ICIs

DCIs and ICIs	M (SD)	M (SD)	Paired sample t-test		
	EG	CG	t	df	SE
DCIs related to Life Science					
Cell functions in tissues	3.32 (0.80)	2.85 (0.70)	5.92**	369	0.08
Aerobic and anaerobic respiration	2.99 (0.88)	2.95 (0.64)	0.49	369	0.08
Heredity and DNA*	3.57 (0.83)	2.84 (0.66)	9.17**	369	0.08
Genetic variation*	3.41 (0.79)	2.83 (0.63)	7.65**	369	0.08
M	**3.32 (0.83)**	**2.87 (0.66)**	**5.81****	**369**	**0.08**
DCIs related to Earth Science					
Rainforest deforestation	2.95 (0.80)	2.90 (0.73)	0.62	369	0.08
Land surface change*	3.00 (0.89)	2.50 (0.52)	6.36**	369	0.08
Weather and climate*	3.12 (0.70)	2.30 (0.66)	11.47**	369	0.07
Natural hazards	3.13 (0.65)	2.69 (0.65)	7.79**	369	0.07
Climate warming	3.09 (0.83)	2.15 (0.57)	12.33**	369	0.08
Solar and lunar eclipse	3.00 (0.87)	2.76 (0.60)	3.00	369	0.08
M	**3.05 (0.79)**	**2.55 (0.62)**	**6.93****	**369**	**0.08**
DCIs related to Chemistry					
Chemical reactions*	2.51 (0.93)	2.38 (0.73)	1.46	369	0.09
Natural phenomena at the particulate level	2.49 (0.89)	2.43 (0.81)	0.67	369	0.09
The nature of interactions between bodies	2.50 (0.90)	2.40 (0.78)	1.12	369	0.09
Characteristics of substances*	2.54 (0.97)	2.37 (0.85)	1.77	369	0.10
M	**2.51 (0.92)**	**2.40 (0.79)**	**1.26**	**369**	**0.09**
DCIs related to Physics					
Electricity generator	2.40 (0.71)	2.05 (0.59)	5.06**	369	0.06
Motions and waves*	2.56 (0.86)	2.32 (0.59)	3.04**	369	0.09
Energy conversion*	2.47 (0.84)	2.17 (0.60)	3.85**	369	0.07
M	**2.48 (0.80)**	**2.18 (0.59)**	**3.98****	**369**	**0.07**
ICIs					
Systems*	3.25 (0.86)	2.52 (0.60)	9.20**	369	0.07
Cause and effect	3.13 (0.86)	2.65 (0.69)	6.16**	369	0.08
Natural and human-made systems	3.30 (0.95)	2.05 (0.66)	14.29**	369	0.08
Structural properties of the objects	3.25 (0.87)	2.25 (0.67)	12.11**	369	0.08
Models*	3.26 (0.85)	2.30 (0.65)	11.92**	369	0.08
M	**3.24 (0.88)**	**2.35 (0.65)**	**10.74****	**369**	**0.08**

Note: DCIs and ICIs used in the intervention research; measured using a 4-point scale; M–mean; SD–standard deviation; t-statistics; ** p-level is < 0.05 and is considered significant**;** df–the degrees of freedom; SE–standard error of the difference.

Table 13 indicated that the comparison of experimental and control group students' self-efficacy towards acquiring DCIs and ICIs reveal similar results to the pre- and post-questionnaire results comparison. This showed that the developed and implemented intervention supported students' meaningful learning. Experimental group students' self-efficacy was statistically significantly higher than control group towards the DCIs related to the Life Science, Earth Science, Physics and ICIs. However, with the disciplinary core ideas related to the Chemistry the change was not statistically important which indicated that the intervention had little influence on students' meaningful learning in this subject area.

An evaluation of the usefulness of student-led expansion of DCI and ICI maps by the experimental group students is given in Table 14.

Table 14. Experimental group evaluation of the usefulness of student-led expansion of DCI and ICI maps (Article V)

The group of core idea	Implemented DCI and ICI map	M	SD
Life Science	Genetic variation	3.21	0.78
	Heredity and DNA	3.11	0.89
Earth Science	Land surface changes	2.98	0.80
	Weather and Climate	3.78	0.85
Chemistry	Chemical reactions	2.45	0.77
	Characteristics of substances	2.56	0.85
Physics	Motions and waves	2.67	0.71
	Energy conversion	3.01	0.91
Models and Systems	Models	3.51	0.90
	Systems	3.01	0.78

Note: M–mean; SD–standard deviation.

In general, the comparison between the experimental and control groups confirmed that the intervention had a positive impact on students' self-efficacy towards acquiring these disciplinary and interdisciplinary core ideas (Table 14). With disciplinary core ideas in Physics and Chemistry, the change was not statistically significantly positive. Table 14 indicated students' agreement (M>2.50) or disagreement (M<2.50) with the usefulness of student-led expansion of DCI and ICI maps. The groups of core ideas are created based on the factor analysis.

The most useful DCI maps in the students' opinion were Weather and Climate, Models and Genetic Variation. At the same time, the least useful DCI maps in the students' opinion were Chemical reactions, Characteristics of substances, and Motions and waves.

To gather a more detailed overview of the usefulness of the student-led expansion of DCI and ICI maps, in terms of improved students' meaningful learning in school science, 25 students and 5 teachers were interviewed, after the intervention. Table 15 shows the overall interview findings.

Table 15. Interview findings (Article V)

Findings from students interviews	**Findings from teachers interviews**
In general students indicated that in their opinion expanding DCI and ICI maps was useful. They added that the DCI and ICI maps were interesting and supportive for meaningful learning. Students agreed that expanding DCI and ICI maps allowed them to collaborate more with their classmates. Students included that expanding DCI and ICI maps raised helped to raise their self-confidence towards learning the topic and also raised their motivation to study science.	In general teachers found useful students expanding DCI and ICI maps useful and they felt that these supported students' studies. They also added that this method (including knowledge integration through mind mapping and concept mapping) supported students' meaningful learning. All teachers agreed that students expanded DCI and ICI maps were in-depth (they added more new knowledge and interconnections on the expanded maps) with DCIs and ICIs related to the Models and Systems, Earth Science and Life Science. Teachers also indicated that in relation to the disciplinary core ideas in Chemistry and Physics, the students expanded maps were significantly less extensive. Students were more active in making connections, with ~~the~~ disciplinary and interdisciplinary core ideas which were more relevant to their everyday lives, (and these were also seen as linked to science-related careers.

The interviews conducted with students who participated in the intervention indicated that, in general, they found expanding DCI and ICI maps useful. According to the interviewed students, they collaborated more with each other and when expanding DCI and ICI maps and noticed the interconnections between different science subjects. In addition, students found the maps interesting, because such a methodology has not previously been used in other subject before. Students became more confident in developing the DCIs and ICIs, because they noticed more easily the interconnections between their prior and new knowledge more easily.

The conducted interviews conducted with teachers who participated in the intervention indicated that, in general, they found it useful for students to expand DCI and ICI maps. The students were motivated to work together and showed interest in expanding the maps. In addition, teachers found that students were more aware of the links between different science subjects.

4.3.2. Students' self-efficacy change towards acquiring 21st century skills

Appendix 6 indicates a pre- and post-questionnaire CFA comparison on students' self-efficacy towards acquiring 21st century skills conducted with respect to:

- Cognitive and problem-solving skills;
- Critical thinking;
- The changeability of scientific knowledge;
- Responsible citizenship;
- Mindset for scientific research.

A more detailed comparison of pre- and post-questionnaire self-efficacy by the experimental group students was as presented below (Table 16). Table 16 indicated the descriptive statistics and t-test results comparing pre- and post-questionnaire results on students' self-efficacy towards acquiring 21st century skills.

Table 16 indicated that the comparison of experimental and control group showed that the developed and implemented intervention supported students' meaningful learning. Experimental group students' self-efficacy was statistically significantly higher than control group towards acquiring the 21st century skills related to the Cognitive and problem-solving skills, critical thinking, and the mindset for scientific research. However, with the 21st century skills related to the changeability of scientific knowledge and responsible citizenship the change was not statistically important which indicated that the intervention had little influence on students' meaningful learning in these areas.

Table 16. t-test results comparing pre- and post-questionnaire results on students' self-efficacy towards acquiring 21st century skills

21st century skills	**M (SD)**	**M (SD)**	**Paired sample t-test**		
	Pre	**Post**	**t**	**df**	**SE**
Cognitive and problem-solving skills					
Creative thinking	2.93 (0.82)	3.33 (0.84)	4.93**	416	0.08
Problem is within my level of understanding	2.62 (0.80)	3.57 (0.88)	11.55**	416	0.08
Evaluating the efforts and effectiveness	2.93 (0.80)	3.52 (0.79)	7.59**	416	0.08
Designing problem-solving strategies	2.67 (0.82)	2.95 (0.80)	3.53**	416	0.08
Finding alternatives	2.79 (0.80)	2.99 (0.96)	2.31**	416	0.09
Motivated to solve challenging problems	2.56 (0.81)	3.69 (0.69)	15.35**	416	0.07
M	**2.75 (0.81)**	**3.34 (0.83)**	**7.54****	**416**	**0.08**

21st century skills	M (SD)	M (SD)	Paired sample t-test		
	Pre	Post	t	df	SE
Critical thinking					
Evaluating efforts of selected strategies after reaching the desired goal	3.02 (0.87)	3.13 (0.68)	1.44	416	0.08
Critical evaluation of information	2.90 (0.83)	3.90 (0.88)	11.95**	416	0.08
Distinguish scientific evidence from non-scientific	3.00 (0.79)	3.65 (0.80)	8.36**	416	0.08
Creativity and imagination	3.07 (0.82)	3.51 (0.75)	5.72**	416	0.08
M	**3.00 (0.83)**	**3.55 (0.78)**	**6.87****	**416**	**0.08**
The changeability of scientific knowledge					
Trying to understand the reasons for other people's actions	3.16 (0.88)	3.31 (0.90)	1.72	416	0.09
Showing respect to other peoples	3.12 (0.90)	3.45 (0.95)	3.65**	416	0.09
Scientific knowledge can change	3.28 (0.82)	3.03 (0.90)	2.97**	416	0.08
Explain natural phenomena	2.85 (0.83)	2.93 (0.86)	0.97	416	0.09
Usefulness of scientific knowledge	3.07 (0.79)	3.10 (0.88)	0.37	416	0.08
M	**3.10 (0.84)**	**3.16 (0.90)**	**1.94**	**416**	**0.09**
Responsible citizenship					
Consequences towards natural environment	2.72 (0.89)	2.83 (0.85)	1.29	416	0.09
Responsibility towards what happens in the environment	3.03 (0.86)	3.03 (0.72)	1.00	416	0.08
Well-being is connected to what happens in nature	2.74 (0.90)	2.76 (0.83)	0.24	416	0.09
Contribute to protecting the natural environment	2.42 (0.82)	2.40 (0.82)	0.25	416	0.08
Ethical standards	2.66 (0.80)	2.64 (0.82)	0.25	416	0.08
M	**2.71 (0.85)**	**2.73 (0.81)**	**0.71**	**416**	**0.08**
Mindset for scientific research					
Scientific models portray nature	2.79 (0.83)	3.69 (0.90)	10.63**	416	0.09
Carefully collected data gives perfect knowledge	2.95 (0.85)	3.99 (0.90)	12.15**	416	0.09
One certain scientific method for creating scientific knowledge	2.89 (0.83)	3.57 (0.86)	8.23**	416	0.08
Apply knowledge from science lessons	2.94 (0.81)	3.72 (0.87)	9.49**	416	0.08
M	**2.89 (0.83)**	**3.74 (0.88)**	**10.13****	**416**	**0.09**

Note: Measured using a 4-point scale; M–mean; SD–standard deviation; t-statistics; ** p-level is < 0.05 and is considered significant; df–the degrees of freedom; SE–standard error of the difference.

The five-factor model fit indices, for students' self-efficacy towards acquiring 21st century skills, are shown in Table 17. The RMSEA value showed reasonable fit for both CFA models. Both CFI and TLI indices were in the recommended level (Bowen & Guo, 2012).

Table 17. Summary of goodness fit indices for CFA models showing students' self-efficacy towards acquiring 21st century skills using a 4-point Likert-type scale, for the experimental group and control group

Model fit indices	χ^2	df	p	RMSEA	CFI	TLI
5-factor model of students' self-efficacy towards acquiring 21st century skills (experimental group)	811.59	416	<0.001	0.07	0.96	0.95
5-factor model of students' self-efficacy towards acquiring 21st century skills (control group)	781.09	416	<0.001	0.06	0.95	0.95

Table 18 indicated the descriptive statistics and t-test results comparing experimental and control group results on students' self-efficacy towards acquiring 21st century skills.

Table 18. t-test results comparing experimental and control group results on students' self-efficacy towards acquiring 21st century skills

21st century skills	M (SD)	M (SD)	Paired sample t-test		
	EG	CG	t	df	SE
Cognitive and problem-solving skills					
Creative thinking	3.33 (0.84)	3.02 (0.75)	3.69**	369	0.08
Problem is within my level of understanding	3.57 (0.88)	2.73 (0.84)	9.30**	369	0.09
Evaluating the efforts and effectiveness	3.52 (0.79)	3.12 (0.68)	5.14**	369	0.08
Designing problem-solving strategies	2.95 (0.80)	2.87 (0.78)	0.97	369	0.08
Finding alternatives	2.99 (0.96)	2.89 (0.92)	1.01	369	0.10
Motivated to solve challenging problems	3.69 (0.69)	3.16 (0.69)	7.34**	369	0.07
M	**3.34 (0.83)**	**2.97 (0.78)**	**4.58****	**369**	**0.08**

21st century skills	M (SD)	M (SD)	Paired sample t-test		
	EG	CG	t	df	SE
Critical thinking					
Evaluating efforts of selected strategies after reaching the desired goal	3.73 (0.68)	3.35 (0.77)	4.96**	369	0.08
Critical evaluation of information	3.90 (0.88)	3.14 (0.75)	8.79**	369	0.09
Distinguish scientific evidence from non-scientific	3.65 (0.80)	3.21 (0.70)	5.55**	369	0.08
Creativity and imagination	3.91 (0.75)	3.87 (0.62)	0.56	369	0.07
M	**3.80 (0.78)**	**3.39 (0.71)**	**4.97****	**369**	**0.08**
The changeability of scientific knowledge					
Trying to understand the reasons for other peoples' actions	3.31 (0.90)	3.16 (0.82)	1.65	369	0.09
Showing respect to other peoples	3.45 (0.95)	3.23 (0.80)	2.37**	369	0.09
Scientific knowledge can change	3.03 (0.90)	2.88 (0.91)	1.58	369	0.10
Explain natural phenomena	2.93 (0.86)	2.85 (0.67)	0.98	369	0.08
Usefulness of scientific knowledge	3.10 (0.88)	2.87 (0.72)	2.70**	369	0.09
M	**3.16 (0.90)**	**3.00 (0.78)**	**1.86**	**369**	**0.09**
Responsible citizenship					
Consequences towards natural environment	2.83 (0.85)	2.68 (0.79)	1.74	369	0.09
Responsibility towards what happens in the environment	3.03 (0.72)	2.65 (0.66)	5.23**	369	0.07
Well-being is connected to what happens in nature	2.76 (0.83)	2.65 (0.92)	2.21	369	0.09
Contribute to protecting the natural environment	2.40 (0.82)	2.32 (0.88)	0.90	369	0.09
Ethical standards	2.64 (0.82)	2.67 (0.82)	0.35	369	0.09
M	**2.73 (0.81)**	**2.59 (0.81)**	**2.09**	**369**	**0.09**
Mindset for scientific research					
Scientific models portray nature	3.89 (0.90)	3.67 (0.73)	2.69**	369	0.09
Carefully collected data gives perfect knowledge	3.99 (0.90)	3.45 (0.88)	5.79**	369	0.09
One certain scientific method for creating scientific knowledge	3.57 (0.86)	3.19 (0.87)	4.20**	369	0.09
Apply knowledge from science lessons	3.97 (0.87)	3.94 (0.86)	0.33	369	0.09
M	**3.86 (0.88)**	**3.56 (0.84)**	**3.25****	**369**	**0.09**

Note: Measured using a 4-point scale; M–mean; SD–standard deviation; t-statistics; ** p-level is < 0.05 and is considered significant**;** df–the degrees of freedom; SE–standard error of the difference.

The comparison of outcomes by the experimental and control group showed that, after the 1.5-year intervention, students' self-efficacy was significantly higher in the experimental group towards acquiring three key 21st century skills – cognitive and problem-solving skills, critical thinking, and the mindset for scientific research (Table 18). However, in two factors, the change in students' self-efficacy was not shown to be statistically significant (the changeability of scientific knowledge, and responsible citizenship).

Table 19 provides an overview of the findings associated with each research question.

Table 19. Overview of the main research findings for the stages I, II and III

Research questions	**Articles**	**Data analysis**	**Findings**
			Stage I
RQ1: What is the students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills?	I, II	**D**escriptive statistics **P**rincipal Component Analysis **C**onfirmatory Factor Analysis	**Students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills:** 1) Students felt lower self-efficacy towards acquiring disciplinary core ideas related to the Physics and Chemistry. 2) In general, students had high self-efficacy towards acquiring ICIs. 3) In general, students perceived 21st century skills as important. Nevertheless, students' self-efficacy was shown to be lower towards acquiring problem-solving and decision-making and critical thinking skills.
			Stage II
RQ2: Which are essential characteristics need to be included in deriving intervention which promote students' meaningful learning?	I, II, III	**D**escriptive statistics **P**rincipal Component Analysis **C**onfirmatory Factor Analysis **A**bductive Thematic Analysis	**Characteristics for supporting students' meaningful learning:** 1) Disciplinary and interdisciplinary core ideas can be helpful for students to make interdisciplinary connections and for supporting students' meaningful learning. 2) Students need more support (on how learned DCIs and ICIs were interconnected) from their science teachers. 3) Students need more help to make integrate knowledge especially conceptual and procedural dimensions of knowledge (including knowledge construction). 4) Students-led expansion of DCI and ICI maps by drawing the connections – between prior and new knowledge could support students' meaningful learning.

Research questions	Articles	Data analysis	Findings
Stage III			
RQ3: In what ways can changes in upper secondary school students' self-efficacy towards acquiring meaningful learning be enhanced by guiding and engaging students in expanding upon DCI and ICI maps?	IV, V	**D**escriptive Analysis **C**onfirmatory Factor Analysis **I**nductive Thematic Analysis	**Intervention impact:** 1) In general, the method in which students expanded DCI and ICI maps was seen as effective and supported students' meaningful learning in Life Science, Earth Science and with Models and Systems. 2) Although positive tendencies were found within Chemistry and Physics meaningful learning, the change in students' self-efficacy was not statistically significant. 3) Students' self-efficacy towards acquiring 21st century skills after the intervention was significantly higher than before the intervention in three factors – cognitive and problem-solving, critical thinking, and the mindset for scientific research. 4) With the factors the changeability of scientific knowledge and responsible citizenship, the change was not found to be statistically significant.

5. DISCUSSION

This study seeks to determine the impact of an intervention in which student-led expansion of disciplinary and interdisciplinary core idea maps, which can contribute to students' meaningful learning. This is addressed by seeking students' self-efficacy based on acquired characteristics seen as essential and involved in deriving DCI and ICI maps as well as acquiring related 21st century skills.

Research was conducted to determine:
1. What is the students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills?
2. Which essential characteristics need to be included in deriving intervention which promote students' meaningful learning?
3. In what ways can changes in upper secondary school students' self-efficacy towards acquiring meaningful learning be enhanced by guiding and engaging students in expanding upon DCI and ICI maps?

5.1. Determining students' self-efficacy

5.1.1. Students' self-efficacy towards acquiring disciplinary and interdisciplinary core ideas

The findings show that students' self-efficacy towards acquiring disciplinary core ideas tends to be low (Table 7). According to Harlen et al. (2010; 2015), this can be linked to the fact that students gain fragmental knowledge in learning science topics. In science education, where knowledge is acquired in order to be applied, it is important for students to develop an integrated knowledge framework (Donald, 2002; Harlen et al., 2015, NRC, 2012). This research shows that acquiring DCIs, ICIs, and 21st century skills can minimise students' sole gain of fragmental knowledge and this can support students' meaningful learning (Alonzo & Gotwals, 2012; Holley & Park, 2020). The findings also show that, post intervention, students' self-efficacy towards acquiring disciplinary core ideas, in particular related to Earth Science, is high (Table 7). This is explained by the fact that such disciplinary core ideas (e.g. the consequences of destroying the rainforests), are more relevant for students and are perceived as being in their daily lives and thus students find it easier to make sense of their learning (Arnold et al., 2021; Teppo et al., 2017).

Table 7 also indicates that students' self-efficacy towards acquiring disciplinary core ideas related to Chemistry (e.g. redox reaction) and Life Science (e.g. hereditary of genetic diseases) factor and Physics (e.g. natural phenomena at the particulate level) tend to be low. Cooper et al., (2017) and Teppo et al., (2017) show that these disciplinary core ideas are often too abstract for students. Also, the science curriculum places considerable emphasis on conceptual science content, which lends itself to focusing on a huge amount of learning material without indicating appropriate structural support allowing connections to be made between the knowledge or skills presented (Duschl et al., 2011; Roche Allred et al., 2020; Schmidt et al., 2002). This points to the importance of providing opportunities for students to be able to conceptualise core ideas and to seek ways by which science knowledge and skills can be interconnected.

For teachers to refocus secondary school studies in order to promote student acquisition of a framework for both disciplinary and interdisciplinary core ideas is shown to be essential in preparing students for their future careers and lives (Flaherty, 2020; Harlen et al., 2015; Krajcik & Delen, 2017; Pleasants et al., 2021).

5.1.2. Students' self-efficacy towards acquiring 21st century skills

The findings show that students' self-efficacy towards acquiring 21st century skills related to the problem-solving abilities (e.g. motivation for solving challenging problems), or decision-making (e.g. defending a standpoint involving the use of appropriate scientific evidence) (Table 8) is low. This is in line with previous studies, which have shown that the self-efficacy of secondary school students was lower in learning and practicing problem-solving, or decision-making skills, compared with other 21st century skills, such as imagination or creativity (Article I; Chalkiadaki, 2018; Soobard & Rannikmäe, 2014). Thus, there still remains a gap between school science learning and societal needs (Choi et al., 2011; Pleasants et al., 2021), (Evans et al., 2020; Article I), despite previous studies indicating that in science studies there is a need to pay more attention to equipping students, to not just comprehend scientific conceptualisations, but also to be able to put forward arguments and to take action in both scientific and societal situations (OECD, 2019; Steward, 2019). This recognises that, in order for students to solve problems, or make justified decisions, it is important that students:

- Conceptualise how scientific knowledge is constructed (Holley & Park, 2020; Rudolph, 2005);
- Are provided opportunities to create and construct new knowledge through their own experiences (Pegg et al., 2012), and;
- Can interconnect knowledge and skills (Holley & Park, 2020).

Learning 21st century skills are essential for successfully adapting to modern work environments.

5.2. Essential characteristics promoting students' meaningful learning

In order for students' learning to be meaningful, it is important that the students, themselves, can actively participate and be involved in the learning process (Ausubel 1968; Novak, 2010). Thus, it is important to develop a methodology that supports students' meaningful learning in science lessons (Article II). With this in mind and based on the findings of the research conducted within the framework of this thesis, a validated scheme was developed in the second research stage to plan an intervention to promote students' meaningful learning in their science lessons (Figure 4).

The findings show that students tend to have low perceptions of acquiring different disciplinary and interdisciplinary core ideas and 21st century skills, but these vary based on different factors (Tables 7 and 8). This is a concern because today's world faces challenges that demand the next generation to be capable leaders with an extensive understanding of public life, honed skills in, for example, critical thinking, and the ability to collaborate with diverse groups. Thus, such skills are important, together with the knowledge to develop students' 21st century skills (including problem-solving skills, critical thinking, etc.) (Laar et al., 2017; Rios et al., 2020). For this, providing a scientific framework for different curriculum topics and paying attention to disciplinary and interdisciplinary core ideas becomes important (Darling-Hammond et al., 2020; NRC, 2012; Article II).

The findings also reveal that for students it is difficult to interconnect and conceptualise different disciplinary and interdisciplinary core ideas (Table 9). They also show that students make more interconnections between factual knowledge (Table 10), although it is noted that even a large body of factual knowledge is not sufficient for conceptualisation if students do not understand the interconnections between the facts (Article III). Thus, science educators need to actively aim at helping students reach higher levels of understanding, when knowledge is actively interrelated and recognise that it is not expected that students reach those levels on their own (Biggs, 2014).

Moreover, the findings demonstrate that students make fewer interconnections between conceptual and procedural knowledge (Table 10). This is seen as a concern, because it is important for students to make links between their prior and new knowledge (Article III). This finding is in line with previous studies, which reveal that guiding students to acquire and integrate new conceptual knowledge has been an important aspect of learning (Krathwohl, 2001; NRC, 2012). Furthermore, it is recognised that it is important to support students in making interconnections during learning activities and to support their long-term memory (NRC, 2012).

The findings indicate that students struggle to interconnect their different dimensions of knowledge (Tables 9 and 10). For supporting students' long-term memory, it is reported that it is important for students to construct their knowledge with mind mapping and concept mapping, and to connect their prior and new knowledge (Bressington et al., 2018; Buzan, 2009a). This is considered important for supporting students' meaningful learning (Ausubel, 1986). One important method for supporting students' meaningful learning is to develop and implement disciplinary and interdisciplinary core idea maps in science lessons, helping students to better conceptualise their learning (NRC, 2012). An essential aspect in constructing an integrated knowledge framework is to create a learning environment in which learning means actively constructing interconnected knowledge and skills on the basis of prior learning (Hailikari et al., 2007; Tobias, 1994).

5.3. Enhancing changes in students' self-efficacy

5.3.1. Students' self-efficacy change towards acquiring disciplinary and interdisciplinary core ideas

Interviews conducted with students and teachers indicate that the use of teaching methods involving DCI and ICI maps (including knowledge integration through mind mapping and concept mapping; group work, etc.), enable students to receive meaningful learning experiences (Table 11). The most frequently reported triggering and sustaining source of meaningful learning is the ability to be able to undertake knowledge integration, which involves the construction of knowledge (i.e. relating prior and new knowledge) (Holley & Park, 2020; Novak, 2010; Odden & Russ, 2019).

The findings reveal that the students' self-efficacy, towards acquiring disciplinary and interdisciplinary core ideas related to the Life Science, Earth Science, and with Models and Systems, increases after the intervention (Appendix 3 and Table 11). This implies that teachers help students develop and integrate knowledge frameworks and that students have an opportunity to move beyond isolated factual knowledge (Biggs, 2014; Borda et al., 2020; Wang & Song, 2021; Article V). As it is seen as important for students to interconnect existing knowledge and to interrelate this with the new knowledge being presented (Biggs, 2014; Wang & Song, 2021), the conducted interviews (with both students and teachers) reveal that the implemented disciplinary and interdisciplinary core idea maps are interpreted as facilitated meaningful learning for students (Table 15).

It has also been shown that, in the subjects Chemistry and Physics, this learning approach is not found to be as meaningful (Tables 11 and 15). A possible explanation for this can be that in Physics and Chemistry disciplinary core idea maps, students are unable to create a wide variety of connections (Bretz et al., 2013; DeKorver & Towns, 2015; Holley & Park, 2020; Novak, 2010). This can be explained based on the findings from interviews conducted with the teachers, which reveal that in areas where meaningful learning occurs, students are more active in making connections, the core ideas are seen as more relevant to their everyday lives, and these tend to be linked to science-related careers (Table 15). Despite this, teachers note a significant lack of connections made by students with disciplinary core ideas in Chemistry and Physics (Table 11 and 15) and these disciplinary core ideas do not seem to be relevant, or important for students. In accordance with previous studies (Bartimote-Aufflick, 2016; Krajcik & Delen, 2017, Novak, 2010), this research study confirms that the experience of learning in a way that is useful for the future, and which provides the opportunity to construct connections while the learning is taking place, make acquiring new knowledge more intriguing.

Students' higher self-efficacy and positive tendencies toward interrelating disciplinary core ideas associated with Life Science and Earth Science are statistically significant (Tables 11 and 15). The findings from the students' interviews indicate that students see these core ideas as more compelling and interesting and thus they are able to make connections between their prior and new knowledge more easily (Table 15). This is in line with previous research that aimed to enhance the students' self-efficacy towards acquiring DCIs and ICIs without intervening (Bartimote-Aufflick et al., 2016; Article IV and V). This research confirms that student perceive themselves as more capable of learning disciplinary core ideas associated with Life Science and Earth Science rather than with conceptualisations within Chemistry and Physics.

The use of DCI and ICI maps is viewed positively by students and teachers as they indicate support for students' meaningful learning (Table 15). The findings support previous studies showing that meaningful learning occurs when students are actively involved in the learning process and the focus is on acquiring the concepts rather than just recalling facts and figures (Bartimote-Aufflick et al., 2016; Thompson, 2000; Novak, 2010). Nevertheless, overall, it cannot be said that the use of DCI and ICI maps to promote meaningful learning is a comprehensive approach in all areas of science education. This is highlighted by the fact that in Life Science, Earth Science, and Models and Systems, students' self-efficacy is seen to be higher, whereas in Physics and Chemistry, it is lower (Tables 11 and 15). This is in line with previous research, which emphasises the positive impact of meaningful learning strategies on students' self-efficacy. This study also emphasises that it is crucial to develop meaningful learning strategies in promoting science education (Baltaoğlu & Güven, 2019). In this research, the developed and implemented disciplinary and interdisciplinary core idea maps are considered unique, because the students themselves developed their maps to recall their previous knowledge and then relate this to the development of new maps during the learning process within science lessons. However, an important factor adding to the importance of this research is that, in all science subjects, there is the need for students' self-efficacy towards acquiring DCIs and ICIs to increase in order to confirm that meaningful science learning has taken place (Ausubel, 1968; Ausubel et al., 1978; Novak, 2010). Thus, it is important to examine comprehensive approaches to improving learning in all science subjects in future research. Integration of different science disciplines can be a major factor in achieving this aim.

The experimental group students, after the intervention, demonstrated significantly higher self-efficacy in Life Science and Earth Science than the control group students (Table 11). These findings (Table 11) point to the impact of the intervention research and underline the importance of integrating science lessons to support meaningful learning for students (Holley & Park, 2020; Howland et al., 2011; Mystakidis, 2019; Novak, 2010; Weick et al., 2005). In guiding the development of interdisciplinary core ideas related to Models and Systems, the self-efficacy indicated by the experimental group students is significantly higher at the end of grade 11 than that of the control group students. This further indicates the impact of the intervention and can be linked to the importance of interdisciplinarity and knowledge integration (Kalyuga & Sweller, 2004; Nordine et al., 2019; NRC, 2012), and, as other researchers have advocated (Darling-

Hammond et al., 2020), highlights the need to more effectively integrate science learning.

Generally, students find that the DCI maps of Weather and Climate, Models and Genetic Variation to be the most useful (Table 11). Chemical Reactions, Characteristics of Substances and Motions and Waves are perceived to be less useful (Table 11). Similarly, previous research has found that students construct their knowledge better around disciplinary core ideas related to Earth and Life Sciences (Cheung, 2015; Jamil & Mahmud, 2019; Article III). Disciplinary and interdisciplinary core idea maps enable students to feel more confident regarding the use of their knowledge and skills in science lessons. The research findings (Tables 11 and 15) are in line with previous research and indicate that constructivist science teaching leads to positive changes in student science performance (Holley & Park, 2020).

Teachers find this developed method (students expanding upon DCI and ICI maps) useful, as it enables collaboration with other educators, as well as raising students' awareness of DCIs and ICIs (Table 15). Researchers have also found that teachers recognise the importance of collaboration and support (Berebitsky & Salloum, 2017; Mowafaq et al., 2019). Research has shown that collaborative efforts with colleagues help teachers guide students to better understand the connections between different knowledge areas, something much appreciated by teachers (Davies & Delvin, 2010; Harlen et al., 2015). However, when science is divided into separate subject lessons, an emphasis needs to be placed on integrating the knowledge from each subject, thus promoting insight into the world, as well as demonstrating an understanding of DCIs and ICIs (Scott, 2017).

5.3.2. Students' self-efficacy change towards acquiring 21st century skills

The findings of this study, by the use of DCI and ICI maps, indicate that the students' self-efficacy impacts positively, on attainment in science lessons (Tables 16 and 18). This is an important finding, because previous studies have shown that the perceived abilities of students to apply 21st century skills differ significantly – for example, students' self-efficacy towards acquiring problem-solving skills is low (Article II; Evans et al., 2020; Wagner, 2010). There are a number of reasons for the low level of students' 21st century skills in science relating to their learning environment, among these being the way information is presented to the students (Scalise, 2016; Stehle et al., 2019).

The research findings show that change in two factors – the Changeability of scientific knowledge, and Responsible citizenship (Table 16 and 18) is not statistically significant. This may be because students experienced difficulties in interconnecting their skills with their knowledge (as is evident from the conducted mind mapping tasks) (Table 16). It can be reasoned that the intervention is unable to make a significant impact, because students do not have a clear understanding of how scientific knowledge is constructed through science lessons. As such, this is problematic, noting that these 21st century skills are essential for conceptualising and reflecting on solutions to today's problems, such as global warming, or environmental degradation (Chalkiadaki, 2018; OECD, 2016). In order to meet the numerous challenges that face today's society, such as the refugee crisis or the COVID-19 outbreak, an excellent background in science, as well as a good understanding of society, are considered essential (Evans et al., 2020; Krskova et al., 2020; OECD, 2019). The findings further indicate that students and teachers need to focus on the ways in which science and 21st century skills can address scientific challenges (Table 16).

After the conducted intervention, the findings show that the students' self-efficacy was significantly higher in the experimental group (compared to the control group) in the areas of Cognitive and problem-solving skills, Critical thinking, and Mindset for scientific research (Table 18). These findings can be explained by the fact that, during the intervention, the focus is on skills, for which, in prior studies, the students' self-efficacy was lower – e.g. problem-solving skills, critical thinking and a research mindset (Article IV). Students' perceptions of their own abilities improved as a result of the active promotion of these skills. The students' perception of self-efficacy is higher when they face Changeability of scientific knowledge and Responsible citizenship (Article IV), but these are not promoted as much during the intervention (Table 18). Since these skills are not a focus of the intervention, the findings show a positive change in the participants' perceptions of self-efficacy, but the change is not shown to be statistically significant.

In this study, students are found to have a higher level of self-efficacy after the intervention (Tables 16 and 18). It appears that including DCI and ICI maps serves the intended purpose of promoting 21st century skills, as perceived by students. In order to enhance the students' self-efficacy in 21st century skills, teachers have encouraged students to take an active role in their own learning (such as constructing mind maps reflecting core ideas). Thus, in line with previous research, the outcomes from this research suggest teachers need to be encouraged to make use of the appropriate teaching and learning methods to enhance students' participation in learning in order to enhance the 21st century skills of their students (Gillies et al., 2014; Kashefpakdel et al., 2021). As a result, students are better prepared for both higher education and the workplace (Chu et al., 2017; Laar et al., 2017; Salonen et al., 2017).

6. CONCLUSIONS, LIMITATIONS, AND IMPLICATIONS

6.1. Conclusions

In undertaking this study, three research questions were addressed:

1. *What is the students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills?*

The findings showed that:
- Students have high self-efficacy towards acquiring Earth Science-related disciplinary core ideas. The findings also indicated that students had a lower self-efficacy towards acquiring more abstract disciplinary core ideas related to Chemistry and Life Science factor, and Physics.
- The findings showed that students have high self-efficacy towards acquiring interdisciplinary core ideas, such as Models and Systems.
- Students' self-efficacy was found to be lower in relation to the problem-solving skills and critical thinking. A concern was raised since many challenging problems required strong problem-solving skills and critical thinking, which were also important to different careers.

2. *Which essential characteristics need to be included in deriving an intervention which promote students' meaningful learning?*

The findings showed that:
- The essential characteristics for to promote students' meaningful learning are: disciplinary and interdisciplinary core ideas, 21st century skills, dimensions of knowledge, knowledge integration (through mind mapping and concept mapping), and DCI and ICI maps.
- The creation of DCIs and ICIs are seen as important characteristics of supporting meaningful learning.
- In addition, 21st century skills are considered as important key characteristic for the meaningful learning. For example, critical thinking includes the ability to reason effectively, use systems thinking, make judgements and decisions, and solve problems. These help students to be more engaged in learning process.
- The findings indicated that more emphasis should be placed on ensuring that students do make sense of learned knowledge, thus making it easier for students to relate to different dimensions of knowledge and thus making learning more meaningful.
- Knowledge integration through mind mapping and concept mapping can make it easier for both teachers and students to relate different gained knowl-

edge and thus make the learning process more meaningful. Knowledge integration is useful for supporting students to interconnect their prior and new knowledge and thus to support their meaningful learning.
- Being able to expand upon DCI and ICI maps by drawing the interconnections between prior and new knowledge supports students' meaningful learning. DCI and ICI maps can be considered as the characteristics for supporting students' meaningful learning by knowledge integration.

3. *In what ways can changes in upper secondary school students' self-efficacy towards acquiring meaningful learning be enhanced by guiding and engaging students in deriving DCI and ICI maps?*

The findings showed that:
- Students' ability to expand DCI and ICI maps was seen as effective and supported their learning in Life Science, Earth Science, and Models and Systems. Students seemed to be able to recall what they had learned in these areas more easily.
- Students' self-efficacy changed in a positive way after the conducted intervention. Positive changes occurred in Life Science, Earth Science and with Models and Systems.
- The change in students' self-efficacy was not statistically significant, even though positive tendencies were found in Chemistry and Physics learning. According to the conducted research, meaningful learning does not take place throughout science education as a whole.
- Based on a comparison of the experimental and control group, it is conclusive that the intervention had a positive effect on students' self-efficacy.
- Students' and teachers' perceptions of the developed method for supporting students' meaningful learning were generally positive, based on the findings of the conducted interviews. Interviewees agreed that the DCI and ICI maps contributed to students' meaningful learning. The interview findings revealed that knowledge integration tasks (mind mapping, concept mapping) are effective in helping students to apply prior knowledge to new.

6.2. Limitations

The current thesis had several characteristics involving design or methodology that influenced the interpretation of the findings. The current thesis thus has the following limitations:
1. A small sample size of students and schools, included as a convenient sample, led to the findings of this study not being generalisable to the whole population. Also, there was insufficient power to detect differences in groups being compared. Further studies with a larger number of participants may provide more conclusive findings.

2. According to the research, students were asked to rate DCIs, ICIs, and 21st century skills on a 4-point Likert-type scale. A 4-point Likert-type scale was used as the smaller number of choices was easier for students to perceive. This provided an overview of how students expressed their opinion between the positive and negative side. However, there was no opportunity for students to indicate a neutral perspective. This forced the students to answer questions that they might be ignorant of or have a different understanding of based on personal perception.
3. Not all components of 21st century skills (e.g. ICT skills) and DCIs and ICIs (e.g. biological evolution) were measured in this study. This was not considered possible with paper-and pencil, large-scale tests.
4. With this study, students' responses to the conducted pre- and post-questionnaires could not be clarified at a later date (e.g., through interviews) because data collection was solely conducted using paper and pencil questionnaires. This made it hard to convey respondents' feelings and emotions. Moreover, it did not give an opportunity for the researcher follow up ideas and to clarify the issues.
5. Several items (such as the so-called soft skills e.g. collaboration and group work) were omitted from the final factorial structure, based on their low factor loadings in the different factors.
6. The questionnaire had several disadvantages that are considered as the limitations of this research such as unanswered questions and differences in understanding and interpretation. In addition, the questionnaire used a 4-point Likert-type scale and did not include any open-ended questions, which could have the advantage of offering a wide range of responses that help to capture students' answers.

6.3. Implications

This doctoral thesis has several scientific and practical implications regarding research in area of improving students' self-efficacy towards acquiring DCIs, ICIs and, 21st century skills to support students' meaningful learning.

6.3.1. Scientific implications

1. The meaningful learning and knowledge construction are strongly interconnected. Instructions and tasks to construct knowledge can help students develop and learn pathways to becoming expert learners whose conceptual frameworks are deeply interconnected. Such tasks where students can interconnect their prior and new knowledge can support their meaningful learning.
2. With the implemented intervention, which promoted students' meaningful learning, students' self-efficacy towards acquiring DCIs, ICIs, and 21st century skills was enhanced. The findings suggested that the developed intervention

and interconnection knowledge through mapping supported students' meaningful learning and is advantageous in science lessons. It can also be useful beyond science lessons, but further studies are needed as a student self-learning exercise. When students can perform tasks in their lessons which encourage them to interconnect their prior knowledge to the new knowledge it can support their knowledge construction and meaningful learning.
3. More emphasis is needed on exploring ways with which to integrate the different dimensions of knowledge, e.g. factual, conceptual and procedural as well as integrating students' prior and new knowledge. The utilisation of disciplinary and interdisciplinary core idea maps can be adopted as a major method to support students' meaningful learning.
4. Structuring science content around the validated progression of disciplinary and interdisciplinary core ideas supports students' meaningful learning. This provides evidence that the expansion of the DCI and ICI maps are useful and helpful for supporting students' knowledge integration and thus supporting their meaningful learning.

6.3.2. Practical implications

1. A recommendation from the current thesis is to promote disciplinary and interdisciplinary core ideas, which form a basis for interrelating the range of possible curriculum content. This can also be valuable for interrelating various conceptual components within subjects' syllabuses in science subjects, and for promoting knowledge integration between different science subjects. This can support interdisciplinarity between science subjects.
2. To prepare teachers for using DCI and ICI maps, these can play a meaningful role in sharpening a pre-service or in-service teachers' science content and thus enable teachers to guide students to conceptualise disciplinary and interdisciplinary core ideas in science along with how to promote their own teaching process.
3. Add the role of student construction of knowledge around DCI and ICI maps (such as by drawing mind maps and concept maps), purposeful promotion of meaningful learning and the improvement of students' self-efficacy is important for students.
4. The findings of such studies can be used to also further theorise the developmental use of disciplinary and interdisciplinary core idea maps and provide practical recommendations for curriculum design and classroom practices which further aim to enhance students' self-efficacy in science.

APPENDICES

Appendix 1. Summary of goodness fit indices for CFA model showing students' self-efficacy towards acquiring DCIs and ICIs using a 4-point Likert-type scale

Model fit indices	χ^2	df	p	RMSEA	CFI	TLI
4-factor model of students' self-efficacy towards acquiring DCIs and ICIs	607.32	246	<0.001	0.07	0.92	0.91

Appendix 2. Summary of goodness fit indices for CFA model showing students' self-efficacy towards acquiring 21st century skills models using a 4-point Likert-type scale

Model fit indices	χ^2	df	p	RMSEA	CFI	TLI
7-factor model of students' self-efficacy towards acquiring 21st century skills	867.91	443	<0.001	0.07	0.91	0.90

Appendix 3. Confirmatory factor analysis on students' self-efficacy towards acquiring DCIs and ICIs, for the experimental group (Article V)

Factors (reliability) and measured items	Factor loadings		M (SD)	M (SD)
	Pre	Post	Pre	Post
F1: DCIs related to Life Science (α = 0.72)				
Cell functions in tissues	0.43	0.65	2.51 (0.78)	3.32 (0.80)
Aerobic and anaerobic respiration	0.58	0.43	2.69 (0.68)	2.99 (0.88)
Heredity and DNA*	0.69	0.55	2.77 (0.83)	3.57 (0.83)
Genetic variation*	0.71	0.53	2.71 (0.73)	3.41 (0.79)
M	**0.60**	**0.54**	**2.67 (0.76)**	**3.32 (0.83)**
F2: DCIs related to Earth Science (α = 0.88)				
Rainforest deforestation	0.56	0.87	2.85 (0.91)	2.95 (0.80)
Land surface change*	0.62	0.59	2.60 (0.77)	3.00 (0.89)
Weather and climate*	0.59	0.70	2.82 (0.76)	3.12 (0.70)
Natural hazards	0.82	0.67	3.02 (0.68)	3.13 (0.65)
Climate warming	0.72	0.68	2.86 (0.83)	3.09 (0.83)
Solar and lunar eclipse	0.67	0.71	2.82 (0.80)	3.00 (0.87)
M	**0.66**	**0.70**	**2.83 (0.79)**	**3.05 (0.79)**
F3: DCIs related to Chemistry (α = 0.76)				
Chemical reactions*	0.55	0.47	2.43 (0.92)	2.51 (0.93)
Natural phenomena at the particulate level	0.72	0.67	2.40 (0.85)	2.49 (0.89)
The nature of interactions between bodies	0.56	0.69	2.46 (0.87)	2.50 (0.90)
Characteristics of substances*	0.65	0.56	2.44 (0.87)	2.54 (0.97)
M	**0.62**	**0.60**	**2.43 (0.88)**	**2.51 (0.92)**

Factors (reliability) and measured items	**Factor loadings**		**M (SD)**	**M (SD)**
	Pre	**Post**	**Pre**	**Post**
F4: DCIs related to Physics (α = 0.61)				
Electricity generator	0.72	0.69	2.40 (0.91)	2.40 (0.71)
Motions and waves*	0.67	0.82	2.36 (0.86)	2.56 (0.86)
Energy conversion*	0.65	0.59	2.37 (0.89)	2.47 (0.84)
M	**0.68**	**0.70**	**2.38 (0.89)**	**2.48 (0.80)**
F5: ICIs (α = 0.76)				
Systems*	0.72	0.73	2.37 (0.86)	3.25 (0.86)
Cause and effect	0.66	0.59	2.64 (0.82)	3.13 (0.86)
Natural and human-made systems	0.47	0.51	2.51 (0.85)	3.30 (0.95)
Structural properties of the objects	0.73	0.62	2.33 (0.87)	3.25 (0.87)
Models*	0.67	0.61	2.38 (0.85)	3.26 (0.85)
M	**0.65**	**0.61**	**2.45 (0.85)**	**3.24 (0.88)**

Note: *DCIs and ICIs used in the intervention research; measured using a 4-point scale; M–mean; SD–standard deviation.

Appendix 4. Summary of goodness fit indices for CFA models showing students' self-efficacy towards acquiring DCI and ICI models using a 4-point Likert-type scale, for the experimental group

Model fit indices	χ^2	**df**	**p**	**RMSEA**	**CFI**	**TLI**
5-factor model of students' self-efficacy towards acquiring DCIs and ICIs (pre-questionnaire)	657.85	416	<0.001	0.06	0.96	0.95
5-factor model of students' self-efficacy towards acquiring DCIs and ICIs (post-questionnaire)	758.23	416	<0.001	0.04	0.96	0.95

Appendix 5. Confirmatory factor analysis on students' self-efficacy towards acquiring DCIs and ICIs after the conducted intervention for experimental and control group (Article V)

Factors (reliability) and measured items	**Factor loadings**		**M (SD)**	**M (SD)**
	EG	**CG**	**EG**	**CG**
F1: DCIs related to Life Science (α = 0.63)				
Cell functions in tissues	0.51	0.46	3.32 (0.80)	2.85 (0.70)
Aerobic and anaerobic respiration	0.72	0.51	2.99 (0.88)	2.95 (0.64)
Heredity and DNA*	0.66	0.53	3.57 (0.83)	2.84 (0.66)
Genetic variation*	0.73	0.67	3.41 (0.79)	2.83 (0.63)
M	**0.66**	**0.54**	**3.32 (0.83)**	**2.87 (0.66)**
F2: DCIs related to Earth Science (α = 0.79)				
Rainforest deforestation	0.57	0.68	2.95 (0.80)	2.90 (0.73)
Land surface change*	0.71	0.62	3.00 (0.89)	2.50 (0.52)
Weather and climate*	0.61	0.66	3.12 (0.70)	2.30 (0.66)
Natural hazards	0.78	0.66	3.13 (0.65)	2.69 (0.65)
Climate warming	0.70	0.56	3.09 (0.83)	2.15 (0.57)
Solar and lunar eclipse	0.61	0.78	3.00 (0.87)	2.76 (0.60)
M	**0.66**	**0.66**	**3.05 (0.79)**	**2.55 (0.62)**
F3: DCIs related to Chemistry (α = 0.82)				
Chemical reactions*	0.72	0.56	2.51 (0.93)	2.38 (0.73)
Natural phenomena at the particulate level	0.66	0.58	2.49 (0.89)	2.43 (0.81)
The nature of interactions between bodies	0.78	0.71	2.50 (0.90)	2.40 (0.78)
Characteristics of substances*	0.65	0.65	2.54 (0.97)	2.37 (0.85)
M	**0.70**	**0.63**	**2.51 (0.92)**	**2.40 (0.79)**
F4: DCIs related to Physics (α = 0.61)				
Electricity generator	0.71	0.57	2.40 (0.71)	2.05 (0.59)
Motions and waves*	0.63	0.81	2.56 (0.86)	2.32 (0.59)
Energy conversion*	0.64	0.63	2.47 (0.84)	2.17 (0.60)
M	**0.66**	**0.67**	**2.48 (0.80)**	**2.18 (0.59)**
F5: ICIs (α = 0.73)				
Systems*	0.71	0.66	3.25 (0.86)	2.52 (0.60)
Cause and effect	0.63	0.54	3.13 (0.86)	2.65 (0.69)
Natural and human-made systems	0.51	0.55	3.30 (0.95)	2.05 (0.66)
Structural properties of the objects	0.70	0.72	3.25 (0.87)	2.25 (0.67)
Models*	0.60	0.63	3.26 (0.85)	2.30 (0.65)
M	**0.63**	**0.62**	**3.24 (0.88)**	**2.35 (0.65)**

Note: DCIs and ICIs used in the intervention research; measured using a 4-point scale; M–mean; SD–standard deviation.

Appendix 6. Confirmatory factor analysis on students' self-efficacy towards acquiring 21st century skills for the experimental group (Article IV)

Factors (reliability) and measured items	**Factor loadings**		**M (SD)**	**M (SD)**
	Pre	**Post**	**Pre**	**Post**
F1: Cognitive and problem-solving skills (α = 0.68)				
Creative thinking	0.71	0.89	2.93 (0.82)	3.33 (0.84)
Problem is within my level of understanding	0.66	0.65	2.62 (0.80)	3.57 (0.88)
Evaluating the efforts and effectiveness	0.71	0.65	2.93 (0.80)	3.52 (0.79)
Designing problem-solving strategies	0.68	0.49	2.67 (0.82)	2.95 (0.80)
Finding alternatives	0.66	0.81	2.79 (0.80)	2.99 (0.96)
Motivated to solve challenging problems	0.81	0.77	2.56 (0.81)	3.69 (0.69)
M	**0.71**	**0.71**	**2.75 (0.81)**	**3.34 (0.83)**
F2: Critical thinking (α = 0.76)				
Evaluating efforts of selected strategies after reaching the desired goal	0.72	0.75	3.02 (0.87)	3.13 (0.68)
Critical evaluation of information	0.66	0.68	2.90 (0.83)	3.90 (0.88)
Distinguish scientific evidence from non-scientific	0.59	0.82	3.00 (0.79)	3.65 (0.80)
Creativity and imagination	0.54	0.57	3.07 (0.82)	3.51 (0.75)
M	**0.63**	**0.71**	**3.00 (0.83)**	**3.55 (0.78)**
F3: The changeability of scientific knowledge (α = 0.68)				
Trying to understand the reasons for other people's actions	0.64	0.72	3.16 (0.88)	3.31 (0.90)
Showing respect to other peoples	0.76	0.66	3.12 (0.90)	3.45 (0.95)
Scientific knowledge can change	0.58	0.62	3.28 (0.82)	3.03 (0.90)
Explain natural phenomena	0.59	0.64	2.85 (0.83)	2.93 (0.86)
Usefulness of scientific knowledge	0.61	0.63	3.07 (0.79)	3.10 (0.88)
M	**0.64**	**0.65**	**3.10 (0.84)**	**3.16 (0.90)**
F4: Responsible citizenship (α = 0.72)				
Consequences towards natural environment	0.64	0.72	2.72 (0.89)	2.83 (0.85)
Responsibility towards what happens in the environment	0.76	0.66	3.03 (0.86)	3.03 (0.72)
Well-being is connected to what happens in nature	0.58	0.62	2.74 (0.90)	2.76 (0.83)
Contribute to protecting the natural environment	0.59	0.64	2.42 (0.82)	2.40 (0.82)
Ethical standards	0.61	0.63	2.66 (0.80)	2.64 (0.82)
M	**0.64**	**0.65**	**2.71 (0.85)**	**2.73 (0.81)**

Factors (reliability) and measured items	Factor loadings		M (SD)	M (SD)
	Pre	Post	Pre	Post
F5: Mindset for scientific research (α = 0.66)				
Scientific models portray nature	0.72	0.81	2.79 (0.83)	3.69 (0.90)
Carefully collected data gives perfect knowledge	0.76	0.59	2.95 (0.85)	3.99 (0.90)
One certain scientific method for creating scientific knowledge	0.62	0.58	2.89 (0.83)	3.57 (0.86)
Apply knowledge from science lessons	0.72	0.49	2.94 (0.81)	3.72 (0.87)
M	**0.71**	**0.62**	**2.89 (0.83)**	**3.74 (0.88)**

Note: Measured using a 4-point scale; M–mean; SD–standard deviation.

Appendix 7. Confirmatory factor analysis on students' self-efficacy towards acquiring 21st century skills for the experimental and control group (Article IV)

Factors (reliability) and measured items	Factor loadings		M (SD)	M (SD)
	EG	CG	EG	CG
F1: Cognitive and problem-solving skills (α = 0.81)				
Creative thinking	0.68	0.78	3.33 (0.84)	3.02 (0.75)
Problem is within my level of understanding	0.59	0.66	3.57 (0.88)	2.73 (0.84)
Evaluating the efforts and effectiveness	0.70	0.76	3.52 (0.79)	3.12 (0.68)
Designing problem-solving strategies	0.82	0.66	2.95 (0.80)	2.87 (0.78)
Finding alternatives	0.70	0.69	2.99 (0.96)	2.89 (0.92)
Motivated to solve challenging problems	0.81	0.77	3.69 (0.69)	3.16 (0.69)
M	**0.72**	**0.72**	**3.34 (0.83)**	**2.97 (0.78)**
F2: Critical thinking (α = 0.69)				
Evaluating efforts of selected strategies after reaching the desired goal	0.69	0.70	3.73 (0.68)	3.35 (0.77)
Critical evaluation of information	0.64	0.78	3.90 (0.88)	3.14 (0.75)
Distinguish scientific evidence from non-scientific	0.69	0.72	3.65 (0.80)	3.21 (0.70)
Creativity and imagination	0.55	0.62	3.91 (0.75)	3.87 (0.62)
M	**0.64**	**0.71**	**3.80 (0.78)**	**3.39 (0.71)**

Factors (reliability) and measured items	Factor loadings		M (SD)	M (SD)
	EG	**CG**	**EG**	**CG**
F3: The changeability of scientific knowledge (α = 0.70)				
Trying to understand the reasons for other peoples' actions	0.64	0.72	3.31 (0.90)	3.16 (0.82)
Showing respect to other peoples	0.72	0.66	3.45 (0.95)	3.23 (0.80)
Scientific knowledge can change	0.79	0.73	3.03 (0.90)	2.88 (0.91)
Explain natural phenomena	0.75	0.73	2.93 (0.86)	2.85 (0.67)
Usefulness of scientific knowledge	0.67	0.61	3.10 (0.88)	2.87 (0.72)
M	**0.71**	**0.69**	**3.16 (0.90)**	**3.00 (0.78)**
F4: Responsible citizenship (α = 0.83)				
Consequences towards natural environment	0.63	0.70	2.83 (0.85)	2.68 (0.79)
Responsibility towards what happens in the environment	0.73	0.65	3.03 (0.72)	2.65 (0.66)
Well-being is connected to what happens in nature	0.62	0.65	2.76 (0.83)	2.65 (0.92)
Contribute to protecting the natural environment	0.66	0.74	2.40 (0.82)	2.32 (0.88)
Ethical standards	0.72	0.64	2.64 (0.82)	2.67 (0.82)
M	**0.67**	**0.68**	**2.73 (0.81)**	**2.59 (0.81)**
F5: Mindset for scientific research (α = 0.71)				
Scientific models portray nature	0.81	0.77	3.89 (0.90)	3.67 (0.73)
Carefully collected data gives perfect knowledge	0.78	0.66	3.99 (0.90)	3.45 (0.88)
One certain scientific method for creating scientific knowledge	0.64	0.61	3.57 (0.86)	3.19 (0.87)
Apply knowledge from science lessons	0.73	0.55	3.97 (0.87)	3.94 (0.86)
M	**0.74**	**0.65**	**3.86 (0.88)**	**3.56 (0.84)**

Note: Measured using a 4-point scale; M–mean; SD–standard deviation.

SUMMARY IN ESTONIAN

Õpilaste enesetõhususe parandamine ainealaste ja aineüleste raamteemade ning 21. sajandi oskuste omandamisel loodusteaduste tähendusrikka õppimise edendamiseks

Kogu maailm vajab haritud inimesi, kellel on loodusteaduslik kompetentsus, et lahendada esile kerkinud probleeme nii teaduses, meditsiinis, poliitikas kui ka teistes olulistes valdkondades (Kober, 2015; OECD, 2019). Loodusteaduste õpetamisel on jätkuvalt probleemiks, et tundides pööratakse suurt tähelepanu ainesisu omandamisele, mitte eluks vajalike oskuste kujundamisele, mis on viinud selleni, et loodusteaduslikud õppeained on muutunud õpilaste jaoks vähem huvitavaks ning et õpilastel tekivad killustunud teadmised (Harlen jt, 2015, 2010). Ka varasemast uuringust „Loodusteaduslik kirjaoskus gümnaasiumiõpilaste karjäärivaliku mõjutajana (LoTeGüm)“ selgus, et gümnaasiumiõpingute jooksul kasvavad õpilaste aineteadmised, kuid oskus neid teadmisi rakendada probleemide lahendamisel ja otsuste tegemisel jääb tagasihoidlikuks või koguni ei muutu üldse. Seetõttu on oluline uurida viise, mis toetaks õpilaste tähenduslikku õppimist loodusainete valdkonnas. Õppimine on õpilasele tähenduslik siis, kui see kannab mingisugust püsivat muutust, mis on õppija igapäevaelus oluline ka pärast õpinguid (Ausubel, 1986; Heddy jt, 2017; Novak, 2010).

Doktoritöö eesmärk on välja selgitada raamteemade kaartide kui õpetamis- ja õppimisviisi kasutamise efektiivsus, mis hõlbustab loodusteaduste õppimise lõimimist ja aitab edendada õpilaste enesetõhusust tähendusliku õppimise suunas. Eesmärgist lähtudes on sõnastatud järgmised uurimisküsimused.

1. Milline on õpilaste enesetõhusus loodusteadustega seotud raamteemade ja 21. sajandi oskuste korral?
2. Millised komponendid on olulised sellise sekkumise väljatöötamisel, mis toetaks õpilaste tähenduslikku õppimist?
3. Kuivõrd muutub õpilaste enesetõhusus loodusteadustega seotud raamteemade ja 21. sajandi oskuste korral, kui toetada õpilaste tähenduslikku õppimist, kaasates neid raamteemade kaartide koostamisse?

Doktoritöös uuritakse gümnaasiumiõpilaste enesetõhusust raamteemade kasutamisel, sealhulgas 21. sajandi oskustega seoses. Bandura (1986) on defineerinud enesetõhusust kui inimese hinnangut oma võimetele teha ja korraldada vajalikke tegevuskäike eesmärgiga saavutada oodatud sooritustulemusi. Mitmed uuringud on näidanud, et õpilase kõrgem enesetõhusus aitab oluliselt kaasa soovitud õpitulemuste saavutamisele, kuna õpilasel on suurem usk oma suutlikkusse (Pajares, 1996; Schunk, 1991).

Doktoritöö fookuses on loodusteadustega seotud raamteemad, mida defineeritakse kui teemasid, mis on teaduse ja ühiskonna poolt hetkeliselt kokku lepitud ning mis on õpilasele olulised nii igapäevaelus kui ka tulevikus (Krajcik ja Delen, 2017; Semilarski jt, 2019). Sellised raamteemad on näiteks energia muundumine ja geneetiline mitmekesisus, mis moodustavad ühtse teadusliku raamistiku Eesti riiklikus õppekavas olevatele teemadele. Raamteemad on olulised loodusnähtuste (nt virmalised, vikerkaar, maavärin) või ka protsesside (nt fotosüntees, käärimine, hingamine) selgitamiseks ning mõistmiseks (Duncan jt, 2016). Samuti võimaldavad raamteemad eri valdkondadest pärit teadmisi või ainealaseid (distsiplinaarseid) ja interdistsiplinaarseid teadmisi seostada (Charles, 2005) ning seejuures toetada õpilaste sisukat õppimist ja teema mõistmist (Harlen jt, 2015). Peaks ju iga gümnaasiumiõpilase jaoks olema õppekavas toodu seostatud ja loogiline, olenemata sellest, millise karjääri ta tulevikus valib (Harlen jt, 2015, 10; Krajcik ja Delen, 2017; Semilarski jt, 2019).

Doktoritöös käsitletaksegi raamteemasid seostatuna Eesti riiklikus õppekavas oleva nelja loodusainega: bioloogia, geograafia, keemia ja füüsikaga. Lisaks raamteemadele uuritakse 21. sajandi oskusi, mis on defineeritud kui kogum teadmistest ja oskustest, mida läheb vaja nii igapäeva- kui ka tööelus, nt probleemilahendusoskus, kriitiline mõtlemine ning otsuste tegemise oskus (Binkley jt, 2012; van Laar, 2017).

Doktoritöö põhineb kolmel etapil, mis toetavad üksteist. Esimeses etapis koostati uurimisinstrument (küsimustik), mis seejärel valideeriti, kasutades nii eksperthinnangut kui ka uurivat ja kinnitavat faktoranalüüsi. Likerti tüüpi skaalal põhinevas küsimustikus paluti õpilastel hinnata oma enesetõhusust, vastates väidetele, mis olid seotud nii raamteemade kui ka 21. sajandi oskustega. Seega oli doktoritöö esimene etapp fookustatud hetkeolukorra kaardistamisele, mis oli koolides läbiviidava sekkumise planeerimiseks oluline (Semilarski jt, 2019; Soobard jt, 2018).

Esimese etapi tulemustest selgus, et uuringus osalenud gümnaasiumiõpilaste enesetõhusus geograafiaga seotud raamteemade korral on kõrge, kuid keemia, bioloogia ning füüsikaga seotud raamteemade korral kipub see pigem madalaks jääma. Seda saab põhjendada asjaoluga, geograafias on ainesisu rohkem seotud igapäevaeluga, kuid füüsikas ja keemias jääb ainesisu sageli õpilaste jaoks kaugeks ning abstraktseks (Cooper jt, 2017; Teppo jt, 2018). Seega on õpilastel raske leida seoseid, kuidas saaks keemias ja füüsikas õpitut rakendada igapäevaelulistes situatsioonides. Lisaks ilmnes, et õpilastel on madal enesetõhusus probleemide lahendamisel ning otsuse tegemisel. See on aga muret tekitav, sest 21. sajandi oskusi (sh kriitilist mõtlemist ja argumenteerimist) läheb vaja nii igapäevaelus kui ka ühiskonnas aset leidvate probleemide lahendamisel.

Doktoritöö esimese etapi üldise järeldusena saab välja tuua, et oluline on toetada õpilaste teadmiste ja ka oskuste arendamist ning seostamist, samuti loodusainetes õpitava põhjal tervikliku pildi loomist. Seega on tähtis välja töötada metoodika, mis toetaks õpilaste tähenduslikku õppimist loodusainete tundides. Ausubeli (1968) tähendusliku õppimise teooria kohaselt peab õppija tundma, et õpitu on tema jaoks loogiline ja see sobib tema olemasolevate uskumustega ja ootustega. Kõrgel tasemel tähenduslik õppimine saab toimuda siis, kui õppija eelteadmised on hästi struktureeritud ning õppija ise teadlikult otsustab, et ta seob uued teadmised olemasolevatega (Novak, 2010). Seetõttu on vaja loodusainete tundides toetada viisi, kuidas õpilased loovad interdistsiplinaarseid seoseid.

Doktoritöö teises etapis keskenduti sellise sekkumise väljatöötamisele, mis toetaks õpilaste tähenduslikku õppimist. Sekkumise väljatöötamisel lähtuti doktoritöö esimese etapi tulemustest ja järeldustest, lisaks viidi läbi uuring, milles õpilased koostasid mõttekaarte eri raamteemade kohta. Koostatud mõttekaarte analüüsiti lähtuvalt sellest, kuivõrd tõid õpilased välja Krathwohli (2002) liigitusele vastavaid teadmiste dimensioone. Uuringust selgus, et õpilased seostasid raamteemasid peamiselt faktiteadmistega (baasteadmised) ning vähem kontseptuaalsete (baasteadmistevahelised seosed) ja protseduuriliste teadmistega (teadmine, kuidas midagi teha). Nii hetkeolukorra kaardistamise (doktoritöö esimene etapp) kui ka õpilaste koostatud mõttekaartide analüüsi järelduste põhjal koostati sekkumise plaan, et toetada õpilaste tähenduslikku õppimist. Sekkumise väljatöötamisel arvestati alljärgnevate aspektidega:

- pakkuda teaduslikku raamistikku erinevatele Eesti riikliku õppekava teemadele ning pöörata tähelepanu distsiplinaarsetele ja interdistsiplinaarsetele raamteemadele (Krajcik ja Delen, 2017; Semilarski jt, 2019);
- koos teadmistega arendada õpilaste 21. sajandi oskusi, sh probleemilahendusoskus, kriitiline mõtlemine (Semilarski jt, 2019);
- panna senisest rohkem rõhku protseduurilistele ja kontseptuaalsetele teadmistele, mitte ainult arendada loodusainete tundides õpilaste faktiteadmisi. Õpilastel peaks olema erinevaid teadmisi, et nad oskaks neid ka igapäevaelus rakendada (Semilarski jt, 2021);
- toetada õpilasi, et nad saaksid oma varasemaid teadmisi seostada uutega ning kasutada selle protsessi visualiseerimiseks mõttekaardi (Buzan, 2009a) ja mõistekaardi metoodikat (Cañas ja Novak, 2018). Mõlemat metoodikat peetakse kontseptualiseerimise ja teadmiste loomise seisukohalt oluliseks (Bressington jt, 2018);
- töötada välja raamteemade kaardid ja rakendada neid loodusainete tundides. Raamteemade kaardid on metoodilised õppevahendid, millel on kujutatud, kuidas läbi eri kooliastmete kujuneb arusaamine loodusteadustes olulistest raamteemadest, pöörates seejuures tähelepanu nendega seotud teadmiste, 21. sajandi oskuste ning karjääriteadlikkuse arendamisele;
- toetada interdistsiplinaarsete seoste loomist, andes õpilastele ülesande raamteemade kaarte täiendada.

Doktoritöö kolmandas etapis viidi koolides läbi 1 aasta ja 8 kuud kestnud sekkumine, et toetada õpilaste tähendusrikast õppimist. Lähtudes eelmises etapis koostatud mudelist, koostati ja valideeriti esmalt koostöös valdkonna ekspertidega (loodusvaldkonna, pedagoogikavaldkonna ning koolikogemusega õpetajatega) kümme raamteemade kaarti, mis vastasid loodusvaldkonna ainekavades olevatele teemadele. Igale kaardile loodi vastav õpistsenaarium, et toetada õpilaste arusaamu loodusteadustega seotud olulistest teemadest ja oskustest. Raamteemade kaardid olid järgmised:

- bioloogiaga seotud raamteemad – geneetiline mitmekesisus ja pärilikkus (sh DNA);
- geograafiaga seotud raamteemad – pinnamoe kujunemine ja ilm/kliima;
- füüsikaga seotud raamteemad – lained ja energia muundumine;
- keemiaga seotud raamteemad – aine ehitus ja keemilised reaktsioonid;
- interdistsiplinaarsed raamteemad – mudelid ja süsteemid.

Koostatud kaardid baseerusid Ameerika Ühendriikide uutel hariduse standarditel (*next generation science standards*), mis on sisult ja tavadelt rikkad ning loodud sidusalt valdkondade ja klasside lõikes, et pakkuda kõikidele õpilastele kvaliteetset loodusharidust (AAAS, 2001; NGSS, 2012). Raamteemade kaardid on metoodilised õppevahendid, millel on kujutatud, kuidas läbi eri kooliastmete kujuneb õpilaste arusaamine loodusteadustes olulistest raamteemadest, samuti nendega seotud teadmistest ja oskustest. Need õppevahendid toetavad õpilaste tähenduslikku õppimist.

Järgmise tegevusena toimus õpetajate täiendkoolitus, milles osalenud õpetajad:
- kuulasid Tartu Ülikooli õppejõudude ettekandeid oma uurimisvaldkondadega seotud raamteemade kohta (nt kliimamuutuste ja vaktsineerimise teemal);
- said ülevaate raamteemadest ning nendega seonduvatest 21. sajandi oskustest;
- praktiseerisid raamteemade kaartide koostamist ning tegid interdistsiplinaarsete teemade õpetamisel koostööd eri õppeainete ja vanuseastmete õpetajatega;
- said oskuse rakendada mõtte- ja mõistekaardi metoodikat, et visualiseerida teadmisi ja luua interdistsiplinaarseid seoseid ning toetada seeläbi õpilaste tähenduslikku õppimist;
- said oskuse reflekteerida oma tegevust kaasaegse õpiprotsessi kavandamisel ning näha selle olulisust ühiskonnas;
- omandasid oskuse kujundada õpilaste teadlikkust loodusteadustega seotud karjäärivalikutest;
- omandasid ülevaate sellest, kuidas raamteemade kaarte oma õppetöösse integreerida ning kuidas õpilasi raamteemade kaartide täiendamisesse kaasata ja neid juhendada.

Pärast täiendkoolitust anti sekkumises osalenud koolide õpetajatele näidistunnikavad, mis sisaldasid kümmet raamteemade kaarti ning nendega seostuvaid õpistsenaariume. Õpetajaid teavitati, et kogu sekkumise ajal on oluline teha koostööd teiste sama kooli loodusainete õpetajatega, et õpilased saaksid raamteemade kaarte täiendada erinevates loodusainete (bioloogia, geograafia, füüsika ja keemia) tundides. Selline metoodika võimaldab toetada interdistsiplinaarsete seoste loomist nii, et õpilastel tekib terviklik pilt kooliaastate jooksul omandatud raamteemadest. 18 kuud kestnud sekkumise jooksul rakendati viies koolis nii raamteemade kaarte kui ka õpistsenaariume eesmärgiga toetada õpilaste tähenduslikku õppimist. Võrreldes varasemate uuringutega töötati uudsena välja raamteemade kaartide kasutamise metoodika loodusvaldkonna ainetundide tarbeks.

Õpilased pidid kogu sekkumisperioodi jooksul täitma kõik kümme raamteemade kaarti ning kandma kaartidele oma uued teadmised ja seostama neid oma varasemate teadmistega. Kogu sekkumisperioodi vältel toimusid sekkumise läbiviijate ja sekkumises osalenute vahel koosolekud, milles õpetajad jagasid oma kogemusi ning esitasid ka soovitusi ja ettepanekuid teistele õpetajatele.

Et mõõta sekkumise efektiivsust, lasti enne sekkumist koolides täita eelküsimustik ning pärast sekkumist ka järelküsimustik. Eel- ja järelküsimustikuna kasutati doktoritöö esimeses etapis koostatud ja valideeritud küsimustikku. Sellesse lisati mõned küsimused, näiteks selle kohta, kuivõrd efektiivseks pidasid õpilased tundides rakendatud raamteemade kaarte. Lisaks kaasati usaldusväärsemate tulemuste saamiseks uuringusse kontrollgrupp. Sekkumise lõpus viidi läbi intervjuud nii sekkumises osalenud õpetajate kui ka õpilastega. Samamoodi nagu sekkumisgrupp, koosnes ka kontrollgrupp viiest koolist, millel olid sarnased tunnused (sh sarnane asukoht, õpilaste arv, täiendkoolituses osalenud loodusainete õpetajate arv).

Sekkumise tulemusena tõusis õpilaste enesetõhusus nii geograafia ja bioloogiaga seotud kui ka interdistsiplinaarsete (nt mudelid, süsteemid) raamteemade korral. Füüsikas ja keemias oli õpilaste enesetõhusus raamteemade kasutamisel vähesel määral kõrgem. Sekkumise tulemusena tõusis õpilaste enesetõhusus ka 21. sajandi oskuste korral. Näiteks oli pärast sekkumist õpilaste enesetõhusus kõrgem kognitiivsete ja probleemilahendusoskuste, kriitilise mõtlemise ning ka teadusuuringute läbiviimise korral. Ka 21. sajandi faktorites vastutustundlik kodanik ning loodusteaduslike teadmiste muutuste osas oli õpilaste enesetõhusus suurenenud, kuid see muutus ei olnud statistiliselt oluline. Intervjuudes tõdesid õpilased, et sekkumine mõjutas oluliselt nende loodusainete tunde. Õpilaste hinnangul olid tunnid huvitavamad, kuna neil oli põnev raamteemade kaarte täiendada. Lisaks mainiti, et loodusainete õpetajate koostööd oli põnev jälgida. Õpilastele meeldis teha omavahel koostööd ning nende jaoks olid raamteemade kaardid kasulikud, kuna nad said oma uusi teadmisi varasematega seostada ning seeläbi õpitut paremini kinnistada.

Õpetajad tõid intervjuudes esile, et tundides rakendatud raamteemade kaartite meetod oli huvitav ning see võimaldas toetada õpilaste tähenduslikku õppimist. Lisaks leidsid õpetajad, et raamteemade kaardid aitasid neil kindlaks teha õpilaste väärarusaamu teatud teemade kohta. Sekkumises osalenud õpetajad olid seisukohal, et selliseid raamteemade kaarte võiks koostada veel rohkem ja neid sagedamini loodusainete tundides rakendada. Nii õpilased kui ka õpetajad tõid intervjuudes välja, et oma teadmiste konstrueerimine raamteemade kaartidel (teadmiste visualiseerimine mõttekaardi meetodit rakendades, õpistsenaariumite kasutamine, interdistsiplinaarsete seoste loomine) aitas õpilastel varasemaid teadmisi uutega paremini siduda.

Doktoritöö eesmärk oli koguda empiirilisi tõendeid selle kohta, kuidas raamteemade kaartide (sh teadmiste visualiseerimine, interdistsiplinaarsete seoste loomine) rakendamine loodusainete tundides võib edendada gümnaasiumiõpilaste tähenduslikku õppimist. Üldiselt peeti meetodit, mille raames täiendasid õpilased raamteemade kaarte, tõhusaks ja leiti, et see toetas õpilaste interdistsiplinaarsete seoste loomist nii bioloogia kui ka geograafia valdkonnas. Seda saab põhjendada asjaoluga, et nendes valdkondades oli õpilastel lihtsam meenutada varem õpitut, kuna raamteemad on rohkem igapäevaeluga seotud (nt kliima muutumine). Kuigi keemia ja füüsikaga seotud raamteemade korral leiti samuti positiivseid muutusi, ei olnud need õpilaste tajutavat enesetõhusust arvestades statistiliselt olulised. Et loodusainetes toimuks tähenduslik õppimine, on oluline, et kõikides loodusainetes oleks õpilaste enesetõhusus nii raamteemade kui ka 21. sajandi oskuste korral kõrge. Sekkumis- ja kontrollgrupi tulemuste võrdlus kinnitas, et koolides toimunud sekkumine suurendas õpilaste enesetõhusust.

Doktoritöö järelduste põhjal saab esitada mitmeid soovitusi, kuidas toetada õpilaste tähenduslikku õppimist.

- Tähenduslik õppimine ning teadmiste konstrueerimine on omavahel tugevalt seotud.
- Distsiplinaarsed ja interdistsiplinaarsed raamteemad moodustavad ühtse raamistiku Eesti riiklikus õppekavas nimetatud teemadele.
- Senisest rohkem tuleb tähelepanu pöörata õpilaste tähendusliku õppimise toetamisele, sh õpetamismetoodikale. Loodusainete tundides on soovitatav kasutada raamteemade kaarte (sh mõttekaardi koostamine, rühmatööd, õpistsenaariumid).
- On oluline luua viise kuidas lõimida erinevaid teadmiste dimensioone.
- Õpetajatele tuleks pakkuda täiendkoolitusi, milles käsitletaks, kuidas saab raamteemade kaarte loodusainete tundides rakendada.

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“There are two things in life for which we are never truly prepared: twins” – Josh Billings.

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Publikatsioonid:

Semilarski, H., Soobard, R., Rannikmäe, M. (accepted). Expanding disciplinary and interdisciplinary core idea maps by students to promote perceived self-efficacy in learning science. (accepted, *International Journal of STEM Education*).

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DISSERTATIONES PEDAGOGICAE SCIENTIARUM UNIVERSITATIS TARTUENSIS

1. **Miia Rannikmäe**. Operationalisation of Scientific and Technological Literacy in the Teaching of Science. Tartu, 2001.
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