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Maisa Mielikäinen

Towards a Digital Learning Ecosystem within a Community of Inquiry

Design-based Research in ICT Engineering Education

LAPIN YLIOPISTO
UNIVERSITY OF LAPLAND

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MAISA MIELIKÄINEN

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- Design-based Research in ICT Engineering Education

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ABSTRACT

Maisa Mielikäinen
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The increasing digitalisation of society has significantly transformed our learning methods and work processes. In the field of information and communication technology (ICT) engineering education, the emergence of new digital technologies and the industrial revolution have created a need to develop new pedagogical approaches that seamlessly integrate with industry methods and practices. This dissertation focuses on creating a design framework for a digital learning ecosystem and supporting design principles that integrate online learning with engineering education, taking into account both educational policy perspectives and the experiences and expectations of community stakeholders. In this research, stakeholders include students, industry representatives, instructors in ICT engineering education and personnel involved in research and development projects in the ICT unit. The research is situated in the context of ICT engineering education at Lapland University of Applied Sciences. This study aims to ensure the realisation of an engaging and meaningful digital learning ecosystem, providing students with the opportunity to acquire the necessary skills and knowledge to solve real-world problems and prepare for the digitising industry. The purpose of this design-based research (DBR) is to deepen our understanding of the design and implementation requirements and principles of ICT engineering education.

To achieve the research goals of this study, which addresses the main research question, '*What are the design principles and characteristics of a digital learning ecosystem that align with the needs of stakeholders and the policies in ICT engineering education?*', three sub-studies were conducted, each reported as a separate article. The first two sub-studies covered the first cycle of the DBR, and the third sub-study covered the second cycle. In the first sub-study, the thoughts and experiences of stakeholders within the current learning ecosystem of ICT engineering education were investigated. The qualitative research data consisted of interviews with students and web survey responses collected from instructors and industry representatives.

The results were analysed using content analysis. The second sub-study piloted project-based learning supported by a team collaboration platform in an integrated curriculum, utilising blended learning in the context of a community of inquiry (CoI). The students' experiences were assessed through a CoI survey, and the usage of the team collaboration platform was analysed based on server log data. The focus of the third sub-study was on students' experiences in a fully online environment, which were examined using the CoI instrument. The results of the CoI instrument in the second and third sub-studies were analysed using the Rasch rating scale analysis method. To gain a deeper understanding, the students were also asked to provide verbal accounts of their experiences and thoughts in the third sub-study. The results of each sub-study served as a basis for planning subsequent phases and interventions, supporting the progress of the DBR and enhancing the understanding of the topic.

As a result of this doctoral research, a design framework for a digital learning ecosystem is proposed for ICT engineering education. The framework is supported by the following design principles: *1) adoption of a team collaboration platform, 2) active participation of all stakeholders in collaboration, 3) creation of an ecosystem culture, 4) utilisation of blended learning methods, 5) establishment of an instructor team, 6) creation of an online resource pool, 7) application of project-based learning methods, and 8) utilisation of industry-specific methods and concepts.* These design principles can be further condensed into the characteristics of the design framework, which establishes a connection between the framework and the emerging ideologies of the present era. The characteristics of the framework include *1) cohesion, 2) collaboration, 3) sharing, 4) virtual, 5) integration, 6) tools, 7) problem-solving, and 8) technology*.

The results of this research, which combines the disciplines of engineering and educational sciences, have expanded the new knowledge of engineering education and generated a theoretically and empirically justified design framework for a digital learning ecosystem in ICT engineering education. This research is significant because it fills a gap in the international research landscape and provides a solid foundation for further discussions, research projects, and advancements in the global digital transformation. In addition, it promotes collaboration between higher education institutions and industry, enabling the exchange of knowledge and expertise in this rapidly evolving field.

Key words: Digital Learning Ecosystem, Community of Inquiry (CoI), Project-based Learning, Blended Learning, Design-based Research, Higher Education, Engineering Education

TIIVISTELMÄ

Maisa Mielikäinen
Kohti tutkivan yhteisön digitaalista oppimisen ekosysteemiä – Design-tutkimus ICT-alan insinöörikoulutuksessa
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Yhteiskunnan lisääntyvä digitalisaatio on muuttanut oppimistapojamme ja työskentelyämme merkittävästi. Tieto- ja viestintätekniikan insinöörikoulutuksen alalla uusien digitaalisten teknologioiden ilmaantuminen ja teollisuuden vallankumous ovat synnyttäneet tarpeen kehittää uusia pedagogisia lähestymistapoja, jotka integroituvat saumattomasti alan menetelmiin ja käytäntöihin. Tämä väitöskirja keskittyy digitaalisen oppimisen ekosysteemin suunnittelukehyksen sekä sitä tukevien suunnitteluperiaatteiden luomiseen, missä verkko-oppiminen integroidaan insinöörikoulutukseen huomioiden sekä koulutuspoliittiset näkökulmat että yhteisön sidosryhmien kokemukset ja odotukset. Sidosryhmiksi tässä tutkimuksessa käsitetään opiskelijoiden lisäksi teollisuuden edustajat, sekä ohjaajina tieto- ja viestintätekniikan insinöörikoulutuksen opettajat ja yksikön tutkimus- ja kehityshanketoiminnan henkilöstö. Tutkimus sijoittuu Lapin ammattikorkeakoulun tieto-ja viestintätekniikan insinöörikoulutukseen. Tutkimuksen tavoitteena on varmistaa opiskeluun sitouttavan ja mielenkiintoa ylläpitävän ekosysteemin toteutuminen, jotta opiskelijoille tarjoutuu mahdollisuus hankkia tarvittavat tiedot ja taidot todellisten ongelmien ratkaisemiseen sekä valmistautumiseen digitalisoituvaan elinkeinoelämään ja teollisuuteen. Design-tutkimuksen tarkoituksena on syventää tietämystä alan tekniikan koulutuksen suunnittelusta sekä toteutuksen vaatimuksista ja toimintaperiaatteista.

Tavoitteiden saavuttamiseksi päätutkimusongelmaa: *Mitkä ovat digitaalisen oppimisen ekosysteemin suunnitteluperiaatteet ja ominaisuudet, jotka vastaavat sidosryhmien tarpeisiin ja tieto- ja viestintätekniikan insinöörikoulutuksen linjauksiin sekä ohjaaviin asiakirjoihin?* lähestytään tässä tutkimuksessa kaikkiaan kolmen osatutkimuksen avulla, joista kukin on raportoitu omana artikkelinaan. Ensimmäiset kaksi osatutkimusta kattavat design-tutkimuksen ensimmäisen syklin ja kolmas osatutkimus kattaa toisen syklin. Ensimmäisessä osatutkimuksessa tutkittiin tieto- ja viestintätekniikan insinöörikoulutuksen sen hetkisen oppimisen ekosysteemin sidosryhmien ajatuksia ja kokemuksia. Laadullisen tutkimuksen aineisto koostui

opiskelijoiden haastatteluista sekä ohjaajilta että teollisuuden ja elinkeinoelämän edustajilta kerätyistä web-kyselyn vastauksista. Tulokset analysoitiin laadullisella sisällönanalyysilla. Toisessa osatutkimuksessa pilotoitiin tiimiyhteistyöalustaa hyödyntävää projektiperustaista oppimista integroidussa opetussuunnitelmassa, käyttäen sulautettua oppimista tutkivan yhteisön (Community of Inquiry, CoI) kontekstissa. Opiskelijoiden kokemuksia arvioitiin CoI-kyselytutkimuksella ja tiimityöalustan käyttöä analysoitiin palvelimen logitietojen perusteella. Kolmas osatutkimus keskittyi opiskelijoiden oppimiskokemuksiin verkossa hyödyntäen myös CoI-instrumenttia. Sekä toisen että kolmannen osatutkimuksen CoI-kyselyn vastausten analyysimenetelmänä oli Rasch Rating Scale Model -malli. Syvemmän ymmärryksen saavuttamiseksi kolmannessa osatutkimuksessa opiskelijoilta pyydettiin myös sanallisia kokemuksia ja ajatuksia. Kunkin osatutkimuksen tulokset muodostivat perustan seuraavien vaiheiden suunnittelulle ja interventioille, tukien design-tutkimuksen etenemistä ja syventäen ymmärrystä.

Tämän väitöstutkimuksen tuloksena ehdotetaan digitaalisen oppimisen ekosysteemin suunnittelukehystä tieto- ja viestintätekniikan insinöörikoulutukselle. Kehystä tukevat seuraavat suunnitteluperiaatteet: *1) tiimiyhteistyöalustan käyttöönotto, 2) kaikkien sidosryhmien aktiivinen osallistuminen yhteistyöhön, 3) ekosysteemin kulttuurin luominen, 4) sulautetun oppimisen hyödyntäminen, 5) ohjaajatiimin perustaminen, 6) online-resurssipoolin luominen, 7) projektiperustaisen oppimisen soveltaminen ja 8) toimialakohtaisten menetelmien ja konseptien hyödyntäminen*. Nämä suunnitteluperiaatteet voidaan edelleen tiivistää suunnittelukehyksen ominaisuuksiksi, joita ovat: *1) koheesio, 2) yhteistyö, 3) jakaminen, 4) virtuaalisuus, 5) integrointi, 6) työkalut, 7) ongelmanratkaisu ja 8) teknologia*.

Tämän insinööritieteitä ja kasvatustiedettä yhdistävän tutkimuksen tulokset ovat laajentaneet insinöörikoulutuksen tietämystä ja tuottaneet teoreettisesti ja empiirisesti perustellun uuden suunnittelukehyksen ICT-insinöörikoulutuksen digitaalisen oppimisen ekosysteemin suunnittelulle. Tämä tutkimus paikkaa aukon kansainvälisessä tutkimuskentässä ja luo vankan perustan jatkokeskusteluille, tutkimushankkeille ja edistysaskeleille globaalissa digitaalisessa muutoksessa. Lisäksi se edistää korkeakoulujen ja teollisuuden välistä yhteistyötä, mahdollistaen tiedon ja asiantuntemuksen vaihdon tällä nopeasti kehittyvällä alalla.

Avainsanat: Digitaalinen oppimisen ekosysteemi, Tutkiva yhteisö, Projektiperustainen oppiminen, Sulautettu oppiminen, Design-tutkimus, Korkeakoulutus, Insinöörikoulutus

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This dissertation has been more than a journey into academia. It has been a voyage that has taken me through thousands of research questions, applied theories and methodologies, observations, findings, results and discoveries. It has amazed me with its breadth and challenged me. It has also fueled my insatiable thirst for knowledge even further. The journey has demanded dedication and passion, carrying me forward through numerous difficulties and challenges, not least of which was balancing this dissertation process alongside my day job. The dilemma of time management has brought challenges, but it has also kept me constantly engaged and active. This experience has also led me to contemplate my future as a researcher and educator. Whether this journey has been a gateway to a career as a researcher or the summit of a long and rewarding career in the industry and engineering education, I am grateful for all the ups and downs of this journey and for the opportunity to delve so deeply into my topic.

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opposition seminar, which significantly contributed to the enhancement and refinement of this dissertation.

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I especially want to express my heartfelt gratitude to my esteemed research partner, my daughter, MSc. Essi Viippola. Her expertise in quantitative research, proficiency in R programming, and application of the Rasch model have been pivotal assets in advancing my research. I also thank Essi for her contribution to crafting linguistic expressions in English. Her language skills and ability to refine expressions have been invaluable, ensuring that the research findings are communicated clearly and effectively to an international audience. Essi has demonstrated researcher's criticality and fearlessly questioned various perspectives throughout the research process. Her skill in challenging thoughts and posing questions has been invaluable, enhancing the quality and depth of our research. Essi has excelled in applying the CoI model, known informally between us as the 'ketchup model', and its terminology and theory to our Rasch RSM analyses, bringing a fresh perspective to our research. Essi, thank you for your exceptional contribution to this research. Our journey together has been educational, inspiring, and filled with meaningful moments. I am proud of our research partnership and of being your mother!

Special recognition also goes to my research partner, my husband MSc. (Tech) Tauno Tepsa. His pedagogical expertise and solid engineering education have formed a strong foundation for our joint research journey. Tauno has demonstrated excellent pedagogical skills, and his ability to clarify even complex concepts clearly and understandably has been a valuable asset. His expertise in engineering education has brought depth to our research and provided a practical perspective on applications.

He has also been an unwavering source of support and encouragement throughout the dissertation project. He is not only a loving partner but also an important research collaborator, whose support and contribution have been invaluable. Thanks to his encouragement, ongoing support, ability to see possibilities, motivation, and positive energy, I have been able to approach my research work with confidence. You have played a crucial role, and our journey together in research, including literature reviews under the equatorial starry night or content analysis in the heat of a motor home, has been an enriching experience in every way.

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Rovaniemi, March 2024
Maisa Mielikäinen

List of Original Articles

The dissertation is based on the following original articles, which will be referred to in the text by their Roman numerals I to III.

Sub-study I
Mielikäinen, M. (2022). Towards blended learning: Stakeholders' perspectives on a project-based integrated curriculum in ICT engineering education. *Industry and Higher Education, 36*(1), 74–95.

Sub-study II
Mielikäinen, M., Viippola, E. & Tepsa, T. (2023). Experiences of a project-based blended learning approach in a community of inquiry from ICT engineering students at Lapland University of Applied Sciences in Finland. *E-Learning and Digital Media*. 20427530231164053.

Sub-study III
Mielikäinen, M. & Viippola, E. (2023). ICT engineering students' perceptions on project-based online learning in community of inquiry (CoI). *SAGE Open, 13*(3), 21582440231180602.

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List of Abbreviations

5G	Fifth-generation of mobile telecommunications technology
AI	Artificial intelligence
CoI	Community of Inquiry
DBR	Design-based research
DevOps	Development and operations: concept combining software and IT operations.
DLE	Digital learning ecosystem
ECTS	European Credit Transfer and Accumulation System: one credit corresponds to 25–30 hours of student work.
FTF	Face-to-face
Git	Open source distributed version control system
HE	Higher education
ICT	Information and communication technology
Industry X.0	Industry 4.0 or higher revision
IoT	Internet of Things
JSON	JavaScript Object Notation; open standard file format.
ML	Machine learning
MOOC	Massive open online course
OCW	Open course ware
OER	Open educational resource
PBL	Problem-based learning
PjBL	Project-based learning
RSM	Rating scale model
SDG	Sustainable development goals
STEM	Science, technology, engineering, mathematics
TCP	Team collaboration platform

Contents

1 INTRODUCTION

1.1 Background of the Study

The increasing digitalisation of society has brought about significant changes in the way we learn and work. In the field of engineering education in information and communication technology (ICT), the revolution of industry and the emergence of new digital technologies have led to a growing need for new pedagogical approaches that align with industry methods and practices. The integration of e-learning into engineering education has become increasingly important because it is crucial in terms of educational policy perspectives and the learning experiences of stakeholders within the community. Ensuring meaningful integration is particularly important, as it provides opportunities for students to acquire the necessary skills and knowledge to solve real-world problems, and to prepare them for the digitalised industry.

The present dissertation aims to contribute to ICT engineering education by developing a theoretical framework that includes design principles for a digital learning ecosystem (DLE). These principles are grounded in the national and international educational goals and policies, as well as in the needs and expectations of stakeholders, and aim to provide a foundation for the development of a DLE in the field of engineering education. Through a comprehensive examination of the current state of ICT engineering education and a thorough analysis of the perspectives of key stakeholders, this study seeks to identify the key design considerations that are essential for the successful implementation of a DLE. A comprehensive understanding of the characteristics and requirements of a project-based, integrated learning context characterised by complexity aims to be provided through a design-based research (DBR) approach (McKenney & Reeves, 2019). Henceforth, the term 'digital learning ecosystem' (Laanpere et al., 2014) will be used to cover pedagogical solutions and content, as well as industry-based methods, concepts, and tools, in addition to stakeholders and digital platforms. The community of inquiry (CoI) (Akyol & Garrison, 2008; Garrison, 2016; Garrison et al., 1999; Swan et al., 2009), as a theoretical framework, is one of the key concepts in this research, which emphasises the construction of meaning as a collaborative process in a digital environment. The main participants in the study were ICT engineering students from Lapland University of Applied Sciences (Lapland UAS) in Finland. In addition, the study seeks to understand the experiences and expectations of, e.g., the members of the ICT Advisory Board of Digital Solutions unit in Lapland UAS, the management, and the instructors (i.e. teachers and research and development (R&D) personnel). This study builds on previous research to deepen the understanding of higher education (HE), specifically engineering education, and its current state and prospects.

This study is situated within the context of engineering education, which endeavours to provide students with the scientific, technical, engineering, and mathematical (STEM) knowledge and related competencies necessary to solve challenges that improve the well-being of individuals and the environment. It is widely acknowledged that engineering education should adopt an interdisciplinary approach, with a shared focus on the application of STEM principles in the design, development, and integration of technical solutions. Jeganathan et al. (2018) defined engineering 'as the skill of applying scientific as well as mathematical principles to design, develop and operate, structures/machines/materials/systems/software, as well as maintaining them, to address a particular challenge for a particular purpose'. This approach allows for a more comprehensive and holistic understanding of the complex systems and challenges faced in the field of engineering, enabling students to effectively address and solve real-world problems. By integrating knowledge and skills from various disciplines, engineering education can better prepare students to be innovative and adaptable professionals who can effectively navigate the constantly evolving landscape of technological advancement. Engineering science is defined by the International Engineering Science Consortium as 'an interdisciplinary field bridging the gap between scientific theory and engineering applications with emphasis on the integration of mathematical, scientific, engineering, and art principles' (IESC, 2022). The engineering curriculum in HE is built on a foundation of technical competency of the underlying methodologies, theories, and mindsets, as well as soft skills, such as communication and teamwork. However, it is unrealistic to expect that the curriculum will fully encompass all current and future technologies, highlighting the importance of cultivating lifelong learning skills in engineering education (Gürdür Broo et al., 2022). Indeed, as summarised by Jeganathan et al. (2018), 'Engineering education is in a piquant situation where we have to make our graduates ready for future jobs that don't exist now, using technologies that have not come up, to solve problems we do not know are problems yet'. The multifaceted and constantly evolving nature of global challenges often requires a multi- or interdisciplinary approach to engineering education (K. L. Jackson et al., 2021) that is grounded in the practical application of knowledge and skills (Lakal et al., 2020; Nasibullov et al., 2015).

This study is related to several national and international educational goals. Currently, the need for communities and ecosystems is underlined in several international and national policy documents. According to UNESCO (United Nations Educational, Scientific and Cultural Organization, 2017b, p. 4), all education stakeholders are encouraged to join forces and share resources to create equitable, dynamic, responsible, and sustainable learner-centred digital learning ecosystems. The Qingdao Declaration, signed by representatives of over 90 member countries of UNESCO, outlines the full potential of ICT to contribute to the achievement of sustainable development goals (SDGs) (UNESCO, 2017a) with a focus on equality, access, quality and learning outcomes, including lifelong learning, over the period of 2015–2030 (UNESCO, 2015). The senior leaders of key Finnish organisations have also outlined the theme and vision of continuous and lifelong learning (Sitra, 2019). According to their statement, knowledge is produced in a new community of education systems, industry and informal networks, in which the level of knowledge and the combination of skills acquired in different ways are seen as challenges. Sitra (2022) conclude that future competence emerges in ecosystems. Educational institutions should work with business life to develop lifelong learning modules (OKM, Finnish Ministry of Education and Culture, 2018). The European Union's key policy message (European Commission & Directorate-General for Education, Youth, Sport and Culture, 2021, p. 18) states that systems should support the innovative and creative use of digital technologies, underpinned by strong pedagogical approaches. Finally, the European University Association (2021, p. 9) declares the university mission in 2030 in the innovation sector as follows:

'Europe's universities will make human-centred innovation their trademark, aiming to achieve sustainability through cooperative models. They will engage in co-creation of solutions with a wide range of partners and with the purpose of meeting common challenges and making a demonstrable difference to society through technological as well as social innovation. As such, universities will play a leading role in innovation ecosystems. They will bring together stakeholders around a common vision, bridging different cultures spanning from academia, business and start-ups, to civil society and the social and cultural scene. They will also reinforce their contribution to the development of knowledge and skills together with partners in the ecosystem.'

This research also has an interface at the national level with the Digivisio 2030 project launched by higher education institutions in Finland, which is led by the Ministry of Education and Culture. The project has three main objectives: creating a national digital service platform; creating guidance based on digital pedagogies, the learner's path, and shared data, and supporting HE institutions for change management (Digivisio, n.d.). Its goal is 'to create an internationally esteemed learning ecosystem that is initially based on Digivisio's digital services, the joint study offering of HE institutions, and interaction with companies and society. Data, education and competence circulate in the ecosystem.' The objectives set for the digital service platform are, among others, ensuring the compatibility of digital services between universities and lowering the threshold for utilising national solutions. The aim of guidance based on digital pedagogies, learner's paths, and shared data is, for example, to support studies regardless of time and place and in an accessible manner using artificial intelligence (AI) solutions as guidance aids. With the support of change management, the Digivisio 2030 project aims to achieve knowledge management models and the development of HE institutions into open communities. It is beneficial to anticipate these objectives and guidelines and enable their compatibility and usability in connection with the design principles developed in this design-based research.

The background of the research is influenced by the ongoing digital transformation in the industry, which means processes that leverage digital capabilities and technology to enable value-producing business models, operational processes and customer experiences (Morakanyane et al., 2017). HE must adapt to the transformation as new generations demand to change delivery methods and curriculum contents (Rodríguez-Abitia & Bribiesca-Correa, 2021). Transformation is causing social, industrial and technological change, culminating in the multidisciplinary concept of Industry 4.0 (Grabowska & Saniuk, 2022). Industry 4.0 comprises the implementation of real-time-data-based systems to develop smart solutions, including emerging technologies, such as the Internet of Things (IoT), advanced robotics and machine learning (ML). The comprehensiveness of the concept that encompasses machines, hardware, and software—from building business models through the production process to solution delivery (Suleiman et al., 2022)—provides the industry with more competitive and efficient ecosystems. In addition to higher quality, improved profitability and resilience to business environmental changes, digitalised processes in the industry enable knowledge-based management and decision-making to support continuous improvement. However, the utilisation of these new trends has posed new challenges to the industry. Engineers must be able to solve problems that did not exist before (Lara-Prieto & Flores-Garza, 2022). New trends require a high level of expertise (Han & Trimi, 2022), cyber security issues, and changes in working processes (Hallstedt et al., 2020), in which case HE, particularly engineering, must also adapt to these challenges. Universities also emphasise their role as innovation test beds in the development of future technologies (Pajpach et al., 2022).

The digital transformation that is currently taking place in both industry and higher education is significantly shaping the operating processes and delivery methods of work. In the profession of highly educated engineers, equipment often plays a significant role in work tasks, which may lead to low teleworkability, defined as 'the technical possibility of providing labour input remotely into a given economic process' (Sostero et al., 2020, p. 39). Fortunately, the COVID-19 pandemic has increased research, and, as a result, knowledge of teleworking and its dimensions have increased substantially. Teleworking is increasingly being used as a strategy to address labour force and skills shortages (Soroui, 2021). However, teleworking is not in itself a challenge for organisations or software developers, as noted by Russo et al. (2021), but resolving cooperation with technology alone is not enough (Hogarth, 2010, p. 2). Indeed, there are certain engineering competencies that are difficult to learn online due to their low teleworkability, such as complex and laboratory-based activities that require students to obtain equipment, materials and instruments or have them delivered by the university when attempted remotely. Remote and virtual laboratories, as well as remote guidance, may eliminate the need for on-site exercises. The pandemic has likely accelerated this shift towards online or blended work due to personal and travel restrictions. Unfortunately, the transition of learning partially or even completely away from laboratories and contact teaching does not always go smoothly (Jo & Jo, 2020), and transferring courses to an online environment requires many infrastructures (Long, 2020). However, there are indications that the employability of graduates in online programmes will be as good or even higher than that of graduates in onsite groups (Long, 2020). The pandemic has also accelerated the introduction of online and blended learning at all levels of education. Moreover, learning in an online environment can also be seen as a solution to support lifelong learning (Ghanem, 2020; Troussas & Sgouropoulou, 2020, p. 3).

This study aims to develop the design principles for a digital learning ecosystem. A DLE is a complex network of interconnected elements that support and facilitate the process of learning and knowledge acquisition. It is characterised as an interactive socio-technical system (Laanpere et al., 2014) that includes a range of pedagogical approaches, social actors, digital tools, learning content, and resources. This type of DLE is designed to support learners in constructing knowledge and developing a sense of communality (Virolainen et al., 2019). It has been argued that a DLE is effective in improving organisational effectiveness by connecting and supporting people with different resources and teaching strategies (Malloch et al., 2021, p. 313). To engage, inspire and motivate action, meaningfulness is sought, and the learner is given ownership of his or her education. Digital ecosystems (Laitinen-Väänänen et al., 2020) serve to improve learning by creating a cohesive body of knowledge that results in both hard skills that go deep into the subject matter and soft skills that prepare for working life as a community. It is important to note that the design of a DLE can have a significant effect on the success or failure of the learning process. If the ecosystem is inadequately designed or fails to align with the needs and characteristics of the learners, it can have detrimental effects on student engagement and motivation, potentially leading to complete disengagement from the learning process (Virolainen et al., 2019). Therefore, it is crucial to carefully consider the design of a DLE to promote student success and engagement.

Higher education is currently undergoing a paradigm shift, which is driven by a variety of factors, including advances in technology, changes in the job market, and shifts in the expectations of students and employers. It is also influenced by the recognition that HE plays a vital role in the development of a knowledgeable and skilled workforce and in the overall advancement of society. Indeed, not only engineering education but also the entire education system can be considered to be in the midst of a paradigm shift, moving from traditional teacher-centred methods to student-centred approaches (Graham, 2018; Shpeizer, 2019). Some of the key features of this shift include an increased focus on critical thinking, problem-solving, and collaboration, as well as the use of technology and online learning to enhance the learning experience. From the perspective of a learning ecosystem, solving complex problems requires a multidisciplinary team of experts, and thus necessitating a flexible curriculum (Laitinen-Väänänen et al., 2020). According to Kolmos et al. (2016), there is a systemic choice to be made regarding the curriculum: either to adapt the current practice or to maintain it while incorporating additional options that are closely linked to the core curriculum. Combinations of learning modalities, such as face-to-face (FTF), blended and online learning, allow for methodological flexibility in modern engineering education (Ralph et al., 2022).

Learning that takes place throughout a person's life and forms his or her unique identity. It is affected by a continuous process in which new knowledge and skills are acquired throughout life and applied at the individual, group and organisational levels. The use of digital technologies and distance connections and the development of the idea of continuous learning in education policy, are blurring the boundaries between formal and informal learning processes in education, work and everyday life (Laitinen-Väänänen et al., 2020). There has also been an active discussion about the meanings and differences and definitions between the concepts of lifewide and lifelong learning (Kinnari, 2020, pp. 112–115). For example, according to Jarvis (2015), lifelong learning is an essential part of the process of living, which he defines as a combination of processes throughout a lifetime of integrating social experiences into a person's biography, resulting in a continually changing person. By contrast, for example, Reischman (2017) suggested that lifelong learning is related to learning in formal education, while lifewide learning would be learning that takes place throughout life, forming one's unique personality and identity. Lifedeep learning has been added to the spectrum of concepts, which means insights and discernments that increase our awareness and understanding of the wider world beyond our immediate environment (Longworth, 2003, p. 46). Furthermore, the term 'continuous learning', according to Sessa and London (Sessa & London, 2015, pp. 10–12), refers to the ongoing process of acquiring and applying deeper and broader knowledge and skills, individually and at the group and organisational levels, through learning new disciplines, expanding expertise and reflecting on processes and outcomes, to adapt to changing conditions and create increasingly sophisticated systems. Conversely, according to Laitinen-Väänänen et al. (2020), continuous learning refers to a combination of lifelong learning and lifewide learning, merging the horizontal perspective of lifelong learning (i.e. learning throughout life) and the vertical perspectives of lifewide learning (i.e., learning in different contexts of life). Continuous learning can also be seen mainly as serving the skills needed by the labour market (Sitra, 2020).

The COVID-19 pandemic has had a significant impact on education and learning around the world. Many educational institutions have had to shift to distance learning using online platforms and other technologies to deliver course content and facilitate student learning. This means that students have had to adapt to a new way of learning, and that they may have had to overcome challenges, such as technical difficulties, limited access to resources, and the lack of in-person interaction with instructors and other students. Some of these practices persisted in educational institutions after the pandemic. This may be referred to as the 'new normal', which represents a shift in the way that education is delivered and experienced. Students may have different expectations for post-pandemic learning, depending on their individual experiences and needs. Some students may be eager to return to in-person learning and the sense of community that it provides, while others may prefer the flexibility and convenience of distance learning. Educators must consider the needs and preferences of their students as they envision the future of learning.

1.2 The Aim, Outline, and Process of the Study

In the field of ICT engineering education, the emergence of new digital technologies and industrial revolution have created a need to develop new pedagogical approaches that seamlessly integrate with industry methods and practices. The primary aim of this dissertation is to explore the characteristics and principles for designing a DLE for ICT engineering education and develop the design framework for the DLE for conducting engineering education in a way that supports the industry-based emergent methods and practices as well as educational policies. This study was conducted at the Lapland UAS in Finland using a design-based research (DBR) approach. In addition to students, the stakeholders involved in the study encompassed industry representatives, R&D personnel and instructors within the Digital Solutions unit at the Lapland UAS.

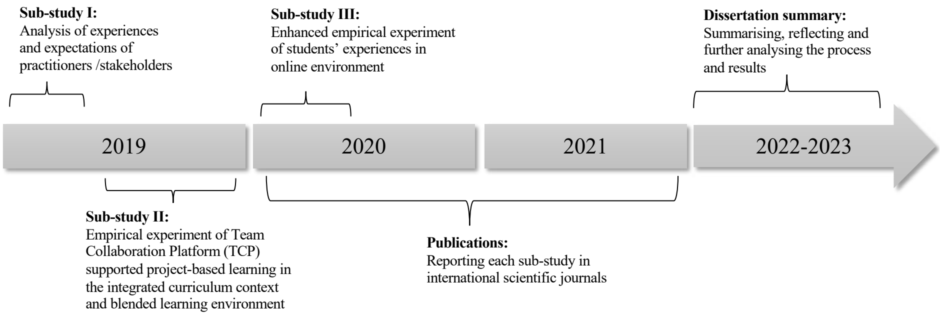
The specific aims of the present study are as follows:

1. To define the design framework and accompanying design principles for an intervention for a DLE for ICT engineering education.
2. To create knowledge from previous research on the characteristics of the ICT engineering education design by combining the perspectives of engineering and pedagogy.
3. To explore the requirements and policies for conducting ICT engineering education.
4. To explore the learning experiences of stakeholders in practical interventions.

The study was conducted in the Digital Solutions unit at the Lapland UAS due to the researcher's role as a senior lecturer and team leader. In addition to implementing ICT engineering education, the unit is also responsible for conducting R&D projects in various areas of ICT, including but not limited to web, mobile, and game development, AI, robotics and IoT. The Lapland UAS has strong collaboration with education and R&D activities, which have also been recognised in the institution's quality audit (KARVI, 2017). This dissertation process started in 2019, with three sub-studies and a summary. The research timeline is depicted in Figure 1.

Figure 1

The Research Process



In the spring semester of 2019, sub-study I of this DBR study was conducted to understand the general requirements of engineering education and the perspectives of various stakeholders, including ICT engineering students at the Lapland UAS, instructors, R&D personnel and members of the ICT advisory board. The following fall semester of 2019, sub-study II examined students' project-based learning (PjBL) experiences in a blended learning approach, in an online and FTF learning environment, including the use of a team collaboration platform (TCP). In spring 2020, sub-study III mapped students' experiences with integrated PjBL in an online setting. The results of these sub-studies were written for international scientific journals in 2020 and 2021. Sub-study I was published in 2022, while sub-studies II and III were published in 2023. The dissertation summary was completed between 2022 and 2023.

After the research background, rationale and research process, Chapter 2 presents the key concepts and theoretical framework of the research and provides a literature review of empirical research related to the topic is presented. Chapter 3 presents the research questions. Chapter 4 discusses the research methodology and a summary of the results of the three sub-studies related to this dissertation. Chapter 5 summarises the design requirements based on the sub-studies and the synthesised design principles developed for the DLE, ending with a visual representation of the design framework of the DLE. Finally, Chapter 6 discusses the evaluation of the ethical and methodological aspects of the study and makes suggestions for future research.

2 KEY CONCEPTS AND THEORETICAL FRAMEWORK

In this chapter, key concepts and a theoretical framework for a digital learning ecosystem in engineering education are introduced. Engineering education in the present era necessitates the establishment of a DLE. Digital learning platforms facilitate seamless collaboration and interaction, fostering a sense of community and knowledge sharing across temporal and spatial boundaries. Leveraging diverse learning materials empowers learners with autonomy in their educational journeys. By embracing a DLE, engineering education can effectively adapt to the evolving needs of working life and prepare learners for the challenges of the digital age. Nguyen and Tuamsuk (2022) found that policy, procedures, technologies, stakeholder capabilities and learning content played a key role in the development of DLEs. Bass and Eynon (2017) proposed four key principles for an emerging digital ecosystem: learner centred to support learner ownership; networked connections between internal and external actors; integrative, intentional and coherent integration of tools for learning, tracking data, and immediate and targeted feedback; and implementation of more agile learning and design cycles, continuous improvement and continuous learning. In this study, the principle of learner-centredness affects the pedagogical methods used. The principle of networking is achieved by involving both internal and external actors in the selection of stakeholders. The integrative approach encompasses not only digital tools and platforms but also the chosen pedagogical approach. By incorporating industry methods and concepts into the development of products, services and processes, the principle of agility is attained, thereby fostering a culture of continuous learning in tandem with pedagogical solutions. As stated above, a DLE in engineering education is also significantly influenced by national and international policies. Consequently, the aspects of a DLE can thus be categorized as follows (Figure 2): 1) industry-specific methods and concepts, 2) pedagogical approaches and 3) digital resources, including learning support materials as well as collaboration tools and platforms, with the student at the centre and interacting with other stakeholders.

Figure 2

Aspects of the Digital Learning Ecosystem (DLE) in Engineering Education

The etymological background of an ecosystem can be found in the term 'ecology' itself, which is the study of the relationships and interactions between organisms and the environment (Virolainen et al., 2019). The idea of learning ecosystems was introduced in the context of the ecological systems theory developed by Bronfenbrenner (1979), in which human learning, development, and socialisation as members of communities and society are perceived as nested and expanding circles. Bronfenbrenner defined circles as micro- (interaction of individuals), meso- (interaction with close microsystems), exo- (indirect interaction with other formal and informal social structures and microsystems), macro- (cultural affects), and chronosystems (lifetime affects) (Guy-Evans, 2020; Virolainen et al., 2019). Laitinen-Väänänen et al. (2020) argued that the thinking model of ecological systems theory is also suitable for describing work-related HE as systems of nested frames centred on the student. According to Laitinen-Väänänen et al. (2020), the term 'learning ecosystem' can refer to formal, non-formal and informal learning opportunities. In formal learning opportunities, learning takes place in situations and environments for that purpose, such as universities (Laitinen-Väänänen et al., 2020). Conversely, non-formal learning occurs in settings in which learning is not the primary goal, such as the workplace. For Laitinen-Väänänen et al. (2020), informal learning takes place in everyday life, often unconsciously and unintentionally. Furthermore, Laitinen-Väänänen et al. (2020) categorise the learning ecosystem into three distinct perspectives: innovation, business and digital. An innovation ecosystem refers to the collaborative efforts of local actors in the development of innovative business ventures (Hautamäki & Oksanen, 2012, p. 6), while a business ecosystem refers to the economic community (Moore, 2006). Laitinen-Väänänen et al. (2020, p. 87) define a digital ecosystem as 'a self-organising, scalable and permanent system of actors using digital technologies and their interrelationship that benefits the system as a whole and its individual actors'[1].

With a digital learning ecosystem, the possibilities for collecting and delivering materials, interaction, evaluation, and learning analytics can improve (Laitinen-Väänänen et al., 2020). Some studies have discussed the topic of a digital ecosystem or a DLE in HE, for example, from the viewpoint of interactive tools (Meepung et al., 2021), developing the competence of teachers (Lameras & Moumoutzis, 2021; Valjataga et al., 2020), open source learning resources (Lane & Goode, 2021), liberal education (Bass & Eynon, 2017), virtual mobility (Wolff et al., 2021), effectiveness and safety of interaction (Protasenko & Ivashura, 2022) and supporting individual programming courses (Sastre-Merino et al., 2022). It should be noted that the concepts of a digital ecosystem and a DLE seem to be synonymously used in the educational context in the literature, as has been done in the sub-studies related to this dissertation, mainly in sub-study I.

In this dissertation, the digital learning ecosystem thus refers to a comprehensive system and community of learning, where industry-specific methods and concepts, pedagogical approach, and digital resources as depicted in Figure 2 converge. At the core of this system is the student as a learner, who interacts with other stakeholders, aiming to enhance learning and competence development. Furthermore, Laitinen-Väänänen et al.'s (2020) digital learning ecosystem definition as an actor system from the perspective of this study can correspond to a community that aims to achieve mutual interaction and benefits for each stakeholder of the DLE through the integration of digital technology as described in the definition. While Bronfenbrenner's (1979) ecological systems theory emphasizing individual interaction with their environment at different levels, the DLE described in this study focuses on examining the comprehensive design and implementation of learning in a digital and collaborative learning environment. When reflecting the concept of the DLE through the lens of Bronfenbrenner's (1979) theory, the microsystem can be seen as the project team formed by students, supported by industry representatives

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1 [1] Translated by the author from the following original Finnish text by Laitinen-Väänänen et al. (2020, p. 87): 'Digitaalisella ekosysteemillä tarkoitetaan digitaalisia teknisiä ratkaisuja hyödyntävistä toimijoista koostuvaa itseorganisoituvaa, skaalautuvaa ja pysyvää järjestelmää sekä heidän keskinäistä suhdettaan, josta hyötyy koko järjestelmä ja sen yksittäiset toimijat.'

and instructors. The mesosystem encompasses close microsystems, such as other students' project teams, and national and international policies can be viewed as the exosystem. Cultural influences that affect the design, implementation, and outcomes of educational systems, such as cultural norms, values, beliefs, and practices, including industry-specific business and operational cultures, could be situated at the periphery of the macrosystem circle. In this study, however, the system levels are only superficially and randomly addressed, and a more in-depth examination of them in relation to Bronfenbrenner's theory exceeds the scope of this research.

The following sections examine the three key aspects, shown in Figure 2: industry-based methods and concepts, pedagogical approaches and digital resources, that influence the design of a DLE. Each aspect is addressed in detail, including its associated key concepts and principles. Previous empirical research is utilised to address the research question.

2.1 Industry-based Methods and Concepts

New graduating engineers must be able to move from technology to solutions and further to operations, that require extensive expertise (Gürdür Broo et al., 2022). The industry's new technologies brought about by Industry 4.0 (Grabowska & Saniuk, 2022) are becoming more widespread and systems are becoming increasingly complex. Their successful implementation requires the integration of all aspects of engineering education (Mills & Treagust, 2003). Graduating engineers should familiarise themselves with and commit to the United Nations' sustainable development goals (UNESCO, 2017a) during their study period to address the challenges and opportunities presented by these goals and contribute to a more sustainable and equitable world, such as efforts to end poverty, protect the planet, and ensure peace and prosperity for all people. The internalisation of a lifelong learning paradigm ensures an approach to the acquisition of new knowledge and skills. The industry's approach is largely project-like. The adoption of agile development and development and operations (DevOps) (Ebert et al., 2016; Ebert & Hochstein, 2023) practices, such as automation, monitoring, and continuous delivery, has allowed the industry to adopt a more efficient approach. DevOps aims to improve collaboration and communication between the teams involved in development and production, enabling organisations to deliver high-quality software effectively. Previous elements should be included in the curriculum, preferably in collaboration with industry, in the form of authentic (McDermott et al., 2017) problems and solutions in authentic project-based learning (Rees Lewis et al., 2019). In PjBL, students learn by actively working on a project that requires them to apply their knowledge and skills to solve a complex problem. Considering these emerging trends is essential to the design of each iterative cycle of this DBR. Endeavours should be undertaken to enhance collaboration between industry and education. Furthermore, the shift towards a digital learning ecosystem is undoubtedly necessary, but it is of equal significance to uphold the social aspect of learning and sustain conducive conditions for effective individual learning and fostering positive learning experiences.

2.1.1 Industry 4.0

The concept of Industry 4.0 brings a challenging context to engineering education, which also requires a change in the educational paradigm. Engineering education must adapt the contents of the curriculum to meet new technological requirements and understand the multidisciplinary approach of the concept, provide students with practical exercises simulating these technological environments and collaborate with the industry, which also needs to be considered in the design principles of the digital learning ecosystem. Today's industry has already largely adapted to change. Technological advancements are transforming our operations, enabling the production of new digital and intelligent systems and services that were previously unattainable.

A generally accepted definition of the Industry 4.0 concept is not quite unambiguous (Culot et al., 2020; Rupp et al., 2021), and synonyms such as 'smart manufacturing', 'digital transformation' and 'fourth industrial revolution' are also used (Culot et al., 2020). Rupp et al. (2021, p. 12) suggested the following definition: 'Industry 4.0 is the implementation of Cyber-Physical Systems for creating Smart Factories by using the Internet of Things, Big Data, Cloud Computing, Artificial Intelligence, and Communication Technologies for Information and Communication in Real Time over the Value Chain.' The concept related to the four industrial revolutions can be roughly summarised as different eras of industrialisation, known as Industry 1.0 to Industry 4.0 (Ciulli, 2019). Industry 1.0, known as the 'age of steam' (Xu et al., 2018), occurred in the 1700s and involved the adoption of steam engines and waterpower in industrial production. Industry 2.0 marked the 'age of electricity' (Xu et al., 2018) during the late 1800s and early 1900s, when electricity, mass production and the development of the steel industry transformed industrial production. In the mid-1900s, Industry 3.0, known as the 'information age' (Xu et al., 2018) or 'digital revolution', introduced computers and electronics. In the 21st century, the fourth industrial revolution, Industry 4.0, or the 'age of cyber-physical systems' (Xu et al., 2018), enabled the digitalisation and integration of industry into a smart network. The concept is commonly traced back to its presentation at the Hannover Fair in Germany in 2011 by the Research Union Economy–Science Working Group of the German Ministry of Education and Research. However, Culot (2020) noted that the concept-like thinking emerged around the same time in the early 2010s in various other contexts, including the US Advanced Manufacturing Partnership, the European Factories of the Future Programme, and the white papers published by consulting firms and major technology vendors. We are currently living in the era of

Industry 4.0, but the demand for socio-economic factors to be taken into account in technological development can lead to a new industrial revolution, as Industry 5.0 complements and extends the hallmark features of Industry 4.0, emphasizing human-centricity, sustainability and resilience (Wang, 2022).

Culot et al. (2020) conducted a comprehensive review of 100 academic and non-academic papers, identifying the key enabling technologies in Industry 4.0. These technologies, based on their frequency of occurrence, include the IoT, cyber-physical systems, cloud computing, big data analytics, ML, AI, interoperability and cyber security systems, visualisation technologies, three-dimensional (3D) printing and advanced robotics. The Industry 4.0 concept makes effects and competence requirements more comprehensive, including not only key technologies but also, for instance, ecological, economic, and social aspects (García-Muiña et al., 2021; Nara et al., 2021). As several paradigm shifts in education and the ICT revolution intensified, it was found that not everything new could be included in the curriculum, in which concepts such as 'lifelong learning' and 'learning-by-doing' also became more common (Gürdür Broo et al., 2022). Moreover, the integration and synergies of sustainable development and Industry 4.0 come to the fore from the industry and research perspectives (e.g., Lupi et al., 2022; Machado et al., 2020).

In recent years, there have been a large number of articles on Industry 4.0 in education (Coşkun et al., 2019). The PjBL approach has often been used in engineering education related to Industry 4.0 technologies (e.g. Benis et al., 2021; K. Gupta et al., 2019; Simons et al., 2017). PjBL is a student-centred approach (Gubacs, 2004; Shpeizer, 2019; Uziak, 2016) that involves the hands-on exploration of real-world problems and challenges, emphasising critical thinking, and problem-solving. The PjBL approach is discussed in more detail below in connection with pedagogical approaches. Coskun et al. (2019) presented a roadmap for the changes and enhancements in the areas of curriculum development, lab concept and student club activities when adapting education to Industry 4.0. In addition to Industry 4.0, the concept of Education 4.0 (Kunnari et al., 2021) has emerged, which not only incorporates Industry 4.0 technologies but also symbiotic relations between education actors (Mogoş et al., 2018). Ramírez-Montoya et al. (2022) proposed a framework based on the five core components of Education 4.0: 1) competencies, 2) teaching–learning methods by incorporating new active learning methods and modalities (e.g. FTF learning, hybrid learning, and distance learning), 3) stakeholders, 4) technologies and 5) infrastructure (e.g. services, platforms and facilities). These components are also central to the design of a digital learning ecosystem.

2.1.2 Sustainable Development Goals (SDG)

According to UNESCO (2017a), education systems should align with the needs of SDGs by establishing pertinent learning objectives, learning contents, pedagogy and management strategies containing sustainability principles, which should also be considered in the design principles of digital learning ecosystem. SDGs encompass 17 goals aimed at fostering a sustainable, peaceful, prosperous and just life on earth for now and in the future. The targets address social needs, such as education, health, social protection and employment opportunities, to prevent climate change and promote environmental protection. To achieve the SDGs, general cross-cutting key competencies relevant for all levels of education have been defined, such as systems thinking, anticipatory, normative, strategic and collaboration competency, as well as critical thinking, self-awareness and integrated problem-solving competency (UNESCO, 2017a, p. 15).

According to recent literature, sustainability (Holgaard et al., 2016; Rose et al., 2015; Stokes & Harmer, 2018; Takala & Korhonen-Yrjänheikki, 2019) is one of the key themes in engineering education that should be strengthened. Gürdür Broo et al. (2022) argue that the sustainability—social, environmental, and economic—to help achieve the SDGs is rarely part of engineering education. Therefore, various strategies and competencies have been proposed to integrate SDGs into engineering education curriculum (e.g., Sánchez-Carracedo et al., 2021). Ghanem (2020) stated that learning in an online environment contributes to achieving the SDGs.

2.1.3 Agile Methods and DevOps

Industry 4.0 solutions connect machines and IT systems, significantly increasing the importance of software development. Agile software development and agile methods, such as Scrum (Gonçalves, 2018; Pries & Quigley, 2010; Rising & Janoff, 2000; Takeuchi & Nonaka, 1986), Lean and Kanban (Ahmad et al., 2013), have been increasingly utilised in the software industry and are beginning to be de facto in the industry and enterprises (Buckl et al., 2011). Scrum is an agile development method based on fixed-length sprints. Sprint results iteratively promote the content of an artefact or service. Each sprint transition involves a review event between the Scrum team and the client, as well as the team's retrospective, which reflects the sprint experiences. Lopez-Fernandez et al. (2021) examined the taxonomy of team structure involving relevant stakeholders from 31 multinational software-intensive companies and found that all but two companies utilised Scrum methodology, with sprint length ranging from two to four weeks. There is already ample evidence of the successful application of the Scrum methodology in HE at the course level (e.g., Barcelos Bica & Silva, 2020; Chassidim et al., 2018; Linos et al., 2020; Mielikäinen et al., 2018; Naik & Jenkins, 2019; Noguera et al., 2018; Stawiski et al., 2017; Vogel et al., 2019). Linos et al. (2020) examined IT professionals in an undergraduate computer science and software engineering course following Scrum methodology, which positively affects the students' learning experience and provides an opportunity to incorporate real-world lessons and scenarios into the course content and help students learn software design principles, techniques, and tools to develop more professionally. This collaboration also provides an opportunity for

IT professionals to mentor students and update their knowledge according to the course content.

DevOps is an extension or evolution of agile approaches being a rapidly growing method for the production of digital services in the industry. DevOps is often used to streamline business processes (Mohammad, 2018). It is built around practices that are not in agile methods' focus, such as monitoring, automation and continuous delivery. The DevOps concept encompasses development practices, cultural philosophies and software tools. The origin of DevOps is to connect development and operation teams, and automate application delivery (Sharma, 2017, pp. 1–20) and make the collaboration between development and operations effective. Therefore, according to Alnafessah et al. (2021), it is a delivery paradigm that pays more attention to continuous re-release, unified tooling, and organisational processes. DevOps has even been found to provide better job satisfaction among professionals than agile methods alone (Hemon-Hildgen et al., 2020). However, agile and DevOps are not mutually exclusive but complementary, with agile providing delivery that meets customer needs and DevOps optimising the process while avoiding silos (F. Almeida et al., 2022).

DevOps has been included in curricula mainly at the course level (e.g., Hobeck et al., 2021; Jennings & Gannod, 2019; Kuusinen & Albertsen, 2019). Bobrov et al. (2019, 2020) argued that curricula put a strong emphasis on the 'Dev' part, but marginally cover the 'Ops' part. They also suggest utilising the following taxonomy for undergraduates to fully understand and implement the DevOps philosophy: 1) how to code, 2) how to create software, 3) how to create software in a team, 4) how to create software in a team based on someone's needs and 5) how to create software in a team based on business needs. Bobrov et al. (2019) also provided the following design principles for the timing related to the vision of a DevOps philosophy-based curriculum: The first three semesters are devoted to hard and soft skills. The first software project course will be implemented on the fourth semester. The fifth semester will include a new iteration of the software project course, with a deep understanding of agile philosophy and the most popular agile frameworks. In the sixth semester, the previous course will be continued, with the addition of automation and optimisation, Ops section presentation, and the feedback concept. In the last two semesters, students will work with real customers from the industry, establishing everything they have learned previously. To promote DevOps philosophies in HE, the relevance of practical tasks should be increased (Bobrov et al., 2020). Collaboration is included in the key values of the DevOps culture (Lopez-Fernandez et al., 2021). Therefore, deploying DevOps means cultural shift towards collaboration for enterprises (Ebert et al., 2016). The DevOps cultural approach to communication and collaboration should also lead to a paradigm shift in educational ecosystems as authentically as possible.

2.1.4 Teleworking

It is important to examine teleworking–referred also as telecommuting, remote work, distributed work, virtual work, flexible work, flexplace, and distance work (Allen et al., 2015)–and its forms within the industry, as well as to explore perspectives to ensure the relevance of education and students' readiness for the workforce. Teleworking is becoming increasingly common, and its significance in organisations has grown significantly. It has become an essential skill in today's workplace. A digital learning ecosystem can also provide effective ways to integrate digital tools and environments and facilitate students' engagement in real-world tasks and projects. However, teleworking also has its limitations, knowing of which can benefit the development and implementation of DLE design principles. Changing practices and experiences in the workforce should also be reflected in the development of HE institutions' activities to meet these evolving conditions and requirements. Understanding these practices, experiences and empirical knowledge can help in developing sensible solutions for collaborative learning experiences, without forgetting well-being.

Organisations have made an effort to enhance their business practices and dedication to their human resources by, for example, determining novel ways to communicate as online technologies have become more widely used and popular (Butler et al., 2021). According to the European Commission study by Sostero et al. (2020, pp. 29–30) on teleworking, teleworkability can be divided into three categories: 1) physical tasks, 2) social interaction tasks and 3) information-processing tasks. Physical tasks with contact with things or people are the most challenging part of telework, while social interaction that does not require physical contact succeeds remotely but with a significant loss of quality. Conversely, data-processing tasks can be generally provided remotely, with hardly any loss (Sostero et al., 2020, p. 30). However, teleworking can have a negative effect on the quality of work input if the job demands teamwork or social interaction with colleagues (Sostero et al., 2020, p. 53). A study on the productivity of teleworking in the post-COVID-19 era published by the Organisation for Economic Cooperation and Development (OECD, 2020) finds that the likely overall relationship between worker efficiency (on the vertical axis) as productivity and the amount of telework (on the horizontal axis) is characterised by a downward U-curve. This curve, which varies by sector and occupation, shows the maximisation of efficiency and telework at intermediate levels, indicating the reducing effect of excessive teleworking on productivity (OECD, 2020).

According to a literature review, the optimal time to telework is approximately 40% of a person's overall working time in the case of a traditional 40-hour workweek (Beckel & Fisher, 2022). Social, psychosocial and productivity effects have also been studied in the everyday lives of professionals working in the software industry during remote work due to the COVID-19 pandemic, and the results did not indicate a significant relationship between productivity, well-being, social and psychological variables and working activities (Russo et al., 2021). The key factors for the success of telework and the achievement of goals have been identified as the exchange of knowledge, such as time requirement estimates, work difficulty assessments and effective use of technology (Stoian et al., 2022). In a study on the resilience of telework in public organisations, Fischer et al. (2022) identified central the factors at the micro level, such as proactive work behaviour, digital competencies and autonomy. Beckel and Fisher (2022) suggest the use of channels in informal online web conferencing environments to meet the need for social interaction.

2.2 Pedagogical Approach

From the perspective of a pedagogical approaches, learning in a digital learning ecosystem is largely based on a social constructivist approach. A successful blended learning experience also requires a research community capable of collaboration (Vaughan et al., 2013). Therefore, the CoI framework (Akyol & Garrison, 2008; Garrison, 2016; Garrison et al., 1999; Swan et al., 2009) was chosen as the key theoretical lens, thus providing pedagogical perspectives for intervention design in this DBR. The CoI framework is a theoretical model that posits that effective online learning environments are supported by the presence of three elements: social presence (SP), teaching presence (TP) and cognitive presence (CP). The CoI framework refers to the interplay between these three elements, which are necessary for creating an engaging and meaningful e-learning experience. The term 'e-learning' is discussed separately, as it clarifies the concepts of online and blended learning. This DBR develops design principles for a DLE in the context of project-based learning (PjBL) and an integrated curriculum. Therefore, these concepts are also introduced.

2.2.1 Social Constructivist Approach

The collaborative nature of a digital learning ecosystem in the context of learning makes it essential to approach it from social constructivism perspectives. The CoI framework and PjBL approach align with these perspectives as they are both founded on the principles of social constructivism. In constructivism, learners' understanding is constructed on experiences from the surrounding world. The knowledge is individually constructed (Phillips, 1995) and socially developed (Fox, 2001). Meanwhile, social learning, emphasizes the role of observation and participation as a means of learning without excluding interaction (Pritchard & Woollard, 2010, p. 8). On the other hand, interaction is particularly emphasised in social constructivism, which emphasizes social interaction in the process of constructing knowledge and understanding (Pritchard & Woollard, 2010, p. 8). As noted by Powell and Kalina (2009), French Swiss developmental psychologist Jean Piaget's constructivist philosophy accentuated the active role of individuals in constructing knowledge, subsequently followed by psychologist Lev Vygotsky's (1978, 1997) development of social constructivism, wherein learning is viewed as a collaborative and social activity involving the creation of meaning through interactions. In social constructivism, learning, has a communal and cultural nature, where thinking, knowledge and skills are transmitted according to Vygotsky (1978) by means of social interaction and the instrumental or psychological artifacts of tools belonging to culture. Drain (2022) further specifies Vygotsky's intended instrumental tools, noting that they encompass artifacts and objects that facilitate interaction between an individual and the external environment, with psychological artefacts encompassing elements such as signs and word. From the perspective of this study, the significance of these instrumental tools is highlighted through digital resources within the context of e-learning, where PjBL is also implemented. These resources provide students with a platform that encourages interaction and collaboration, ultimately enhancing the overall learning experience.

Therefore, in social constructivism, individuals develop knowledge, meaning, and understanding in a coordinated manner together (Amineh & Asl, 2015). In PjBL, students participate in projects where they work together to solve problems or create new things. This process reflects the principle of social constructivism, which emphasizes learning through interaction and collaboration. The students bring their own views, experiences, and knowledge to the common reflection, and together they create meanings and understanding. However, Powell and Kalina (2009) pointed out that ideas are constructed from experience having a personal meaning for the student. Thus, social constructivism allows learners to interact with each other to change the traditional approach to education, which attempts to transfer knowledge verbally to passive learners (Reed et al., 2008). According to Reed et al. (2008), sociocultural and later social constructivist theories have led to active learning—that is, the notion that learning is an active process and requires active participation and commitment to materials and peers. Learners are active participants in creating their own knowledge (Schreiber & Valle, 2013). Indeed, Lefoe (1998) asserted that regulating students' own learning can be made possible by providing real-world context and collaborative opportunities. From the standpoint of this study, social constructivism is primarily emphasized in DLE through students' participation in interactive learning situations and collaborative learning environments. With the help of DLE's digital resources, learners can share information, engage in discussions, co-construct meaning, and learn from each other, which promotes their collaborative and active role in knowledge construction.

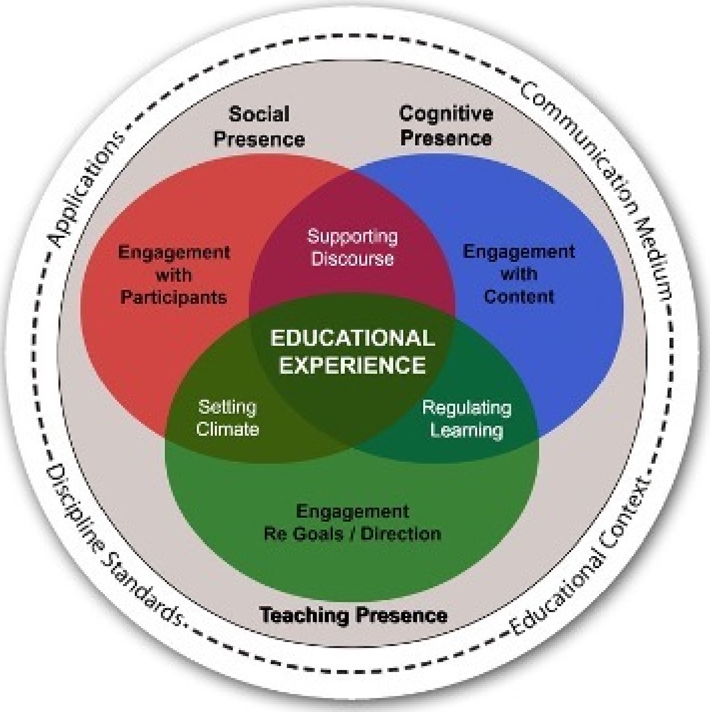
2.2.2 The Community of Inquiry Framework (CoI)

The CoI framework, introduced by Garrison et al. (1999), provides a framework for exploring the relationships of three core elements: teaching presence, cognitive presence and social presence. Because the intervention is situated in a digital learning environment and is strongly based on a collaborative approach, CoI was chosen as the theoretical framework for this research. The current study examined how the TP, CP and SP perspectives were realised using the CoI survey instrument (Arbaugh et al., 2008; Swan et al., 2008) in sub-studies II and III. The instrument offers a tool to evaluate the learning experience in an e-learning environment through the components of TP, CP and SP. The CoI survey instrument is presented in more detail in the methodology chapter in connection with sub-study II. Finally, the design requirements arising from the sub-study findings were further synthesised into design principles through the theoretical lens of CoI.

The CoI framework (Akyol & Garrison, 2008; Garrison, 2016; Garrison et al., 1999; Swan et al., 2009) is a social constructivist-based process model for online learning (Kozan & Caskurlu, 2018; Swan, 2019; Swan et al., 2009; Tolu, 2013). According to Garrison (2016, p. 24), it is a 'structure of a transactional educational experience whose core function is to manage and monitor the dynamic for thinking and learning'. Fiock (2020) stated that the term 'community' is often used in educational research to refer to cognitive or emotional connections between physically separated students. At the core of the CoI framework is John Dewey's philosophy of educational experience (Swan et al., 2009). In a well-known declaration, Dewey (1897) argued that education is a social process and that the development of individuals depends on the community. In contrast to Vygotsky's view of the importance of cultural transmission as the primary goal of social constructivist learning, Dewey emphasises the construction of personal knowledge through individual cognition (Hyslop-Margison & Strobel, 2007). Dewey (1938) viewed the learner as a member of a community, for example, a school, assisting learners in socially constructing knowledge (Hirtle, 1996). In Dewey's philosophy, the teacher is a classroom facilitator who helps students design their own learning experiences (Hyslop-Margison & Strobel, 2007). According to Swan et al. (2009), Dewey believed that students will assume the responsibility for actively constructing and confirming meaning through collaboration. Thinking and learning collaboratively is also the idea of e-learning, which provides opportunities for deep and meaningful learning experiences (Garrison, 2016, p. 4). Garrison (2016, p. 24) described CoI as 'establishing procedures for critical inquiry and the collaborative construction of personal meaningful and shared understanding'.

As shown in Figure 3, the CoI framework views the online educational experience as arising from the interaction of three asymmetrically overlapping (Garrison & Vaughan, 2008, p. 19) presences: TP, SP and CP (Garrison, 2016, p. 25). These elements are essential for engagements with participants, content, goals and directions. In the outer perimeter are the terms 'communication medium', 'educational context', 'discipline standards' and 'applications', for which Garrison does not give specific definitions. In the current study, the communication medium is equated with the TCP, which supports a PjBL approach and an integrated curriculum of ICT engineering education as an educational context. In the PjBL approach, the discipline standards represent the industry concepts, methods and practices, such as DevOps, Scrum and Industry 4.0, and the applications are represented by authentic PjBL assignments.

Figure 3
The CoI Framework



Note. From the Community of Inquiry: About the Framework by the Community of Inquiry, (https://www.thecommunityofinquiry.org/framework). CC BY-SA 4.0.

The element of TP supports and enhances SP and CP to achieve educational outcomes (Garrison et al., 1999). For an activity to be productive and sustainable, an architect and a facilitator are needed to design, direct and inform the transaction (Garrison, 2016, p. 27). Anderson et al. (2001, p. 5) defined TP as 'the design, facilitation and direction of cognitive and social processes for the purpose of realising personally meaningful and educationally worthwhile learning outcomes'. Furthermore, TP is defined in terms of the following: 1) design and organisation of approaches to teaching and learning, curriculum, architecture and content;

2) facilitating discourse includes the construction of personal meaning and collaboratively shaping and confirming mutual understanding; and 3) direct instructions are given to 'scaffold' learning experience by a subject matter expert (Anderson et al., 2001; Garrison, 2016, pp. 71–76).

SP is defined as 'the ability of participants in the CoI to project their personal characteristics into the community, thereby presenting themselves to the other participants as "real people"' (Garrison et al., 1999, p. 4). However, Akyol and Garrison (2008) found that SP has no effect on learning but is associated with satisfaction. This is interesting because CoI is grounded in social constructivism, in which learning is seen as a social process. Furthermore, SP represents the degree to which participants in computer-mediated communication feel affectively connected to one another (Swan et al., 2009). It has three categories of indicators: 1) affective expression establishes the emotional and academic climate for open and purposeful communication; 2) open communication allows questioning while protecting self-esteem and acceptance, encouraging reflective participation and discourse; and 3) group cohesion helps sustain commitment and focus to enable constructing meaning, confirming understanding and completing collaborative activities (Garrison, 2016, pp. 44–46; Rourke et al., 1999).

Garrison et al. (1999, p. 4) defined CP as 'the extent to which the participants in any particular configuration of a community of inquiry are able to construct meaning through sustained communication'. It comprises four phases: 1) a triggering event that reflects the initiation phase of critical inquiry, 2) exploration where participants shift between critical reflection and discourse, 3) an integration phase for constructing meaning from the ideas and assessing their applicability and 4) resolution for implementing the proposed solution or testing the hypothesis through practical application (Garrison et al., 2001).

Garrison and Akyol (2011; 2015) explored the role of metacognition in the CoI framework. In sub-study III of the current study, the concept of metacognition was required to expand the concept to cover the motivation and regulation aspects that emerged in the results. Sub-study III focused on an empirical experiment on students' experiences in an online environment as a CoI. Metacognition involves individuals possessing knowledge about their cognitive structure and their ability to organize this structure (Flavell, 1979; Akturk & Sahin, 2011). According to Garrison (2016, p. 60), metacognition refers to the sharing of roles and responsibilities in a community, which requires awareness to take individual and collaborative responsibility for regulating the process of thinking and learning. In the CoI framework, shared metacognition is located at the intersection of CP and TP (Garrison, 2022; Garrison & Akyol, 2015; Vaughan & Wah, 2020). Garrison describes shared metacognition as a fusion of self-regulation and co-regulation in which monitoring and management functions reflect the integration of a private and a shared world (Garrison, 2016, p. 63). The effect of metacognition on CoI has already been empirically studied to some extent (Kilis & Yıldırım, 2018), and a quantitative instrument for assessing shared metacognition has been developed (Garrison, 2016, p. 161; 2022).

During the last decades, researchers have proposed additional presences. Shea and Bidjerano (2014) and Shea et al. (2022) suggested a revised CoI model with a learning presence component to represent self-efficacy and other cognitive, behavioural and motivational structures based on earlier studies (Shea et al., 2012, 2013; Shea & Bidjerano, 2010). Garrison (2016, p. 31) considered the proposal difficult because the participants work together and take responsibility as both a teacher and a student and because self-regulation is incorporated into the CoI framework, primarily at the intersection of TP and CP, through shared metacognition. Moreover, Cleveland-Inness and Campbell (2012) proposed extending the CoI framework with an emotional presence, to which Garrison (2016, p. 31) responds that it is already taken into account in the structures of SP. Lam (2015, p. 57) proposed to extend the CoI with the dimension of autonomy presence, in which 'the students direct and interpret their own learning and the sharing of ideas for extending the discourse without teaching instruction and facilitation'. Kilis and Yıldırım (2018) suggested a regulatory presence construct that addresses learners' self-regulation. The role of the social presence in the model has also been discussed in Annand's (2011) study.

The CoI framework is widely used for its original purpose—the study of text-based asynchronous online discussion (Garrison et al., 1999; Garrison & Arbaugh, 2007). The application of the CoI framework for the development of an intervention is consistent with PjBL, which is a constructivist and collaborative learning approach that emphasises interaction. By adopting the CoI framework, the intervention not only considers the perspectives of e-learning but also gains a more comprehensive perspective informed by collaborative learning theory. According to Whipple (1987), collaborative learning is a pedagological style emphasising cooperative efforts among students, faculty and administrators, which, when supplemented by industry representatives, corresponds to the core of the digital learning ecosystem developed in this study. Whipple (1987) discussed collaborative learning in aspects such as the active participation of learners and teachers, collaboration, a sense of community, knowledge creation, the blurring of the boundaries between teaching and research and the positioning of knowledge in the community instead of the individual. These elements are also important in the study described in this dissertation, which is based on the social constructivist approach of the CoI framework.

2.2.3 E-Learning Approach

The context of the present study is strongly related to e-learning, although several researchers have found the definition of e-learning to be challenging and contradictory (Arkorful & Abaidoo, 2015, 2015; Guri-Rosenblit & Gros, 2011; Moore et al., 2011; Rodrigues et al., 2019; Sangrà et al., 2012; Troussas & Sgouropoulou, 2020,

p. 3). A review by Choudhury and Pattnaik (2020) elucidated a number of changed definitions of e-learning across the timeline. In addition to these definitions and as an example, in the early 2010s, Sangrà et al. (2012) sought an inclusive definition of e-learning in their research. The definition was developed on the basis of an extensive literature review and through surveys of well-known experts in the field. Their study resulted in an almost unanimous, positive consensus on the definition:

> *E-learning is an approach to teaching and learning, representing all or part of the educational model applied, that is based on the use of electronic media and devices as tools for improving access to training, communication and interaction and that facilitates the adoption of new ways of understanding and developing learning.* (Sangrà et al., 2012, p. 152)

Garrison (2016, pp. 2–6) defined e-learning as 'the utilisation of electronically mediated asynchronous and synchronous communication for the purpose of thinking and learning collaboratively' or the 'form of online and blended approaches over time and space'. As a result of Rodriques et al.'s (2019, p. 95) systematic review, e-learning is defined as 'an innovative web-based system based on digital technologies and other forms of educational materials whose primary goal is to provide students with a personalised, learner-centred, open, enjoyable and interactive learning environment supporting and enhancing the learning processes'. Among the definitions described above, Rodriques et al.'s (2019) definition is the most modern, and it corresponds mostly to this study's approach.

Blended and online learning can be considered two primary applications of e-learning (Garrison, 2016, p. 3), which were also applied in sub-studies II and III of this research. Sub-study II was conducted in a blended learning environment, and sub-study III was conducted in an online environment. Therefore, it is necessary to address these concepts. Garrison (2016, p. 3) emphasised the collaborative nature of online learning, which is what differentiates it from traditional distance education, and considers it to be primarily about content delivery and autonomous approaches to learning. As in the case of e-learning, online learning has received different definitions. Singh and Thurman (2019) systematically reviewed the definition of e-learning for 30 years and found 46 definitions and 18 synonyms. They found the definitions confusing because they lack learning, cognition, awareness and retention, focusing mainly on technology, time and physical differences. Because their research is fresh and relevant to the context of this dissertation, the following definition is highlighted:

> *Online education is defined as education being delivered in an online environment through the use of the internet for teaching and learning. This includes online learning on the part of the students that are not dependent*

on their physical or virtual co-location. The teaching content is delivered online and the instructors develop teaching modules that enhance learning and interactivity in the synchronous or asynchronous environment. (Singh & Thurman, 2019, p. 302)

Conversely, blended learning combines FTF instructions with computer-mediated instructions (Bonk & Graham, 2012, p. 5) or FTF with online activities (Garrison, 2016, pp. 100–108). Vaughan & Garrison (2006, p. 68) defined it as 'the integration of on-campus and online education for the express purpose of enhancing the quality of the learning experience', proving that, as in previous terms, it has received several definitions over the years (Hrastinski, 2019; Kim, 2007; Smith & Hill, 2019). Blended learning is also often referred to as hybrid learning (Graham, 2012; O'Byrne & Pytash, 2015). Based on a literature review, Cronje (2020, p. 120) found that the definition should be built around learning theory and should refer to a blend of direct instruction and learning-by-doing; thus, he proposed a completely new definition of blended learning, which is 'the appropriate use of a mix of theories, methods and technologies to optimise learning in a given context'.

Numerous studies have identified the advantages of a blended learning approach for learners. The identified benefits include a positive effect on students' motivation (Asgari et al., 2021; Ghazali et al., 2018; Kharb & Samanta, 2016; López-Pérez et al., 2011; K. Smith & Hill, 2019), self-regulation (K. Smith & Hill, 2019), cognitive skill development (Kharb & Samanta, 2016), reducing the dropout rate (López-Pérez et al., 2011), performance improvement (Ghazali et al., 2018; Singh et al., 2019) and improved teacher–student interaction (S.-C. Chang & Hwang, 2018; Ismadi et al., 2018). With regard to e-learning, some of its advantages are promoting lifelong learning (Abumandour, 2022) and self-paced education (Abumandour, 2022). Sustaining and engaging the motivation of learners are considered critical to success (Choudhury & Pattnaik, 2020). Levy and Ramim (2017) explored instructors' thoughts about the benefits students should gain from successful e-learning in engineering and computing courses. According to their study results, the most important skills were knowledge acquisition and critical thinking, while the least important skill was socialisation with other students. This finding is interesting because it implies that instructors might hold traditional epistemological views on teaching and perceive learning as a highly individual process.

Conversely, some studies have found no improved motivation in the context of blended learning compared with traditional FTF learning. Shenck and Hoxhaj (2019) explored the challenges of transitioning to blended learning in HE and found, among other things, that students believed they would benefit more from instructors' skills and enthusiasm in traditional classroom teaching. They also reported that students lacked the motivation to attend lectures because they prioritised other course tasks with clear deadlines. Ensuring interaction with the tutor and other classmates was considered important in moving towards a technology-based blended learning approach.

Numerous studies have aimed to identify the challenges of a blended learning approach. Rasheed, Kamsin and Abdullah (2020) conducted a systematic literature review of the challenges in blended learning's online component. According to their research, the challenges students faced were self-regulation, challenges related to technical literacy and competence, challenges in student isolation and technological adequacy and complexity challenges. According to Ghanem's (2020) literature review on e-learning challenges, the reported challenges were inadequate learner support and academic advising as well as the quality of the educational system, software and content. Czauderna and Guardiola (2021) studied remotely collaborated teams in game development education and found that teleworking requires additional attention in terms of time management, job sharing and mutual understanding, among other things. Psychosocial challenges were highlighted, which were affected not only by teleworking but also by the pandemic, for example. In a study by Riekkinen et al. (2022), which examined the negative and positive experiences of university teachers during the pandemic-induced online teaching, it was found that many teachers experienced frustration and annoyance due to perceived inefficiencies in digital communication. This led to reduced interaction, increased mental strain, and a longing for social aspects like discussions, laughter, and a sense of community. With regard to blended learning from the students' perspective, challenges were also mentioned, such as the 'free rider' problem (Fearon et al., 2012), lack of support or FTF interaction with instructors (Fearon et al., 2012; Schenk & Hoxhaj, 2019), lack of motivation (Choudhury & Pattnaik, 2020), the illusion of unlimited time and schedule (Schenk & Hoxhaj, 2019), increased workload (Singh et al., 2019) and lack of practical and lab-based training (Asgari et al., 2021). The disadvantages related to online learning are almost identical, such as a lack of interaction with instructors (Almahasees et al., 2021; Fearon et al., 2012).

The literature also includes examples of how individual students have diverse views of the relationship between online and campus work that would provide them with the best possible learning experience. In Czauderna and Guardiola's (2021) study, some of the students wanted to work according to the hybrid model and meet physically occasionally, while others were enthusiastic about teleworking (Czauderna & Guardiola, 2021). Czauderna and Guardiola (2021) justified the differences with possible different personalities and/or social circumstances, and hybrid work was found to be a successful solution. To develop self-regulation, Martínez et al. (2020) used extensive calendaring for planning and time management, monitoring of the ongoing work stream, asynchronous learning, tracking of student submission and prompt feedback to assess progress. In the case of self-regulated learners, the metacognitive strategy guides the use of the right approach in actions in their learning, leading to better learning outcomes (Boles & Whelan, 2017). Efforts have also been made to solve problems related to blended learning in HE by applying constructivism and conversation theories (Al-Huneidi & Schreurs, 2012; Alkhatib, 2018).

The ability to study at one's own pace and location can significantly alter the way time is allocated and facilitate the integration of learning into daily life, ultimately fostering lifelong, lifewide and lifedeep learning (Vuojärvi, 2013). The development and virtuality of information technology have led not only to the development of new educational technologies but also to terminological diversity. This phenomenon has also been referred to as ubiquitous learning or u-learning (Istiyowati et al., 2021; López et al., 2022), which is defined in the International Organization for Standardisation and International Electrotechnical Commission (ISO/IEC TS 29140-2:2011, 2011) standard as learning that is stimulated and supported through various means and is always readily accessible. Mobile learning, or m-learning (Gupta et al., 2021; Qashou, 2021; Saikat et al., 2021), is also used in the context of the definition in which learning takes place using mobile and wireless technologies (Sarrab et al., 2012). With the pandemic, the use of the hybrid flexible or HYFlex approach (Kohnke & Moorhouse, 2021; Sanchez-Pizani et al., 2022) has emerged, which refers to synchronous FTF and online lessons and asynchronous content approaches (Howell, 2022). In some contexts, the terms 'distance learning' (da Silva et al., 2021; Kireev et al., 2019; Zahariev et al., 2021) and 'digital learning', or d-learning (Kumar Basak et al., 2018; Persada et al., 2019; Pratiwi & Pratiwi, 2020), have also been used alongside e-learning. The interconnectedness of these notions has been described previously. For example, m-learning is a component of e-learning (El-Sofany & El-Haggar, 2020), which is itself a component of distance learning (Georgiev et al., 2004; Rimale et al., 2016). Although d-learning as digital learning is increasingly said to replace e-learning (Kumar Basak et al., 2018), e-learning is used in this dissertation because of its theoretical basis in relation to the CoI framework and the sub-concepts of e-learning, such as online learning and blended learning.

2.2.4 Project-based Learning Approach

The importance of collaboration and teamwork is emphasised not only in learning but also in preparing engineering students for working life (Boles & Whelan, 2017). Therefore, in engineering education, meaningful collaboration is natural to implement the principles of a PjBL approach, which is already applied in the engineering education curriculum of several universities so that students can solve open-ended problems (Isomöttönen et al., 2019; McDermott et al., 2017) of real clients or companies in small groups (Chen et al., 2021). PjBL provides not only the development of technical skills but also the improvement in soft skills (Daneva et al., 2019; Snape, 2017), such as communication and teamwork. (Martseva et al., 2021). Combining theoretical and practical training is required to prepare specialists for practical employment (Martseva et al., 2021).

Similar to CoI, the origins of PjBL can be found in the constructivist approach to learning (Pecore, 2015; Ríos et al., 2010), influenced by Piaget, Vygotsky and Jerome Bruner (Pecore, 2015), and the philosophy of progressive education and learning by experience by Dewey (1938). Whereas Dewey (1897) viewed education as a social process and the development of individuals as dependent on the community, Vygotksy (1997) considered learning to be a social and cooperative activity in which people create meaning by interacting with each other in a cultural context. According to Hadrianto and Rahman (2019), Vygotsky also believed that learning occurs when an individual discovers new tasks that have not yet been learned. Conversely, Piaget considered learners to be building knowledge based on their previous knowledge and experiences through interaction with the environment (Ackermann, 2001). According to Bruner (1995), learning is a subjective process in which students learn by finding meanings. These respected educators created a psychological background for learning that has lasted into today's education system, also contributing to the development of the PjBL approach.

When dealing with PjBL, it is often pointed out in the literature that project learning is not the same as doing a project (Lenz et al., 2015, p. 68; Markham, 2011). PjBL, which is also naturally compared with experiential (Efstratia, 2014; Kolb, 2014) or collaborative learning (Kokotsaki et al., 2016), is a student-centred (Gubacs, 2004; Shpeizer, 2019; Uziak, 2016), inquiry-based learning approach (Ai et al., 2020) integrating theoretical and practical content (Zhu et al., 2019). PjBL aims to increase students' ability to learn actively, think critically, solve practical problems and engage in group discussions (Uziak, 2016). It focuses on achieving a shared goal through collaboration (Kokotsaki et al., 2016). At least in 2015, there was no generally accepted definition of PjBL (Pecore, 2015). According to Shpeizer (2019) and Pecore (2015), one of the most popular definitions of PjBL is that by Markham et al. (2003, p. 7): 'a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks'. Five essential features need to be met to be considered PjBL (Barron & Darling-Hammond, 2008; Pecore, 2015; Thomas, 2000). These are listed by Pecore (2015, p. 159) as follows:

1) a central project;
2) a constructivist focus on important knowledge and skills;
3) a driving activity in the form of a complex question, problem or challenge;
4) a learner-driven investigation guided by a teacher;
5) a real-world project that is authentic to a learner.

Furthermore, PjBL offers an alternative to the traditional teaching presentational model called the 'pour it in' model (Smith, 2005), which is characterised by the following (Adderley et al., 1975, p. 1):

1) Projects involve the solution of a problem often set by a student;
2) Projects involve self- or group initiatives and necessitate a variety of educational activities;
3) Projects commonly result in end products;
4) The work often lasts a long time;
5) Teaching staff are involved in an advisory rather than an authoritarian role in all the stages.

The role of a teacher is largely to promote learning and effective mentoring (Sanchez-Romero et al., 2019). Shpeizer (2019) listed the characteristics of PjBL, such as in-depth inquiry, authenticity, active learning, freedom and autonomy, challenging questions or problems, collaborative learning and product and product presentations. The PjBL concept is based on the close networking of stakeholders, such as students, research and educational institutions and business organisations (Vasiliene-Vasiliauskiene et al., 2020).

In PjBL, the product is a real-world task rather than a problem solution—that is, problem-based learning (PBL) (Hung et al., 2019, p. 111). However, the terms are often cross-referenced (Mills & Treagust, 2003) or discussed closely together (Bertel et al., 2021; Kolmos et al., 2021). Sindre et al. (2018) argued that the two have more in common than differences, whereas Guo et al. (2020) asserted that the two should be differentiated, especially in HE. Helle et al. (2006, p. 295) specified the difference between the approaches as follows: 'The starting point in both approaches is a problem but in PBL, students' activity is directed to "studying", whereas in PjBL, students' activity is directed to constructing the product'. Perhaps the most significant difference is that the application of knowledge or data is emphasised in the PjBL model, while the acquisition of data is mostly emphasised in the PBL model (Mills & Treagust, 2003; Perrenet et al., 2000). Partly because of their familiarity with the PjBL concept, PjBL is likely to be more easily adopted and adapted in university engineering programmes than PBL (Mills & Treagust, 2003). For clarity, in this dissertation, the abbreviations for the terms are differentiated into PBL and PjBL. An exception to this is in the publication of sub-study I, which uses the abbreviation PBL to describe PjBL.

PjBL has been covered extensively in articles regarding K–12 education (e.g., Culclasure et al., 2019; Miller et al., 2021). However, Spheizer (2019) noted that development at the HE level was slow. Conversely, approaches such as PjBL and HE–industry collaboration may have been studied in HE institutions, but they are reported under different concepts (Akele & Chukwu, 2020; D. Jackson et al., 2022).

Recent empirical PjBL studies on HE (Guo et al., 2020) and the growing number of research and practices in engineering education (Chen et al., 2021) indicate an expanding application of this approach in the HE field. Sanchez-Romero et al. (2019) found that the application of the methods is largely focused on studies in the final years of the degree. From an interdisciplinary perspective, PjBL has been found to be the dominant educational paradigm in engineering education (Van den Beemt et al., 2020). Chen et al. (2021) reviewed 103 research articles in their literature review between 2000 and 2019, summarising current PjBL and PBL practices in engineering education. These articles focused mainly on computer and software engineering (27 articles), and six articles dealt with multidisciplinary practices. According to their article, PjBL and PBL were mostly applied at the course level (73 articles), usually lasting for one semester. In six articles, it was applied at the cross-course level, which here means a series of related or multidisciplinary courses combined to support a student project, most often over one semester. At the curriculum level, the approach was applied in 23 articles, in which the approach forms the backbone of the curriculum, while other traditional learning methods, such as lectures, become assistant elements. Chen et al. found individual short- or long-term projects in six articles, representing mainly elective studies. However, it should be noted that Chen et al. (2021) discussed the concepts of PBL and PjBL together in their article. They specified that at the course level, engineering educators adopted both PBL and PjBL methods, but at the cross-course, curriculum and project levels, a more PjBL approach was used. Some studies have also called for community and industry involvement (Janse van Rensburg & Goede, 2020; Roach et al., 2018). In the case of combining blended learning and PjBL, researchers have obtained successful results in engineering education (Andersen et al., 2019; Medeiros et al., 2017; Tay et al., 2020) or HE in general (Alamri, 2021; Amaral et al., 2018; Kalaichelvi & Sankar, 2021; Sulistiyarini et al., 2021; Surahman et al., 2019; Wahyudi, 2020; Yustina et al., 2020).

According to Kolmos et al. (2021), Danish engineering students who used systemic PBL (in Aalborg University, Denmark, the term 'PBL' covers both PBL and PjBL) developed a greater sense of preparedness in terms of generic and contextual competencies, but they felt less prepared when considering more traditional and domain-specific competencies related to natural science. Other advantages of PjBL have been mentioned in the literature, such as enhanced motivation (Guo et al., 2020; Hogue et al., 2011; Mills & Treagust, 2003; Shpeizer, 2019; Vasiliene-Vasiliauskiene et al., 2020) and from the teacher's point of view (Aksela & Haatainen, 2019), better teamwork (Sindre et al., 2018) and communication skills (Mills & Treagust, 2003), better content knowledge and skills (Guo et al., 2020; Hogue et al., 2011) and better ability to apply them (Mills & Treagust, 2003), improved creativity (Sindre et al., 2018), better academic results or achievements (Bell, 2010; C.-H. Chen & Yang, 2019; Sindre et al., 2018), greater engagement (Bell, 2010; O'Sullivan et al., 2017; Vasiliene-Vasiliauskiene et al., 2020) and a higher retention rate (Hogue et al., 2011).

The challenges that have been mentioned are changing student and teacher roles (Chen et al., 2021; Shpeizer, 2019), 'hitchhikers' (Chen et al., 2021; Shpeizer, 2019), challenges in the evaluation due to the need to evaluate both the process and the product (Shpeizer, 2019), students' weak performance (Nwokeji et al., 2018), uncertainty in the project assignment (Hussein, 2021), less rigorous understanding of engineering fundamentals (Mills & Treagust, 2003), team cohesion (Nwokeji et al., 2018), challenges in collaboration such as priority conflicts between students (Chen et al., 2021; Hussein, 2021) and from the teacher's perspective e.g. facilitation including time management, teachers' skills and project organisation (Aksela & Haatainen, 2019; Chen et al., 2021) and challenges in assessment (Chen et al., 2021). The adaption of self-oriented learning and unclear and open-ended tasks were seen as challenges (Nepal & Jenkins, 2011).

Kokotsaki et al. (2016) gave recommendations that were important for the successful adoption of PjBL, such as providing support for both students and teachers, effective group work, balancing didactic instruction with an independent inquiry method, emphasising an assessment on reflection, self- and peer evaluation and student autonomy throughout the process to help develop a sense of ownership and control over their own learning. To address challenges in collaboration, Hussein (2021) proposed that the project management structure should be adequate and that an atmosphere of mutual support and understanding should be created.

Recent literature has provided a few examples of HE that have applied CoI in the PjBL context. Hsu and Shiue (2017) examined the relationships between the three presences of CoI in a multidisciplinary online PjBL context and found that incorporating collaborative technology is important for promoting the development of learners' perceptions of CP. Based on their study of the online PjBL context, Guo et al. (2021) found that expressions of affectiveness and exploration are the most commonly used SP and CP in students' online group discussions. Liew et al. (2021) observed that PjBL complements the CoI framework by creating the right kind of TP to achieve CP while encouraging SP in the virtual classroom environment. Beneroso and Robinson (2022) believed that more designed teaching approaches, including a major component of SP (e.g. wider open communication and cohesion), would be crucial in developing students' skills to high standards in engineering education. Each tool (e.g. blogs and Twitter) has its distinct role and provides complementary support to the CoI, as Popescu and Badea (2020) noted in their study on a social media-based learning environment in which they used an extended four-component version of the CoI, including a learning presence.

2.2.5 Integrated Curriculum

In the current study, PjBL was conducted in the context of an integrated curriculum approach. The growing interest in an integrated curriculum has been actively discussed since the 1980s (Jacobs, 1989) and is increasingly growing, although its definition is still imprecise and under discussion (Drake & Burns, 2004, p. 8; Drake & Reid, 2020; Junevicius et al., 2021). Drake and Burns (2004, p. 8) provided a definition based on approaches that are seen as a continuum (Drake & Reid, 2020) in curriculum integration, such as fusion, multidisciplinary, interdisciplinary and transdisciplinary. The terms 'multi-', 'inter-' and 'transdisciplinary' are often considered synonymous, but there are some distinctions between them (Fawcett, 2013; Stock & Burton, 2011). Drake and Reid (2018) found that *fusion* is often the first way to start curriculum integration. For example, it requires critical literacy to be included in a subject-specific curriculum (Drake & Reid, 2018). In a *multidisciplinary* curriculum, a similar theme is addressed in different subject areas, as exemplified by Drake and Reid (2018) in terms of identity, which could be addressed in terms of geography mapping, history citizenship, literature characterisation and scientific classification. In the *interdisciplinary* approach, subjects are less distinct, and skills are taught across different subject areas (Drake & Reid, 2018). For example, Drake and Reid (2018) cited the application of critical thinking to the development of a social justice campaign around a local issue, such as homelessness or water quality. In a *transdisciplinary* curriculum, subjects are holistically blended around the question, crossing subject boundaries and focusing on a question, issue or problem (Drake & Reid, 2018). An example of this is the issue given to students concerning controversial perspectives on citizenship in public spaces (Drake & Reid, 2018). In the case of a transdisciplinary approach, this is a paradigm shift in which the real-life context is emphasised and the teacher can be seen as a colleague or specialist (Drake & Burns, 2004, p. 17). The study described in this dissertation is primarily a transdisciplinary approach (Drake & Burns, 2004, p. 17) to an integrated curriculum. Based on Drake and Burns' (2004, p. 17) classification, the transdisciplinary approach in this study can be justified by the roles of disciplines, which are identified by courses, but the real-life context at the centre is emphasised. Co-planner, co-learner and specialist are emphasised in the roles of instructors. The degree of integration is holistically blended (Drake & Reid, 2018), encompassing the entire curriculum and semesters, in which case a paradigm shift is required.

Recently, some articles have been published on integrated curricula in HE. An integrated curriculum has been examined in the context of sustainability (Carey et al., 2021; Herrera-Limones et al., 2020; Tabucanon et al., 2021), team teaching (Vesikivi et al., 2019), teacher education (de Sousa Borges et al., 2021) and multiliteracy (Rasi et al., 2019). An integrated curriculum design framework to assist institutions to proactively design, develop and deliver curricula for stakeholders has even been provided (Murphy & Curran, 2020). For instance, at Metropolia University of Applied Sciences, a shift towards a problem- and project-based pedagogical approach has taken place, integrating teaching of communication and teamwork skills in addition to information technology through modules comprising 15 European credit transfer and accumulation system (ECTS) credits as part of the curriculum (Holvikivi et al., 2016; Vesikivi et al., 2019). The development of an integrated curriculum has also been examined. Rasi et al. (2017) asserted that curriculum development is a multi-step process that also involves gathering students' experiences. An integrated curriculum with PjBL has been mentioned mainly in the context of the conceive–design–implement–operate (CDIO) approach (Crawley et al., 2014). See, for example, articles by Le and Do (2019), Nguyen (2017) and Säisä et al. (2017). CDIO is an international organisation focused on the systematic development of engineering education and that offers standards for the development of syllabus (www.CDIO.org, n.d.). The goal of the CDIO approach is to support students in developing a deep understanding of technical fundamentals and professional skills based on mutually supportive subject courses and engineering projects in an integrated curriculum (Edström et al., 2020). In the recently updated CDIO 3.0 standard, the aim of an integrated curriculum is expressed as follows: 'A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, system and service building skills' (Malmqvist et al., 2020, p. 65).

2.3 Digital Resources for Learning

The third key aspect for a digital learning ecosystem is digital resources, such as digital tools, platforms and learning resources. New educational technologies are emerging as a result of the overall progress of technology and societal development (Scanlon, 2021). In HE, the focus is on the benefits and opportunities of these technologies and their ability to support the learning process (Shpeizer, 2019). Whereas educational psychology explores learner-centred approaches (Massouleh & Jooneghani, 2012), educational technology research focuses on bringing technological innovation to the classroom (Müller & Wulf, 2020), in which the most important trends are identified as personalisation, social learning, learning design, ML and data-driven improvement (Scanlon, 2021). However, Bozkurt (2020) expressed concern about the efforts to integrate technologies into educational processes, taking into account the sociality and contextuality of learning. This requires adaptation, not integration, which, according to Bozkurt (2020), essentially means combining two things with a planned series of events. Bozkurt (2020) urged us to think about whether one should learn with technology or from technology.

In engineering education, especially students in ICT engineering education who are considered 'digital natives' (Margaryan et al., 2011; Šorgo et al., 2017), it is easier to introduce new technologies and systems in principle. It should be noted that in the case of digital natives, technical skills are highlighted, but media literacy as a 'skill set that promotes critical engagement with messages produced by the media' (Bulger & Davison, 2018, p. 3) is generally controversial for them (Rodríguez-Abitia &

Bribiesca-Correa, 2021; Šorgo et al., 2017). It is not sufficient for students to possess only technical skills; they must also be able to adapt rapidly to the technologies and methods utilised in industry. Therefore, individuals need to learn to communicate, interact with different actors and exploit digital tools and environments used in the industry. It is necessary to support these working life skills during their studies by providing students in the digital ecosystem with the most authentic learning environment possible, which substantially lowers the threshold for moving to work.

2.3.1 Learning Management System (LMS)

In many universities, LMSs serve as the primary learning environment. LMSs are a platform that provides educators with the tools and resources they need to create, manage and deliver courses. These techno-social systems (Turnbull et al., 2022) provide learners with a time- and place-independent online learning environment, serving as a portal to individual courses and study units. Typical contents of these virtual classrooms include assignment management instructions, discussion forums, assignment return boxes and learning material resources. Proprietary and purchased systems (e.g. canvas and Blackboard Learn) and open-source LMS platforms (e.g. Moodle and Sakai) are available depending on institutions' budgets and requirements. The possibility of integrating the system with other systems is considered a strength (Kasim & Khalid, 2016). The learning analytics (Fahd et al., 2021; Hernández-de-Menéndez et al., 2022; Macfadyen & Dawson, 2010; Tamada et al., 2022; Zhang et al., 2020) connected to the systems offer instructors a view of the statistics of the learning process of the group and individual students. With personalised solutions (Chang et al., 2022) and even ML techniques (Kanokngamwitroj & Srisa-An, 2022), it is possible to offer students individual learning experiences.

The results of Lonn and Teasley's (2009) study on the use of LMSs indicated that document and communication management tools (e.g. content sharing, announcements, assignments and syllabi) were often rated more valuable than the interactive tools (e.g. chat, discussion and wiki). Furthermore, teachers valued effective communication slightly more than students. The use of interactive tools was also found to be less in the study of the mobile use of Moodle (Hu et al., 2016). However, interactive learning activities and constructive dialogue can both be considered to encourage a deep approach to learning, development of communication skills and understanding of content (Kember et al., 2010). When examining user satisfaction with platforms, it is important to consider the quality of the service, implemented services and their content, learners' perspective, instructors' attitudes and supportive issues (Ozkan & Koseler, 2009). In addition, the architectural requirement to determine solutions plays a significant role. Gorshenin (2018) listed this requirement as storing all data on a server, including learning materials and tests. Students should also have the ability to access learning materials on diverse subjects and receive feedback from teachers and other students. Therefore, there is a demand for numerous features, but technical complexity has been found to have a negative effect on ease of use (Lavidas et al., 2022). The acceptance of LMSs in HE communities has been studied, but the results are still limited (Al-Nuaimi & Al-Emran, 2021).

It can be concluded that technological development has led to the need to incorporate social features to improve functionality (Krouska et al., 2017). Alhazmi et al. (Alhazmi et al., 2021) called for the rapid development of more advanced communication and content-sharing features. Although LMSs have added features such as wikis and blogs to their offerings, their technologies have not developed enough to keep up with online communities (Ferretti et al., 2018). LMSs have been criticised for being teacher-centred (Green & Chewning, 2020). Ferretti et al. (2018) also criticised LMSs because their design did not take into account the social constructivism approach to support lifelong learning.

2.3.2 Open Learning Platforms

In addition to LMSs, there are numerous e-learning platforms, online academies, websites and software applications that enable the delivery of educational content and resources to students over the internet. Their contents range from simple static websites to more complex systems with interactive elements, such as assessments, simulations and collaboration tools. Some online learning platforms are self-paced, whereas others are more structured and may include synchronous or asynchronous discussions, lectures and other interactive activities.

Open educational resources (OERs) have grown in popularity (Sandoussi et al., 2022). They are freely accessible and openly licenced resources for use by the public. UNESCO (2022, p. 5) defined OERs as 'learning, teaching and research materials in any format and medium that reside in the public domain or are under the copyright that has been released under an open licence, that permits no-cost access, re-use, re-purpose, adaptation and redistribution by others'. With the paradigm of open education, the main goals of OER are to increase the availability of educational resources, reduce the production costs of educational organisations and lower the educational costs for students (Menzli et al., 2022; Sandoussi et al., 2022; Tlili, 2021).

OER variants include OpenCourseWare (OCW), which is a university-level open and free online publication material structured into courses, and massive open online courses (MOOCs), which are open to all and are mostly regulated online courses with no formal entry requirement (Adu et al., 2022). Perhaps the most well-known OCW is Massachusetts Institute of Technology's, or MIT's OpenCourseWare published in 2001 (Knox, 2013). Examples of MOOCs are Coursera in the United States and Future Learn in the United Kingdom (Menzli et al., 2022). The most important difference between OCW and MOOCs is probably the degree of openness: whereas OCW is completely free without performance principles and a certification, MOOCs can be paid and based on schedules and completion criteria, ending with a certification (Adu et al., 2022). Stracke et al. (2019) considered MOOCs as enablers of innovative learning processes and experiences. In this sense, they are not resources but learning opportunities and environments for self-regulated and collaborative learning. The nationwide Digivisio 2030 project (Digivisio 2030, 2021) corresponds to OER principles, as it also offers individual learning paths for self-regulated learning.

Overall, some MOOCs may provide course credits or certification, whereas others are solely for personal enrichment or professional development. They encourage lifelong learning (UNESCO, 2021, p. 26). However, in both cases, the learning process also needs support; for example, it is possible to develop virtual assistants to answer students' questions in real time (Tlili et al., 2021). However, providing immediate feedback and student self-regulation can prove challenging; thus, the opportunities offered by ML techniques should be taken into account (Tlili et al., 2021). In any case, as OERs and MOOCs require self-direction, they may also require a high level of self-motivation. Furthermore, at the educational institution level, practitioners are encouraged to make wider use of OERs' capabilities, but they are also reminded to consider the service's two-way nature—to produce content themselves (Menzli et al., 2022).

2.3.3 Team Collaboration and Developer Platforms

One of the most significant digital resources of this research is team collaboration platforms. These platforms for virtual teamwork are online tools that enable teams to collaborate, share documents and communicate in real time. In education, these platforms are commonly used to facilitate collaboration and communication among students and instructors. TCPs are also used in industry to facilitate collaboration and communication between employees, especially in distributed or remote teams. After the pandemic, platforms such as Canvas, Asana, Slack and Microsoft (MS) Teams have been widely adopted and popularised (Squillaro, 2021).

Collaboration platforms or tools are simply defined as those 'that enable remote collaboration' (Lomas et al., 2008). These tools are often associated with the concept of computer-mediated communication (Papathoma, 2022; Tuhkala et al., 2018), which refers to synchronous or asynchronous communication between people through the use of computers and computer networks (Tuhkala and Kärkkäinen, 2018). This definition emphasises the social media likeness of the platforms. According to Carr and Hayes (2015, p. 50), these are 'internet-based channels that allow users to opportunistically interact and selectively self-present, either in real-time or asynchronously, with both broad and narrow audiences who derive value from user-generated content and the perception of interaction with others'.

TCPs have also been used to expand the communication gaps of learning management systems (e.g. Ross, 2019). Hyman et al. (2022) found that using a collaboration tool increased student engagement, especially in an asynchronous online environment. Susanti (2021) obtained similar results in the use of the MS Teams platform, in which student commitment could be assumed to increase through stronger cooperation and participation. Electrical engineering laboratories and collaborations on the MS Teams' TCP have even been found to be enjoyable by engineering students (Ma et al., 2021). However, Sobaih et al. (2021) found that university students did not view MS Teams as an effective platform for obtaining support from their peers and instructors. By contrast, in Tuhkala and Kärkkäinen's (2018) study on computer-mediated communication, the Slack platform was found to facilitate asking questions by lowering the threshold for doing so.

Developer platforms are designed to facilitate collaboration among developers and help them stay organised as they work on ICT projects (Peng et al., 2014). Platforms provide tools for version control (Zolkifli et al., 2018), task management and communication, among other things. Some popular developer collaboration platforms include Git repositories, such as GitHub and GitLab (Herbsleb, 2021), and Atlassian's Bitbucket and Jira, Microsoft Azure DevOps and Pivotal Tracker. These platforms provide features such as version control, which allows developers to track changes to the code over time, and task management, which helps developers keep track of the tasks they need to complete and collaborate with others. In addition to these features, many developer collaboration platforms also offer tools for communication, such as chat rooms, forums and wikis, which can help developers stay connected and collaborate more effectively. Developer collaboration platforms are an important tool for engineering and programming teams because they help streamline the development process and improve communication among team members. There are a few examples in the literature in which collaborative developer platforms have been used, such as in learning programming skills (Angulo & Aktunc, 2019; Szynkiewicz et al., 2020). There also seems to be a gap in studies on the comprehensive use of team communication and developer platforms in learning before the pandemic, but the pace is expected to accelerate, as pandemic experiences are taking root in more permanent educational practices.

3 RESEARCH QUESTIONS

The primary research question addressed in this dissertation is as follows:

What are the design principles and characteristics of a digital learning ecosystem that align with the needs of stakeholders and the policies in ICT engineering education?

The main methodology used in the three sub-studies was the design-based research, which facilitated the collection of data from stakeholders through diverse data collection and analysis methods. These sub-studies are described in three scientific articles related to this dissertation and are later summarised in Section 4 of this summary.

The impetus for the initial activities was to understand the current state and expectations in ICT engineering education. The first sub-study presents the first phase—analysis and exploration—of the first cycle in the DBR, examining the ideas and experiences of stakeholders, such as students, staff and industry representatives, in the PjBL approach in ICT engineering education. The stakeholders also provided perspectives on transferring activities to an online environment. The sub-questions of sub-study I are as follows:

1) *How do stakeholders experience the current curriculum, ecosystem and project-based learning framework?*
2) *What thoughts and expectations do stakeholders have for ICT engineering education over the next few years?*

In sub-study II, how the solutions formulated based on the results of sub-study I were performed in this first iterative cycle was investigated. The perspectives from sub-study I were analysed and formed into intervention components as preliminary design principles, which were exported to sub-study II to present the rest of the DBR phases in the first cycle. In sub-study II, students were exposed to a blended learning approach in a digital learning environment supported by the team collaboration platform. Learning experiences were examined through the theoretical lens of CoI (Garrison, 2016). Sub-study II addressed the following research questions:

3) *How do students experience the team collaboration platform in terms of teaching, social and cognitive presence?*

4) *How do students use team collaboration and developer platforms?*

In sub-study III, the intervention was designed and updated based on the results of the previous DBR cycle. The intervention components were further refined as preliminary design principles in preparation for the next cycle, which was conducted in sub-study III. The learning experience in the digital learning ecosystem was examined in a fully online environment. The original intention was to maintain a blended learning solution in line with the main goal, but due to the COVID-19 pandemic, the iteration took place entirely in an online environment. To this end, the following question was asked in sub-study III:

5) *How do students experience TP, SP and CP in an online environment?*

To address the main research question, the preliminary design principles of all three sub-studies were ultimately synthesised and reflected into a design framework. This framework encompassed eight final design principles for a digital learning environment of ICT engineering.

4 RESEARCH DESIGN

In this chapter, the iterations and sub-studies positioned in the layout of the overall design-based research, the curriculum and the context are presented. The principles of design-based research methodology and its application in this study are described. A summary of the three empirical studies is presented, and the context of each sub-study, the participants, the data collection and analysis methods and the contributions of the results to the main and sub-study questions are examined. At the end of each sub-study, specifications of the design requirements for the starting points of the next sub-study are presented. For clarity, it should be noted that in this study, design requirement refers to the preliminary design principles based on the DBR methodology. These design principles synthesised based on the design requirements are described in Chapter 5.

4.1 Overall Research Design

This study was conducted as a DBR, which is well suited for designing educational interventions (Design-Based Research Collective, 2003) and producing design principles that inform the intervention (Gundersen, 2021; Kolmos, 2015; van den Akker, 1999). Due to the pragmatism and complexity of the intervention (Edelson, 2006; Kolmos, 2015; Wang & Hannafin, 2005), DBR can be considered highly suitable for this study, as one of its primary objectives is to establish a strong connection between educational research and real-world problems (Amiel & Reeves, 2008; Collins et al., 2004; Kolmos, 2015). The suitability of DBR for the present study is further supported by its iterative and collaborative nature, as this study was designed and developed in close collaboration with instructors (Gundersen, 2021). A summary of the sub-studies with the methodology and current DBR cycle and phase are presented in Table 1.

To address the research questions, data were gathered from various sources, including previous empirical research, students, instructors such as teachers and R&D personnel from the Digital Solutions unit at the Lapland UAS, industry representatives and server data from the platforms used. This approach converged the data collected to enhance the credibility of the findings (Hesse-Biber, 2010, pp. 1–6). As both qualitative and quantitative evaluations are an essential part of the design research methodology (Collins et al., 2004), qualitative and quantitative methods were used, and data were collected from multiple sources using several instruments, such as online questionnaires and interviews, visual data of mind maps and server logs. These data collection methods and instruments are also summarised in Table 1 and explained in more detail in the following chapters.

Table 1

The DBR Process in the Years 2019-2022

DBR Phase		Research Questions	Sub-studies	Participants	Pedagogical approach and context	Data collection methods and Instruments	Data	Data analysis methods
First cycle	Phase I: Analysis of the experiences and expectations of stakeholders	1) How do stakeholders experience the current curriculum, ecosystem and PjBL framework? 2) What thoughts and expectations do stakeholders have for ICT engineering education over the next few years?	Sub-study I: Mielikäinen, M. (2022). Towards blended learning: Stakeholders' perspectives on a project-based integrated curriculum in ICT engineering education. *Industry and Higher Education, 36*(1). 74–95.	All third-year students, instructors and industry representatives	Project-based and integrated curriculum on site	Semi-structured interview and survey questions based on Collins' (2014) characterised variables	Interview data from third-year students (N = 27). Survey data from instructors (N = 15) and industry representatives (N = 3).	Qualitative content analysis using NVivo version 12.
	Phases II–III: Piloting TCP-supported PjBL in the integrated curriculum context and blended learning environment as the CoI	3) How do students experience the TCP in terms of TP, SP and CP? 4) How do students use team collaboration and developer platforms?	Sub-study II: Mielikäinen, M., Viippola, E., & Tepsa, T. (2023). Experiences of a project-based blended learning approach in a community of inquiry from ICT engineering students at Lapland University of Applied Sciences in Finland. *E-Learning and Digital Media*. 20427530231164053.	All second- and third-year students	CoI: Project-based and integrated curriculum in a blended learning setting supported by TCP and developer platforms	CoI survey Server data from Mattermost and GitLab	Survey data from students (N = 56) Server data from Mattermost and GitLab	Rasch RSM analysis using R version 3.6.2 and RStudio 1.2.5033. TAM version 3.7 for R was used for the rating scale models.
Second cycle	Phases I–III: Enhanced empirical experiment on students' experiences in an online environment as a CoI	5) How do students experience TP, SP and CP in an online environment?	Sub-study III: Mielikäinen, M., & Viippola, E. (2023). ICT engineering students' perceptions on project-based online learning in community of inquiry (CoI), *SAGE Open.*	All first, second- and third-year students	CoI: Project-based and integrated curriculum in an online learning setting supported by TCP and developer platforms	CoI survey Open questions	Survey data from students: CoI survey (N = 79), open questions (N = 77)	Rasch RSM analysis using R version 3.6.2 and RStudio 1.2.5033. TAM version 3.7 for R Qualitative content analysis using manual techniques

Curriculum and Context of the Study

The Lapland UAS' four-year (240 ECTS) competence-based integrated curriculum was developed in 2017 and revised in 2021 for ICT engineering education's daytime groups. It consists of semesters (30 ECTS each) in which the semester courses, each with 5 ECTS, are integrated into an authentic, industry-based project. The extent of horizontal integration (i.e. the integration of parallel subjects into the learning stage) (Zhang et al., 2020) usually varies from 20 to 30 ECTS per semester, depending on the placement of the internship course in the curriculum.

In the initial situation, the project assignments for the semester mainly depended on the content of active, industry-specific R&D projects conducted by the R&D personnel of the ICT education unit in relation to the objectives of the study units during the period. Responsible teachers formed a teacher team for the semester in the ICT engineering education unit (Angelva et al., 2017), with the task of completing the semester by designing, guiding, supporting, monitoring and evaluating the implementation with the support of the R&D personnel. The assessment methods and criteria for the courses were distributed through learning management system Moodle.

From the point of view of the project-based learning approach, project management methods as discipline standards commonly used in the field must also be applied to learning tasks. In ICT engineering education at the Lapland UAS, the learning process of project management involves familiarising students with the PMBOK concept (PMI, Project Management Institute, 2021) in their first year of study. They acquire fundamental teamwork skills and develop the necessary documentation, such as project plans, meeting memos, risk analyses and closing reports. This comprehensive approach to project implementation and management ensures that students consider stakeholder needs and requirements. In the second year of study, agile methods, such as Scrum (Gonçalves, 2018; Pries & Quigley, 2010; Rising & Janoff, 2000; Takeuchi & Nonaka, 1986), are introduced and applied in practice, which naturally succeeds in accumulating the project management principles learned in the previous year. In addition to the actual project planning and closing reports, the students' project teams engage in various activities, such as designing sprints, creating backlogs, prioritising tasks, scheduling, follow-up and reflection. The instructor team organises Scrum reviews at regular intervals at the end of the sprints, and the students document and monitor the progress of their projects by creating and maintaining backlogs and holding daily scrums and retrospectives at the end of sprints. In the third academic year, project management expertise has expanded further, especially through quality assurance and more advanced development methods, such as DevOps (Almeida et al., 2022; Bobrov et al., 2020; Ebert et al., 2016). Each semester project ends with a project exhibition organised by the ICT engineering education unit, in which students concretely present the outputs of their projects to the public. The closing ceremony provides important expertise in the engineering profession in terms of presentation skills and certainty, facing customers and naturally understanding the importance of a controlled and high-quality completion of the project.

It should be mentioned that in the curriculum reform in autumn 2021, the curriculum structure was changed so that no semester project was organised in the spring semester of the first study year, but studies progressed as silos. This is due to the internal numerical goals related to lifelong learning of institutions, which aim to involve non-degree students in learning with the opportunity to study individual courses. However, in light of recent experience and feedback, the PjBL approach may also return this semester.

4.2 Design-based Research Approach

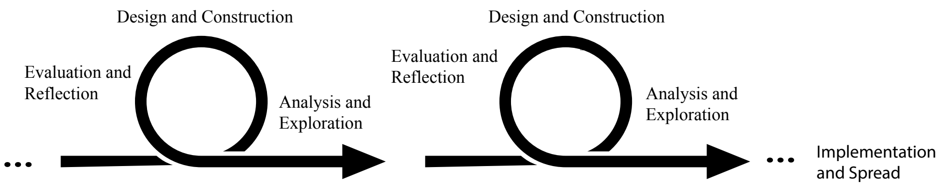
Design-based research can be considered to be based on Brown's (1992) theory of design experiment, which aims to transform classrooms into learning environments, encouraging reflective practice among students, teachers and researchers. Collins (1992) reported that design theory determines the dependent and independent variables affecting the success or failure of plans. He outlined the factors considered critical and provided an example of their application in developing a method for conducting design experiments. This theory can also be considered the basis for the methodology (Collins et al., 2004).

In DBR, knowledge is generated simultaneously from both practice and theory (Goff & Getenet, 2017). It is argued to help create and extend knowledge about the development, adjustment and sustaining of innovative learning environments (Design-Based Research Collective, 2003). DBR is characterised by an iterative design and formative research in complex real-world conditions (Edelson, 2002). As a pragmatic research approach (Kolmos, 2015; Wang & Hannafin, 2005), DBR seeks to increase the impact, transfer and translation of education research into improved practice, emphasising the need to build theory and develop design principles (Anderson & Shattuck, 2012). In addition to developing solutions to complex and practical educational design problems, it also provides a context for empirical research that produces theoretical understanding (McKenney & Reeves, 2019, p. 6). The set goals are achieved through disciplined and systematic research combined with creative innovation (McKenney & Reeves, 2019, p. 163). DBR results in a set of design principles or guidelines that can be applied to similar environments (Amiel & Reeves, 2008). Whereas other types of studies utilise the results of the process, problem analysis and design solutions to create a successful design product, design research adds to it the development of generalisable theories (Edelson, 2002). DBR typically involves mixed methods using a variety of research tools and techniques (Anderson & Shattuck, 2012).

In the literature, the methodology terms 'design research' (Edelson, 2002; McKenney & Reeves, 2019; Reeves et al., 2005), 'development research' (van den Akker, 1999) and 'design experiment' (Brown, 1992; Collins, 1992) have also been used interchangeably (Euler, 2014). Wang and Hannafin (2005) conducted a comprehensive examination of various terms describing the paradigm and concluded that while the emphases may vary, the underlying principles and approaches are similar. The DBR process, along with its steps, has been described in several different ways, and the number, purpose and objectives of the phases and the designation differ. For example, Bannan-Ritland's (2003) model has nine phases, beginning with identifying the problem area and ending with publishing/presenting the results. Reeves (2006) summarised the phases into four: a) analysis through collaboration by researchers and practitioners, b) development of solutions, c) iterative cycles of testing and refinement of solutions in practice and d) reflection to produce design principles and enhance solution implementation. Easterday et al. (2014) described six iterative phases: focus, understand, define, conceive, build and test. The current study applied the DBR process defined by McKenney and Reeves (2019). Their iterative process includes four core processes (Figure 4), the three of which (i.e. analysis and exploration, design and construction, and evaluation and reflection) interact in practice through the fourth core process (i.e. implementation and spread of interventions).

Figure 4

The Ideology of the Iterative Cycles of the DBR



Note. Adapted from McKenney and Reeves (2019).

This study included two DBR cycles of iteration, each consisting of three phases, as shown in Figure 4. The fourth phase (i.e. the actual implementation and spread) is in progress. Table 2 shows the DBR phases, the main activities and the results of McKenney and Reeves (2019, pp. 89–222), which are summarised and connected with this study in more detail in the following sections.

Table 2
The DBR Process

Phase of DBR Process	Main Activities	Main Outputs
Analysis and exploration	Context analysis Needs assessment Literature review Networking	Problem definition Articulation of long-range goals
Design and construction	Exploring solutions Mapping solutions Construction	Design ideas and specification Prototype of intervention
Evaluation and reflection	Empirical tests Analysis	Test results Reflection of findings
Implementation and spread	Adoption, Enactment, and Sustained maintenance	Dissemination Diffusion

Note. Adapted from McKenney and Reeves (2019).

According to McKenney and Reeves (2019), in the *analysis and exploration phase*, the origins, observations and causes of the problem are addressed through context analysis and a literature review. Cooperation with the stakeholders involved in the problem can improve the understanding of the problem. The results of the analysis phase define the problem and the long-term goals. The resulting design requirements are only preliminary and partial in relation to understanding the context and needs. To understand the jurisdiction of change, it is necessary to determine which factors are changeable and which do not change.

The first phase of the first cycle of the current DBR included a context analysis that mapped the general requirements for engineering education, the experiences and the expectations of stakeholders for further analysis. The results provided a perspective on the problem areas and starting points for the subsequent phases of the first iteration. At the beginning of the second cycle of iteration, the results and design requirements of the first cycle were exposed to the definition and analysis of problem areas, forming the starting point for the subsequent phases of the iteration. Theoretical and empirical literature were used to deepen the understanding of the target area.

Input for the *design and construction phase* can come from the phases of analysis and exploration, evaluation and reflection, or interaction with practice through implementation and spread (McKenney & Reeves, 2019, p. 126). This phase produces products as a starting point for the design. Ideas are further developed and refined to map solutions. The development of ideas needs to be documented to understand the process, which is especially essential in educational design research.

While design requirements define the criteria for action, design proposals provide guidance for achieving a long-term goal. Information is sought from a literature review to design a solution. It should be noted that in the analysis and exploration phase, the purpose of the literature review was to increase the understanding of the problem. Design proposals served the theoretical objectives of design research by providing a starting point for a theoretical framework. After designing the solutions, the actual intervention components were developed. The different approximations of the constructed solution (i.e. prototypes) were refined through common project management strategies and methods, such as time management, phasing and resourcing. McKenney and Reeves (2019, p. 148) compared prototyping in educational design research with engineering and solving real-world problems; early prototype versions were often discarded, and mock-ups began to stabilise later.

In the current study, in the design and construction phases, solutions were explored based on the design requirements raised from the previous phase. The prototypes of the intervention were designed and constructed in the first and second iteration cycles. A relevant literature was used to support the solutions.

According to McKenney and Reeves (2019, p. 161), in the *evaluation and reflection phase*, ideas and solutions are explored empirically. A reflection on the results provides an understanding of the functionality of the intervention features. Evaluation guides the development of interventions and should be informed, systematic and formalised. For McKenney and Reeves (2019, p. 161), evaluation is any kind of data collection that provides an idea of the intervention planned and constructed, while reflection is about retrospective results. After the empirical cycle of planning (e.g. selecting strategies and methods), fieldwork (e.g. preparing instruments and collecting data) and meaning making (e.g. analysing data and reports), the evaluation shows the effects of the intervention, and reflection helps to explain the results. According to McKenney and Reeves (2019, p. 190), a theoretical understanding is developed through evaluation and reflection, from which it is possible to formulate design principles that can be used in similar interventions and to refine the work in progress.

Stakeholders' experiences with the intervention of this DBR were evaluated empirically after data collection in the evaluation and reflection phase of both iteration cycles. The findings and reflection of the iterative cycles resulted in the design requirements and, finally, the synthesised design principles for the digital learning ecosystem.

The implementation and spread phase starts immediately from the first analysis and exploration phase, in which a realistic assessment is made of what can be accomplished by addressing the concerns of practitioners (McKenney & Reeves, 2019, p. 199). Implementation can be divided into three main stages: adoption (decision to use an intervention), enactment (fidelity and integrity during implementation) and sustained maintenance (efforts to maintain intervention without external support). McKenney and Reeves (2019, p. 203) noted that the term ‘spread’ refers to the propagation of designed interventions or their ideas to settings outside the initial field-testing context. Interventions and their underlying ideas spread through dissemination (information about an intervention is spread widely to raise awareness) and diffusion (interventions are pulled into practice from within).

Based on this, McKenney and Reeves treated the implementation and dissemination phases practically as a separate process from the iteration phase. In the current study, adoption, enactment and sustained maintenance after revisions are underway in the ICT engineering education of the Lapland UAS through continuous improvement. In addition, there is an ongoing effort to disseminate the findings beyond the field testing context.

DBR resembles action research in some respects. Both design research and action research focus on practical problems and are conducted in a real environment with the active involvement of actors. The difference is that action research does not aim to generate design principles (Anderson & Shattuck, 2012; Plomp, 2013). Anderson and Shattuck (2012) found that the distinction between action research and DBR is often difficult to distinguish due to several common epistemological and ontological criteria. According to Cole et al. (2005), from an ontological point of view, the phenomenon of interest does not remain static through the application of the research process, and from an epistemological point of view, both research approaches subscribe to assuming a mode of knowing that involves intervening to effect change and reflecting on this intervention. Action research is usually conducted by the teacher alone without the expertise of the DBR’s research and design team (Anderson & Shattuck, 2012). In the present study, the design team was formed by the instructors during the semesters.

DBR is based on close cooperation between researchers and practitioners (Kolmos, 2015; van den Akker, 1999) in which the researcher is an active participant (Barab, 2006, p. 157). Practitioners are not usually involved in the research design process. However, Amiel and Reeves (2008) suggested that DBR should begin with the negotiation of research goals by practitioners and researchers, as practitioners would be able to identify problems that require research while establishing research questions and identifying problems. Different participants bring different expertise to both design and analysis (Barab & Squire, 2004). Researchers have the opportunity to directly affect education and promote understanding (Edelson, 2002). Therefore, the success of innovation can be seen as dependent on sustaining a partnership between researchers and teachers (Design-Based Research Collective, 2003). In this study, the researcher closely collaborated with the instructor team to design the intervention and was also able to influence the implementation.

4.3 Sub-study I: Stakeholder Perspectives

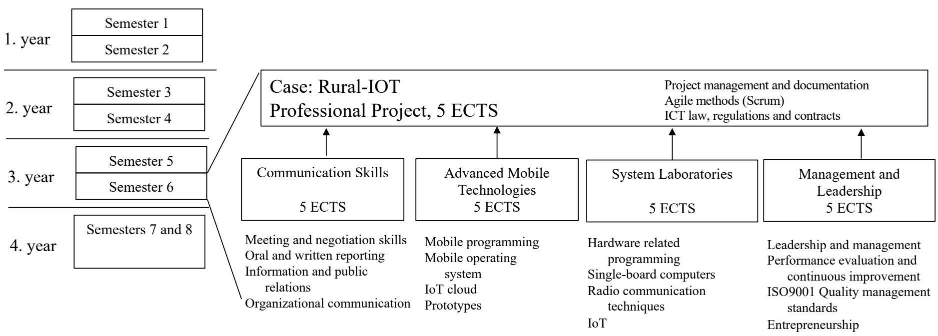
The first sub-study (Mielikäinen, 2021)—the analysis and exploration phase of the first cycle of the DBR—included an in-depth review of the stakeholders' thoughts and experiences regarding the current ecosystem in ICT engineering education in spring 2019 before the COVID-19 pandemic. The following research questions describe the aim of sub-study I: RQ1) How do stakeholders experience the current curriculum, ecosystem and project-based learning framework? RQ2) What thoughts and expectations do stakeholders have for ICT education over the next few years? The answers were utilised in the subsequent phases and cycles of the DBR intervention as design requirements—that is, as preliminary design principles.

4.3.1 Research Setting

The context at the time of sub-study I was an integrated PjBL approach for third-year students. The semester included a semester project with 5 study units of 5 ECTS, including the professional project course as an integrator at the core. The courses and the main content of the semester are presented in Figure 5. The semester also included an off-site internship of 5 ECTS, which was excluded from the semester project.

Figure 5

Integrated Semester Project for Third-Year Students in Spring 2019

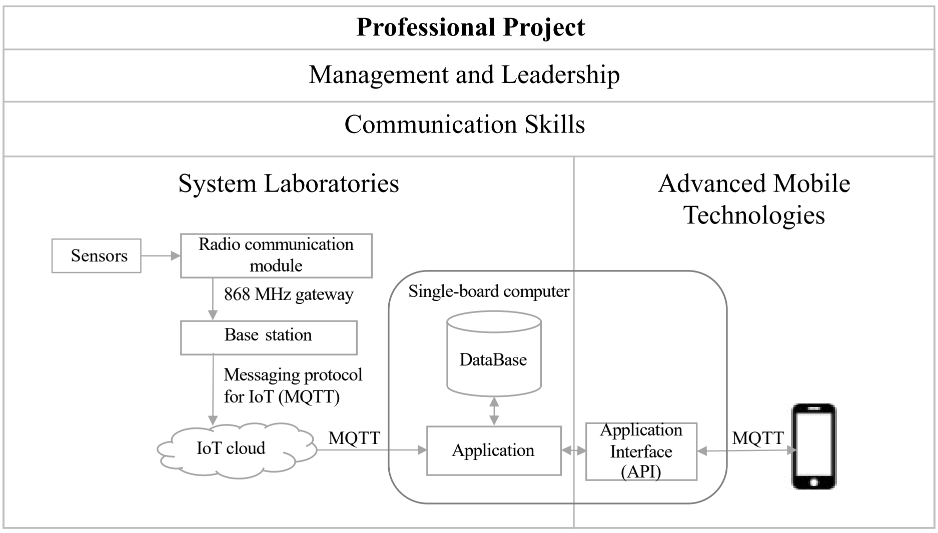


The context theme for the semester project was chosen as project RURAL-IOT (IoT Innovations for Sensing and Positioning in Rural Areas; IoT, Internet of Things) (Vatanen et al., 2019) because the goals and contents of the courses could be adapted to the project's technologies and goals. The purpose of the original project, funded by the Regional Council of Lapland, was to create innovations in Lapland that utilise low-cost, low-power and mobile IoT applications in areas with poor telecommunication connections and no electricity. An authentic learning assignment was designed as follows:

> 'Innovate and build a prototype for a product that is low power and low cost and utilises LoRa (Long Range) wireless communication technology. The product should be suitable for environmental monitoring'.

Students were presented with an architecture that utilised the LoRa and the Pycom module. LoRa is a radio communication technique at a frequency of 868 MHz, and Pycom is the device manufacturer. Sensors, such as for a global positioning system GPS, accelerometer, temperature, pressure, humidity and light, were connected to the radio communication module. Message queuing telemetry transport (MQTT) is a messaging protocol widely used in the IoT and mobile systems. This architecture is shown in Figure 6 with the ontology of the integration of courses.

Figure 6
RURAL-IOT Architecture Principles with the Ontology of Integrated Courses.



Project management was carried out using the Scrum method, which was described earlier in conjunction with industry-based methods and concepts. The semester began with an introductory phase in which students became familiar with the selected technologies and methods. In the design phase, students came up with ideas and innovated, after which they proceeded to the project planning phase. The subsequent lessons of the courses were reserved for students of laboratory work in which they received guidance and support. The actual project work was conducted through Scrum sprints, during which prototypes were developed in workshops held at campus laboratories. The procedures had to comply with general industry practices. The technical expertise of the teachers and R&D project staff supported the students throughout the semester.

Stakeholders who represented different perspectives on the problem under study were invited for the analysis and exploration phase of the first cycle of the DBR in autumn 2019 (described in sub-study I). In addition to students, these stakeholders comprised teachers and R&D personnel as instructors, operational management and industry representatives. All third-year ICT engineering students (N = 33) who had already participated in several semester-wide PjBL implementations during their studies were invited as student representatives. Their views as a target group can be considered to represent the views of the first priority. All instructors, such as teachers and R&D staff, and operational management (N = 15) were also invited to participate in the study, representing the organisational perspective of the intervention. Members of the ICT Advisory Board, formed by representatives of the ICT industry (N = 20), were invited as representatives of the industry. Consisting of national and provincial industry representatives, this advisory board is an unofficial cooperation association for ICT engineering education at the Lapland UAS.

4.3.2 Data Collection Methods

Semi-structured Interviews

In sub-study I, data were collected qualitatively through semi-structured interviews and surveys. Collins et al. (2004) suggested viewing the intervention from different aspects that are relevant to educational design, such as the cognitive level, interpersonal, group of a classroom, resource and institutional level. Furthermore, it is important to evaluate the success of innovations through the variables described in Table 3. Originally, Collins et al. (2004) specified that this was done to determine how particular independent variables affect a few dependent variables. There is a web of interrelations between dependent and independent variables, with changes in any variable affecting other variables. Although Collins et al. suggested using variables to assess an ongoing intervention through various observation techniques, in the current DBR, a variable framework was used specifically during the analysis and exploration phase to evaluate the baseline and target status prior to the actual design and construction phases of the first cycle of intervention. For these reasons, it is also not necessary to consider the division into independent and dependent variables but rather to look at the overall context holistically through the variables provided by the framework.

Interview themes and 64 supporting questions were derived using deductive reasoning, which was based on the previously described characterised variables of Collins et al. (2004) relevant to educational designs, and inductive reasoning, which was applied to identify meaningful subjects according to the research questions.

Table 3 provides a summary of these variables, subcategories and indicator examples. Table B1 in Appendix B shows the variables identified by Collins et al. (2004) that are relevant to the research questions, the student interview topics and the auxiliary questions derived from them.

Table 3
Variables, Categories and Indicator Examples

Variable	Categories	Indicator (examples)
Climate	Engagement Cooperation Risk taking Student control	Degree of engagement of students in learning in the classroom, the degree of cooperation among students in the classroom, and the degree of effort students are making to understand the curriculum topic
Learning	Content knowledge Skills Dispositions Metacognitive strategies Learning strategies	Content, reasoning, and dispositions
Systemic	Sustainability Spread Scalability Ease of adoption Costs	Ease of adoption of a design into the curriculum, the degree to which it is sustained in subsequent years and the spread of use to other teachers and students.
Setting		Experimenting with innovation in different settings Collins et al. listed examples such as homes, workplaces, museums, schools, colleges, rural schools, etc.
Nature of learners		Determines for which type of learners the design is effective and in what ways (e.g. age, socioeconomic status, turnover rate, attendance rate, etc.)
Required resources and support for implementation		Resources and support (e.g., materials, technical support, and administrative support)
Professional development		Recognise what kind of professional development teachers need to offer to implement the design successfully
Financial requirements		Costs of technological innovation and professional support and development, etc.
Implementation path		How the innovation is introduced, the time devoted to it, the duration of its usefulness, etc.

Note. Adapted from Collins et al.'s (2004) characterised variables.

As the third-year semester project was ongoing and the students had already formed scrum teams of 3–5 students, it was natural to invite them for an interview on a team-by-team basis. The interview sessions included three sections: 1) individual background questionnaire in an electronic form, 2) semi-structured conversation themes and supporting questions and 3) group brainstorming. In the first phase, demographic information was collected using an electronic form to which students responded via a QR code in their mobile phones. The form was created using Webropol version 2.0. In addition, students were asked if they had ever taken an online course and if they were currently working aside from studying. It should be noted that this interview was conducted before the COVID-19 pandemic, when engineering education was widely formal and conventional. In the second section, the pre-prepared themes were addressed partially through support questions and partly spontaneously led by the students' own thoughts and reflections. Not all topics and support issues (summarised in Appendix B) were covered within the time frame in all sessions. The last section involved a group brainstorming session in which students had to work together with a pen and paper to create a mind map of the curriculum according to their wishes. Sessions were recorded for further processing. Their duration varied between 19 and 51 minutes.

Online Surveys

In sub-study I, qualitative data were also collected through an online survey from other stakeholders, such as instructors, R&D personnel, management and the ICT advisory council. The questions were also derived from Collins et al.'s (2004) characterised variables. Systemic variables were not relevant for students as stakeholders but were significant in the questions on online surveys presented for other stakeholders. Regarding the evaluation of systemic variables, Collins et al. (2004) proposed a questionnaire that addresses the advantages and difficulties teachers encounter in adopting a design in the classroom. Systemic variables were also used to determine the baseline and target. The classification of the survey questions is shown in Appendix C. The survey underwent initial validation by distributing it to two staff member representatives and obtaining their feedback. Following this initial round, the survey, along with the study's background information, was provided to the participants five days in advance to allow them sufficient time for familiarisation. The actual response took place in connection with the operational development day, following information related to the purpose of the study and the processing of the material to the Webropol system version 2.0. The Webropol questionnaire link was shared with the ICT Advisory Board as a preliminary task for the following assembly. The members of the board were presented with systemic questions regarding the future of the regional ICT ecosystem over a five-year time frame. Some of the questions overlapped with the questions in the survey for the personnel representatives, as indicated in Appendix C.

4.3.3 Data Analysis

The data obtained from the final participants through the data collection methods described earlier were passed on to the analysis step as follows: interview data from third-year students (N = 27), survey data from instructors (N = 15), including teachers (N = 10), R&D personnel (N = 4), management (N = 1) and industry representatives (N = 3). In this study, both teachers and R&D personnel will henceforth be collectively referred to as instructors. Since only one response was received from the management, and as the perspectives of management were not examined or considered in the subsequent study presented in this dissertation in accordance with the research questions, the management is also included as instructors in this sub-study and excluded from the stakeholders after.

Content Analysis

Qualitative data from interviews, surveys and visual data in sub-study I were examined using qualitative content analysis (Bengtsson, 2016; Elo et al., 2014; Elo & Kyngäs, 2008). Inductive reasoning was the approach used for analysis in which data were analysed open-mindedly to identify meaningful subjects (Bengtsson, 2016). Figure 7 illustrates the analysis process.

Figure 7
Description of the Qualitative Content Analysis Process

The interviews were listened and read through several times

↓

The transcribed text was divided into analysis units

↓

Analysis units were labeled with codes

↓

The codes were analysed to avoid the redundance and filtered to exclude the codes irrelevant for research questions

↓

The codes were categorized first to the sub-categories and after to the main categories of the theory

↓

Coding and categorizing were verified through the review

The interview recordings of the students' project teams in sub-study I were transcribed by an academic proofing service, including 49,094 words in Finnish. Coding took place using inductive reasoning to search for relevant expressions in the data that shed light on RQ1 and RQ2. Qualitative research software NVivo version 12 for Mac was used to code the data as analysis units. After coding, the overlapping codes were combined to avoid redundancy. Codes whose content was irrelevant to the research questions were excluded. The codes were grouped into subcategories and classified into a theoretical framework for analysis. The analysis frame was based on Collins et al.'s (2004) theory of the aforementioned characterising variables. The final structure of the coding is presented in Appendix D. Validation of the coding was conducted in a separate session in which the researcher presented the coding of the data with its classifications to a colleague, and consensus was reached after the discussions.

The mind maps created by the students in sub-study I were analysed using inductive reasoning. The free version of the SimpleMind version 1.25 mind mapping tool for Mac was used in the analysis. The researcher went through the eight mind map drawings received several times, after which the nodes were reclassified and attached to the main map one at a time. Using this process, one mind map was eventually formed with three main categories: instructor activities, competencies and learning environments. No theoretical framework was used in this reasoning.

4.3.4 Summary and Contribution of the Results to the Next Phase

The data analysis methods yielded the results and responses to the research questions posed to this sub-study:

RQ1) How do stakeholders experience the current curriculum, ecosystem and project-based learning framework?

All stakeholders agreed that PjBL is a successful method for ICT engineering education. According to the students and the majority of instructors, it is a more meaningful way to learn than traditional methods, such as separate courses in silos. Collaboration and learning by doing are effective in learning practical skills, and PjBL activates critical thinking, problem solving and a comprehensive understanding of broader concepts. Furthermore, the findings suggest that PjBL also increases students' motivation. In the students' opinion, the project management methods used in the industry and in the PjBL approach brought positive pressure on deadlines, and the feedback, support and guidance provided by the instructors during the reviews were perceived as particularly positive. The effect of integration was also reflected in the instructors' increased collaboration across courses. The students spontaneously used team communication tools and cloud services and felt that collaborative problem solving was more natural than individual problem solving.

However, the experiences were not entirely positive. The students perceived the limited opportunities to interact with the R&D personnel and the complete lack of interaction with the industry representatives as shortcomings. The need for initial guidance and support was significant. Furthermore, the students reported that the threshold for asking for support was high, and the availability and accessibility of support were challenging. For the teachers, the negative experiences were more pronounced than the positive experiences. For example, they were concerned about their survival, coping and resourcing. As the reviews and assessments took time, they felt that the PjBL had loaded the semester very unevenly. In terms of assessment, identifying the contributions of an individual student was considered challenging. Some teachers were reluctant to change the traditional approach and saw the PjBL approach as limiting content development and challenging the integration into natural sciences and math. In their view, PjBL also highlighted the hitchhiker phenomenon and the unequal division of tasks and workload among students as individuals.

RQ2) What thoughts and expectations do stakeholders have for ICT education over the next few years?

The instructors perceived the current curriculum to be sustainable, provided that its content would be updated with new technologies. However, the industry representatives found it challenging to find specialists for tasks that met the requirements of the industry and hoped that education would be more profiling. This perspective was also emphasised by the students and instructors, who hoped for more alternative specialisation studies. The industry representatives saw particular potential in new technologies (e.g. ML, AI, 5G (fifth-generation of mobile telecommunications technology), test automation, blockchain, IoT and 3D printing), substance areas (e.g. smart cities) and soft skills (e.g. entrepreneurial skills, teamwork skills, understanding trends and algorithmic thinking). The teachers considered strong basic competence important, although it was not specified in the responses. The teachers also suggested organising less integrated modules or semester projects. When considering a vision to shift the current approach from a fully on-campus activity to a blended learning approach, the students suggested organising laboratory-oriented studies on campus and the teachers organising programming on campus. In their opinion, instructors should focus more on support and guidance than lecturing. The industry representatives were suggested to participate in the reviews. Fully technology-focused reviews were also seen as necessary.

For the development of the digital learning ecosystem and the design principles, sub-study I suggests that the design requirements, as preliminary design principles for sub-study II, be transferred to the subsequent phases of the DBR (Table 4).

Table 4
Key Results and Design Requirements as Preliminary Design Principles to be Transferred to the Next Phase of the First Cycle of the DBR (Sub-study II)

<table>
<tr><th>Key Results/Triggers</th><th>Design requirements for the next phase of the first DBR cycle (sub-study II)</th></tr>
<tr><td>PjBL is a successful method and a more meaningful way of learning than traditional separate courses.</td><td rowspan="4">PjBL should be applied as an integrated curriculum context, with particular attention paid to the orientation phase.</td></tr>
<tr><td>Instructors are expected to cooperate more intensively between different courses.</td></tr>
<tr><td>PjBL activates critical thinking, problem solving and a comprehensive understanding of broader concepts.</td></tr>
<tr><td>The need for initial instructions and guidance is significant.</td></tr>
<tr><td>Collaboration and learning by doing are effective in learning practical skills.</td><td>Collaboration in PjBL should be further supported.</td></tr>
<tr><td>Project management methods bring positive pressure on deadlines.</td><td rowspan="2">PjBL should be applied with authentic project management methods and reviews used in the industry. Particular attention should be paid to project management and monitoring in reviews.</td></tr>
<tr><td>Feedback, support and guidance provided by the instructors during the reviews were perceived as positive.</td></tr>
<tr><td>Opportunities for interaction with the R&D staff were limited.</td><td rowspan="3">Deploying a TCP is needed to facilitate communication and promote accessibility.</td></tr>
<tr><td>The availability and accessibility of guidance were limited.</td></tr>
<tr><td>The threshold for requesting support was high.</td></tr>
<tr><td>Opportunities for interaction with industry representatives were limited.</td><td>The involvement of industry representatives should be promoted.</td></tr>
<tr><td>PjBL is challenging to integrate into natural sciences and mathematics.</td><td>Particular attention should be paid to integrating mathematical skills.</td></tr>
<tr><td>Challenges arise in identifying individual students' contributions.</td><td rowspan="2">Particular attention should be paid to the assessment methods.</td></tr>
<tr><td>Hitchhikers and uneven workloads occur among students.</td></tr>
<tr><td>The current curriculum is sustainable but needs to be updated with new technologies.</td><td>Emergent technologies related to the Industry 4.0 concept should be utilised.</td></tr>
<tr><td>The requirements for engineering are suggested to be followed (e.g. potential seen in the smart city concept).</td><td>SDGs should be implemented in context.</td></tr>
</table>

The findings showed that the PjBL approach with authentic industry-based assignments and project management methods as an integrated semester project should be maintained and confirmed because it was perceived as particularly positive. According to McKenney and Reeves (2019), factors that do not change can also be determined, such as PjBL, which must be incorporated into design principles. The results also highlighted clear resource-level aspects relevant to educational design (Collins et al., 2004), such as uneven workload during the semester and concern for the survival of instructors. However, the focus is on the shift to student-centred methods (Shpeizer, 2019), which also require teachers to re-adapt to changing circumstances and requirements (Abbas et al., 2021). Presumably, the experience, the active cooperation of the teachers and the number of semesters implemented with the approach would contribute to the solution of the problem. Feedback on the structure of the curriculum, such as profiles, specialisation studies and individual study paths, was postponed for consideration and implementation in the next round of curriculum reform.

4.4 Sub-study II: Experiences in a Blended Learning Approach in CoI

Sub-study II (Mielikäinen et al., 2023) aimed to pilot the team collaboration platform supported project-based learning approach in the integrated curriculum context and blended learning environment as the CoI in autumn 2019. It continued the first cycle of the DBR with the remaining phases. After the solution exploration phase based on the requirements as preliminary design principles mapped from sub-study I, the following research questions were set for sub-study II: RQ3) How do students experience the team collaboration platform in terms of teaching, social and cognitive presence? RQ4) How do students use team collaboration and developer platforms?

To explore the main goals and research question posed for the DBR described in this dissertation, a blended learning approach was applied by establishing the CoI according to its seven design principles (Garrison, 2016, p. 112):

CoI-1	Plan for the creation of open communication and trust.
CoI-2	Plan for critical reflection and discourse.
CoI-3	Establish community and cohesion.
CoI-4	Establish inquiry dynamics (purposeful inquiry).
CoI-5	Sustain respect and responsibility.
CoI-6	Sustain inquiry that moves to resolution.
CoI-7	Ensure assessment is congruent with intended processes and outcomes.

In the solution exploration phase, the design requirements from the analysis and exploration phases in this first DBR cycle were explored. The CoI design principles (Garrison, 2016, p. 112) listed above were used as the basis for the design, along with the results and requirements of the previous phase. The examination yielded the characteristics listed in Table 5 for setting in sub-study II for the subsequent phases of the first DBR cycle.

Table 5
Solutions and Strategies as Intervention Components

Requirement from the previous phase in the first DBR cycle (sub-study I)	**Related CoI principle**	**Strategy for the next phases of the first DBR cycle (sub-study II)**
PjBL will be applied as an integrated curriculum context, with particular attention paid to the orientation phase.	CoI-2 CoI-3 CoI-4 CoI-5 CoI-6	PjBL with semester projects will be applied with students' project groups, completing the joint assignment. PjBL with authentic project assignments, project management methods and reviews used in the industry will be applied. The outcomes and results will be presented to the public at the end of the semester. An adequate orientation phase will be organised before the project kick-off.
Collaboration in PjBL should be further supported.	CoI-3	PjBL will be applied by facilitating group cohesion in students' project groups.
PjBL should be applied with authentic project management, methods and reviews used in the industry. Particular attention should be paid to project management and monitoring in reviews.	CoI-2 CoI-4 CoI-5 CoI-6	Reviews and platforms' climates and cultures should be guaranteed to be respected and encouraged to respond. Guidance on the division of responsibilities and tasks must be guaranteed during the project planning phase and project implementation. A fair distribution of tasks in reviews should be ensured. Active monitoring and follow-up at the project group and individual levels must be ensured.
Deploying a TCP is needed to facilitate communication and promote accessibility.	CoI-1 CoI-2 CoI-3	Mattermost as an application will be used to support the creation of a learning climate and trusting expression.
The involvement of industry representatives needs to be promoted.	CoI-2 CoI-4	Postponed to the second cycle of DBR (sub-study III).
Particular attention will be paid to integrating mathematical skills.	CoI-4	Some aspects of mathematics should be included in the setting. An instructor/teacher team will be established to consider integration in collaboration.
Particular attention needs to be paid to the assessment methods.	CoI-7	The capability to evaluate the individual contributions of each student should be assured. Specification and cross-examination of the assessment methods and criteria by instructors should be completed with the collaboration of the instructor/teacher team.
Emergent technologies related to the Industry 4.0 concept should be utilised.	CoI-4 CoI-6	Ensure that the project assignment follows the concept of Industry 4.0 with technology selection. The design and evaluation should be completed in close collaboration with the instructors.
SDGs should be implemented in the context.	CoI-4	SDG themes should be conducted in the semester project.

Note. Explored in relation to the seven design principles of CoI (Garrison, 2016, p. 112) based on the design requirements as preliminary design principles from the previous phase of the first DBR cycle (sub-study I). Partially reprinted and adapted from 'Experiences of a project-based blended learning approach in a community of inquiry from information and communication technology engineering students at Lapland University of Applied Sciences in Finland' by M. Mielikäinen et al., 2023, *E-Learning and Digital Media*, CC BY 4.0.

4.4.1 Research Setting

The assignments of the semester projects for the target groups—the second- and third-year students—were selected to require special innovation and creativity, which were used to develop a prototype based on Industry 4.0 technologies to be presented to the public at the end of the project. The assignment for the second-year students was as follows:

> 'Create a game based on your own idea and a wireless game controller for it'.

For the third-year students, the topic of a cyber-physical system development was assigned:

> 'Build a camera stabilisation system (gimbal) that stabilises the camera of a mobile phone. The camera's image is sent to a cloud service that has image recognition capabilities. The gimbal should be built'.

The study units, 5 ECTS each, integrated into the case of the second-year students were as follows: Game Development and Embedded Systems project: Software Engineering, Game Engines, Embedded Systems and Game Physics. For the third-year students, the following courses were integrated: Mobile Systems Project, Basics of Mobile Programming, Automation Technology, Cloud Computing, Information Management and Event-driven Programming. Table 6 describes the courses included in the semester project and their content related to the Industry 4.0 concept technologies as an example (classification remodified and adapted after the publication of sub-study I to follow the taxonomy based on the key enabling technologies in Culot's (2020) study.).

Table 6
Course Contents of the Third-year Students' Semester Project Related to Industry 4.0 Technologies

Technologies in the Industry 4.0 concept (Culot et al., 2020)	Technology in the semester project	MP	BM	AT	CC	IM	EP
IoT	BLDC motors, Bluetooth connections, SPI bus, camera sensors, gyro, magnetometer		x	x			x
Cyber-physical systems	Image recognition system with mobile phone stabilised by gimbal	x	x	x	x	x	x
Cloud computing	Cloud services				x	x	
Big data analytics	Dashboards Pattern recognition		x				
ML	Image recognition				x	x	
AI	TensorFlow algorithms				x	x	
Interoperability and cyber security systems	Mobile application Ethical hacking	x	x				
Visualisation technologies	Unity 3D models for physical calculations	x					
3D printing	3D prints of gimbal mechanics	x					
Advanced robotics	Proportional integral derivative control, Kalman filter, etc. Mechanics for gimbal	x		x			

Note. Abbreviations in the titles correspond to integrated study units: Mobile Systems Project (MP), Basics of Mobile Programming (BM), Automation Technology (AT), Cloud Computing (CC), Information Management (IM) and Event-driven Programming (EP).

The Scrum method was used for project management, and students worked in project groups of 3–4 members. Sprint reviews were held FTF at the end of each two-week sprint with the cooperation of the instructor team. The instructors consisted of responsible teachers and laboratory staff from the ICT engineering education unit. Following the initial orientation, most of the lessons were conducted FTF, with the instructors primarily providing guidance and support for the project work of the project teams. Support materials, such as web links, videos, photos and sample codes, were provided in a step-by-step manner through either learning management system or team collaboration platform. Instructors were involved in TCP's public channels, which were used for sending messages and conversations. Mattermost does not have built-in audio, video or screen-sharing capabilities, but it does provide support for the integration of the most common video conferencing systems. GitLab served as the primary platform for collaborative source code version management utilised by the project teams.

After the analysis and exploration phase in sub-study I, all second- and third-year students (N = 63) were invited to the first iteration of the intervention in spring 2020. First-year students were excluded. As it was important to prioritise their strong grouping, they primarily engaged in on-site studies. According to Garrison and Vaughan (2008, p. 34), grouping is especially important in the early stages of community building for establishing trust to support collaborative learning. The fourth-year course was also excluded due to its active thesis stages.

4.4.2 Data Collection Methods

CoI Survey

The CoI survey served as the primary instrument for gathering data in sub-studies II and III. Students' perceptions of the three CoI framework constructs—TP, SP and CP—can be measured by utilising the CoI survey. The CoI instrument, including 34 survey questions, was developed and validated by (in alphabetical order) Arbaugh, Cleveland-Innes, Diaz, Garrison, Ice, Richardson, Shea and Swan and reported in articles by Arbaugh et al. (2008) and Swan et al. (2008). Based on a literature review, Stenbom (2018) found that the CoI survey provides valid and reliable results. Table 7 shows the categories associated with these three core presences and the examples provided by Garrison et al. (2006) as indicators. It also presents the number of questions related to each presence and category (Garrison, 2016, pp. 173–175) and assigns a question number to the categories. The complete list of these question numbers and associated questions can be seen in Appendix A.

Table 7
The Categories, Related Question Numbers and Indicator Examples

Presence	Category	Questions (number of questions)	Indicator (examples)
Teaching presence (13 questions)	Design and Organisation	TP1–TP3 (3)	Setting curriculum and methods
	Facilitating Discourse	TP4–TP10 (7)	Shaping constructive exchange
	Direct Instruction	TP11–TP13 (3)	Focusing and resolving issues
Social presence (9 questions)	Personal/Affective	SP14–SP16 (3)	Expressing emotions
	Open Communication	SP17–SP19 (3)	Learning climate/Risk-free expression
	Group Cohesion	SP20–SP22 (3)	Group identity/Collaboration
Cognitive presence (12 questions)	Triggering Events	CP23–CP25 (3)	Sense of puzzlement
	Exploration	CP26–CP28 (3)	Information exchange
	Integration	CP29–CP31 (3)	Connecting ideas
	Resolution	CP31–CP33 (3)	Apply new ideas

Note. Question ID refers to the questions in the CoI survey presented in Appendix A. Partially reprinted and adapted from 'Revisiting methodological issues in transcript analysis: Negotiated coding and reliability' by Garrison et al. (2006), *The Internet and Higher Education, 9*(1), p. 1–8 (10.1016/j.iheduc.2005.11.001). Copyright year by Elsevier (2006). Reprinted with permission.

In a systematic literature review spanning from 2008 to 2017, Stenbom (2018) highlighted the versatile applications of the CoI instrument. The review, encompassing 103 articles, reveals that the CoI instrument has been utilised to gain insights into a specific learning environment, to compare different features or test an intervention and to explore the general relationships between the core elements and between the CoI elements and other data, such as causal relationships, prediction searching and building structural models.

It is meaningful to explore students' project-based learning experiences in an e-learning context using a CoI instrument that provides a quantitative research tool for assessing the state of CoI (Garrison, 2016, p. 29). Questions were answered using a five-point Likert scale, with missing responses allowed: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. The original English instrument contained questions related mainly to a single study unit facilitated by a single instructor. As the purpose of this study was to examine the CoI framework and learning experiences in the context of a project-based approach, it was natural to adapt the questions to a project-based and multi-instructor environment. The adaptation was made by changing the term 'course' to 'project' and changing the singular 'instructor' to its plural form. All the questions were then translated into Finnish. The adapted CoI survey is presented in Appendix A. The original CoI survey is an open resource under the Creative Commons licence (CC BY-SA) on https://www.thecommunityofinquiry.org/coisurvey maintained by Dr. Randy Garrison, Dr. Marti Cleweland-Ines and Dr. Norm Vaughan. The CoI survey was provided to students as an online survey, conducted using Webropol query software version 3.0.

Server Data

Data were also collected from the team collaboration and developer platforms to gather knowledge about student behaviour and productivity in CoI during the semester projects in sub-study II. Data were collected from the logs of two platforms between September and December 2019: Mattermost version 4.2.3 (a free trial) and GitLab version 12.5. Mattermost is an instant messaging application for the internal communication of distributed groups and organisations that can be installed independently on the organisation's premises on private servers. GitLab is an open-source DevOps application that offers functionality software developers to collaboratively plan, build, secure and deploy. It can also be hosted on premises or in cloud storage. Platforms were provided by the server of the software engineering laboratory of the ICT education unit in the Lapland UAS, administered by the laboratory's R&D personnel. Mattermost and GitLab are used in the context of DevOps solutions by industry, research and education (Chitic et al., 2019; Lautenschlager & Ciolkowski, 2018; Süß et al., 2022; Werner & Jeske, 2021). Git repositories, such as GitLab and GitHub, as version control systems and a 'social coding' environment (Herbsleb, 2021) are already de facto. The administration in its possession and the possibility of collecting log data influenced the choice of these specific platforms in the iteration.

4.4.3 Data Analysis

Rasch Rating Scale Model

Rasch psychometric analysis (Rasch, 1993) techniques, such as the Rasch rating scale model (RSM) for polytomous data developed by Andrich (1978a, 1978b), were used to analyse the CoI instrument responses in sub-studies II and III. Abbitt and Boone (2021) presented the Rasch technique as an additional method to the prior analyses used in CoI research. They justified its primary advantage as an analysis technique over other techniques by what it yields: 1) a difficulty level to agree with the survey items and their mutual order, 2) a visual presentation of the item difficulty based on the difficulty indices and 3) a value known as a person measure to represent a respondent's social, cognitive or teaching presence score (Abbitt & Boone, 2021). Rasch also provides researchers the possibility of expressing the respondents' performance on a linear scale, taking into account the unequal difficulties of the test items (Boone, 2016). Therefore, non-linear raw data can be converted into a linear scale using Rasch techniques, making it possible to use parametric statistical tests (Abbitt & Boone, 2021; Boone & Noltemeyer, 2017).

The Rasch RSM is based on determining the difficulty level of the items and the person ability to measure latent traits, such as the attitude or ability to get a correct response on a test item (Stephanie, 2016). The mathematical form of the dichotomous Rasch model with ordinal data in two categories has been extended to polytomous extensions, broadening the model application to the separation of sequential integer scores representing the categories of increasing levels or magnitudes of a latent trait. An example of such a polytomous application of integer score separation is the Likert scale survey, in which the answer options (e.g. 1 = strongly disagree, ..., 5 = strongly agree) represent the item categories. The Rasch RSM is one of these applications for polytomous models from the Rasch model (Komboz et al., 2018). It is defined as follows:

$$P(X_{si} = x) = \frac{exp[\sum_{k=0}^{x}(\theta_s - \delta_i + \tau_k)]}{\sum_{h=0}^{m_i} exp\left[\sum_{k=0}^{h}(\theta_s - \delta_i + \tau_k)\right]}$$

where $\boldsymbol{\theta}_n$ is the person ability, δ_i is the location (difficulty) of the items on the latent variable, and τ_k are the category parameters across items (Engelhard Jr., 2012, p. 103). The Rasch RSM gives a probability for each polytomous scored item in the *m+1* response categories with the integer random variable $X_{si} \in \{0, 1, \ldots, m_i\}$, where m_i is the maximum score for item *i*. The parameter τ_k is called the centralised threshold—the location on the construct where the probability of responding in adjacent categories is equal across items. It represents the deviance of a particular category from overall item difficulty or severity (Katz et al., 2021). The maximum score is identical for all items in the RSM (Engelhard Jr., 2012, p. 100).

Rasch RSM is capable of eliminating common mathematical errors using traditional statistical analysis techniques in the case of nonlinear data (Boone, 2016). Boone (2016) provided examples of this, such as whether the difference in exam scores means an equal difference in the level of knowledge or whether the researcher could be sure that the size of the jump between the grading scales (e.g. from strongly agree to agree or from strongly disagree to disagree) is equal (Boone & Noltemeyer, 2017; Cohen et al., 2007, p. 605). The CoI instrument contains responses utilising a nonlinear ordinal Likert scale. As a general rule, the means and standard deviations should not be calculated when the data are on ordinal scales (Allen & Seaman, 2007). Moreover, Jamieson (2004) emphasised that the means (and standard deviations) are inappropriate for ordinal data and noted that 'the average of "fair" and "good" is not "fair-and-a-half"'. According to Engelhard (2012, p. 97), the Rasch models offer the possibility of parameterising the intervals defining the categories without the assumption that the categories are of the same size. Abbitt and Boone (2021) found that in most studies, the results of the CoI survey were analysed by calculating a raw score for each respondent on each subscale. Numerical equivalents (e.g. 5 = strongly agree, 4 = agree, etc.) are assigned to the Likert scale, after which the averages are calculated for the subscales. These averages were then used in subsequent statistical tests, such as the t-test (Abbitt & Boone, 2021).

Therefore, the Rasch analysis can be used to statistically measure a person's performance, attitudes and perceptions (Tesio, 2003) as well as the difficulty level of the items. Depending on the purpose, one may be interested in either or both. Person metrics can be used to define student behaviour and to map the most positive and negative aspects of item difficulties as latent traits. The Rasch model has been used for identifying learning difficulties (Habibi et al., 2019), students' conceptual or subject understanding (Mešić et al., 2019; Susac et al., 2018) or students' attitudes (Alasgarova, 2022; Romine et al., 2017). Abbit and Boone (2021) used the Rasch RSM not only to evaluate instrument functioning but also to analyse the data produced by the CoI survey instrument to evaluate the practices in blended online courses. They concluded that the person and item measures are suitable for replacing raw score mean values for use in the statistical analysis of CoI framework-related perspectives (Abbitt & Boone, 2021).

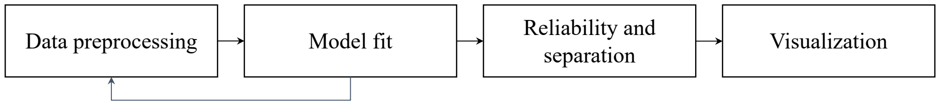
The Rasch analysis techniques also provide the possibility of constructing Wright maps, which are also called person–item maps and were named after the University of Chicago's Benjamin Wright for his contribution to promoting awareness of the Rasch measurement model (Boone & Noltemeyer, 2017; Wilson, 2011), to explain the meaning of test or survey scores (Boone, 2016). Wright maps make use of rating scale information based on the hierarchical order relationship of rated items by plotting the items on the instrument in order of difficulty (Boone, 2016). The difficulty of the item is expressed on a linear logit scale, extending from negative infinity to positive infinity (Boone, 2016; Boone & Noltemeyer, 2017). In the case of exams, at the top of the graph is the best test performance or, applying a Likert scale, the hardest or most difficult to agree with. At the bottom of the graph is the correspondingly weakest test performance or the easiest to agree with. Therefore, Wright maps serve to visualise the differences between items.

CoI Survey Data

The following data obtained in sub-study II through the data collection methods described earlier were transferred to the analysis phase: survey data from students (N = 56), server data from Mattermost with 297 messages and GitLab with 1,154 commits. A commit makes the initial source code changes permanent.

A Rasch RSM analysis was conducted using R version 3.6.2 and RStudio version 1.2.5033, with the TAM package version 3.7 for R (Robitzsch et al., 2021). The analysis process is presented in Figure 8.

Figure 8
Process of the Rasch Rating Scale Model Analysis



In the preprocessing phase, after reading the data into R, the Likert value 6 of the dataset was changed to N/A to avoid the model misinterpreting it as the next value of the Likert value 5 ('strongly agree'). The fit statistics of the initial model were iteratively reviewed for possible misfit of items by examining the value of the measure in relation to the acceptable mean square (MNSQ) fit value, following Wright and Linacres' (1994) recommendation of excluding objects with a value higher than 1.4. Three items—questions CP23, CP27 and CP27—and 6, 9 and 8 persons in TP, SP and CP, respectively, were excluded as misfits. After the exclusion of misfit persons and items, the final model was used for reporting (Table 8) and visualisation.

Table 8
Indices and Descriptions for Reliability and Separation Evaluation Used in Reporting

Index	**Description**
Total score	Sum of the numerical Likert scores
Total count	Total number of respondents who answered the item
Measure (δ_i)	Rasch estimate of the item difficulty measure in logit units
Model S.E.	Standard error of the item measure in logit units
Outfit MNSQ	Rasch model fit statistic, outlier sensitive
Infit MNSQ	Rasch model fit statistic, inlier sensitive

Each of the three core presences, TP, SP and CP, was analysed separately, as each of them can be considered to represent a distinct latent attribute. The numerical values for the statistical indices were evaluated for person and item separation reliability (Wright & Stone, 1999, p. 151). This is discussed in more detail in Section 6 in relation to the evaluation of the reliability of the study. The results were finally visualised and inspired by the Wright map, with estimates arranged hierarchically according to the difficulty of each item.

Server Data

In the cases of Mattermost and GitLab, the data were provided from public channel logs as a JavaScript Object Notation (JSON) file by the administrator. The data description tables for both data are presented in Appendix E in Tables E1 and E2. Data were read from JSON files into R Studio version 1.2.5033 and processed with R version 3.6.2. In the preprocessing phase, the GitLab data were read. Relevant variables were selected from the dataset; they are presented in Table E1 of Appendix E. The dates were parsed to obtain the hour and the day of the week. Commits made after the end of the semester project were excluded. The Mattermost data were pre-processed by changing the date in milliseconds to a datetime format, from which the date, hour and weekday were parsed. Messages sent after the end of the semester project were also excluded from the data. After preprocessing the data, the distributions of the students' messages and commits were visualised.

4.4.4 Summary and Contribution of the Results to the Next Phase

The data analysis methods yielded the following results and responses to the research questions posed to this sub-study II (question ID refers to the questions in the CoI survey presented in Appendix A):

RQ3) How do students experience team collaboration platform in terms of teaching, social and cognitive presence?

The majority of students' responses were positive, with a total of 83% of all 34 CoI instrument items in TP, SP and CP. The rating scale model of the item difficulties in TP, the design and the organisation-related items concerning course goals, instructions, important dates and time frames (questions TP2, TP3 and TP4 in the CoI survey presented in Appendix A) were the most easily agreed with. The most difficult items to agree with were the instructor's role in creating a sense of community (question TP10) and the timing of feedback (TP13). The facilitation of discourse-related items to keep discussions and project assignments conducive to learning (TP8) was among the most difficult to agree with. In SP, the easiest to agree was the emergence of an impression of the other members of the project team (SP15). With regard to group cohesion, an individual's own proposals being accepted by the project team (SP21) and the respondents being comfortable disagreeing with the project team (SP20) were the easiest to agree with. Conversely, the most difficult item was agreeing with a statement that suggested a sense of collaboration fostered by online discussions (SP22). The most difficult to agree with were questions about comfort in online discussions (SP17) and interactions with other teams (SP19). In the case of CP, the statements regarding the search for information from several sources (CP26), the project topic as an arouser of curiosity (CP24) and the resolution-related question about applying knowledge to other related activities (CP34) proved to be the easiest to agree with. The question on the exploration of the effect of information exchange online on different perspectives (CP28) was the most difficult to agree with. Item difficulty was among the hardest to agree with in the statement of integration about the effect of reflection and discussions on understanding fundamental concepts (CP31).

RQ4) How do students use team collaboration and developer platforms?

The number of commits in GitLab increased towards the end of the semester. There were no activities during the fall holiday week, but there were many events before that. The sprint reviews every two weeks did not show any spikes in the data. The final deadline showed the effect that most commits were made in the last two days. A few commits were also made after the deadline. The activities were mainly completed not only on weekdays during office hours but also on weekends, even at night. The content of the subject field of commits ranged from professional to non-professional and the occasional random keystrokes. The majority of the students were passive messengers, at least on the public channel. When the number of commits increased close to the deadline, the number of messages in Mattermost decreased. The autumn break did not show any activities based on the Mattermost log data. The discussions took place on weekdays and during office hours, although activities were also found outside office hours and in the evening. In this regard, Mattermost and GitLab data were congruent.

The design requirements suggested by sub-study II as preliminary design principles are presented in Table 9. The requirements were transferred to the second cycle of the DBR. It is worth mentioning that in the article discussing sub-study II, the term 'design principle' is used to refer to these preliminary design principles or design requirements. The requirements previously approved for retention, such as the PjBL approach, are no longer discussed here.

Table 9
Design Requirements as Preliminary Design Principles to be Transferred to the Second DBR Cycle (Sub-study III)

Key Results/Triggers	**Design requirements for the next phase of the second DBR cycle (Sub-study III)**
TP2: The instructors clearly communicated important course goals. TP3: The instructors provided clear instructions on how to participate in project learning activities. TP4: The instructors clearly communicated important due dates and time frames for learning activities.	LMSs should be utilised to compile course completion criteria, assessment criteria and course schedules supplemented by instructions from instructors.
TP10: The instructors' actions reinforced the development of a sense of community among project team members. SP15: I was able to form distinct impressions about some project team members. SP20: I felt comfortable disagreeing with other project team members while still maintaining a sense of trust. SP21: I felt that my point of view was acknowledged by the other team members. SP22: Online discussions help me develop a sense of collaboration.	Group cohesion with risk-free expression and encouraging cooperation must be maintained.
TP13: The instructors provided feedback in a timely manner.	All stakeholders (e.g. R&D personnel, industry representatives and peer support by other project teams) of the digital ecosystem need to be activated in discourse, feedback and support activities.
TP8: The instructors helped keep the project team on a task in a way that helped me learn. CP28: Online discussions were valuable in helping me appreciate different perspectives. CP31: Reflection on project content and discussions helped me understand the fundamental concepts in this project. Most of the students were passive messengers.	Discussion on task-related questions, technologies and concepts needs to be maintained.
SP19: I felt comfortable interacting with members from other teams.	Encouraging collaboration across project team boundaries needs to be ensured.
CP26: I utilised a variety of information sources to explore the problems posed in this semester project.	Sufficient digital material to support the learning needs to be provided.

Note. ID in the key results refers to the question numbers in the CoI survey presented in Appendix A. Adapted from the 'Experiences of a project-based blended learning approach in a community of inquiry from information and communication technology engineering students at Lapland University of Applied Sciences in Finland' by M. Mielikäinen et al., 2023, *E-Learning and Digital Media*, CC BY 4.0.

The results of sub-study II suggest that the implementation of CoI with technologies in accordance with the Industry 4.0 concept was successful (see the results in questions CP24 and CP34), but they contained items to be developed that are related to the role of the instructor, online discussions and cooperation between the project teams. Among the solutions, those that can be interpreted as successful in light of the objectives and results will be retained.

4.5 Sub-study III: Experiences in an Online Learning Approach in CoI

Sub-study II (Mielikäinen & Viippola, 2023) aimed to explore students' learning perceptions in CoI with an online learning approach in spring 2020. It also sought to explain the prevailing circumstances in more detail from the students' perspectives. Sub-study III further continues the second cycle of the DBR. After the analysis and solution exploration phases based on the requirements as preliminary design principles mapped from sub-study II, the following research question was formulated for sub-study III: RQ5) How do students experience teaching, social and cognitive presence in an online environment?

The original aim of sub-study III was to explore solutions associated with the requirements of a blended learning approach. However, COVID-19 caused the total transition to an online approach in spring 2020, soon after the beginning of the semester, and the entire semester shifted to be held online. The student project teams were given the equipment and components needed for the projects. It should be noted that due to the ongoing intervention and related solutions, the transition proved to be easy once the necessary structures and solutions were already established. This finding indicates the rationality of solutions in relation to rapidly changing requirements.

To explore the main goals and research question posed for the outcomes, the following characteristics were set (Table 10). The requirements as preliminary design principles approved for retention in the previous sub-studies are no longer discussed here.

Table 10
Solutions and Strategies as Intervention Components.

Requirement from the previous phase of the first DBR cycle (Sub-study II)	Related CoI-principle	Strategy for the next phases of the second DBR cycle (Sub-study III)
Involvement of industry representatives needs to be promoted. (The requirement was postponed from sub-study I to sub-study III; see Table 5)	CoI-2 CoI-4	The authentic industry-based assignment will be strengthened with the involvement of industry representatives in reviews.
LMSs should be utilised to compile course completion criteria, assessment criteria and course schedules, supplemented by instructions from instructors.	CoI-4 CoI-7	Special attention will be paid to the coverage of LMS criteria and guidelines.
Group cohesion with risk-free expression and encouraging cooperation must be maintained.	CoI-1 CoI-2 CoI-3	Instructors will be involved in the private channels of the project teams. TCP will switch to one of the industry's most commonly used products, which provides improved support for audio and video transfer and screen sharing.
All stakeholders of the DLE should be activated in discourse, feedback and support activities (e.g. R&D personnel, industry representatives and peer support by other project teams).	CoI-2 CoI-3 CoI-4	A community related to the digital ecosystem utilising TCP and developer tools according to the principles of DevOps will be established.
Discussion on task-related questions, technologies and concepts should be maintained.	CoI-2 CoI-4 CoI-6	Instructors will contribute more to maintaining discussions. Instructors will also be involved in the private channels of project teams.
Encouraging collaboration across project team boundaries should be ensured.	CoI-3 CoI-6	DevOps' culture of collaboration and communication will be introduced, applied and encouraged.

Note. Explored in relation to the seven design principles of CoI (Garrison, 2016, p. 112) based on the design requirements as preliminary design principles from the previous phase of the first DBR cycle (sub-study II). Adapted from Mielikäinen and Viippola (2023).

4.5.1 Research Setting

In addition to all second- and third-year students as participants in sub-studies I and II, all first-year students were also included in this second cycle (sub-study III). This time, their learning experiences were of particular interest for the broader utilisation of the intervention.

The courses included in the integration and the Industry 4.0-based assignments for the semester projects assigned to the study year are described in Table 11. The assignments for the second- and third-year semester projects came from industry. The first-year assignment was carried out for an imaginary client. As electromagnetism in the field of physics was incorporated into the first-year assignment, students were required to ensure the operating time of a product based on the characteristics of the battery and build a website to provide details on the operation of the electric motor. This was in response to the requirement of paying special attention to the integration of mathematical skills.

Table 11

Integrated Study Units and the Assignments for the Semester Projects Assigned

Study year, total ECTS of integration	Study units (5 ECTS each)	Open-ended assignment	Technologies, devices and platforms
1st 25 ECTS	Simulation Project of Intelligent Technologies Basics of Electronics Server Programming Networks Electromagnetism	Implement an autonomous vehicle with features such as acceleration, location, conditions, battery charge status and power consumption. The features should be monitored through a web-based interface.	Radio-controlled autonomous vehicle controlled with Arduino and Raspberry Pi control unit, a Python application with WebSockets, Node.js runtime services and MongoDB
2nd 25 ECTS	Product Development Project Entrepreneurship and Business Product Development System-oriented Programming Information Management	Implement a mobile application for the audience of a real snow-cross event.	Android, Google Cloud Platform, Azure Web Services and a robotic building system
3rd 25 ECTS	IoT Project Advanced Mobile Programming Measurement Systems Management and Leadership Professional English for ICT Engineers	Implement a mobile application and measurement system for a modern, versatile and sensored apartment building.	Android OS, MQTT, IBM Cloud, Raspberry Pi, Pycom, Arduino and Azure DevOps

Note. Adapted from Mielikäinen and Viippola (2023).

MS Teams was chosen as the team collaboration platform because it supported the required features. The TCP selected was already in active use by the unit's personnel before the start of the pandemic. In sub-study III, the instructors were given access and participated in discussions on project team-specific channels. The server log files were no longer accessible when server management was the responsibility of the institution's information management, but they were no longer needed considering the objectives of sub-study III and the research question. The representatives of the industry were involved in the TCP's public channels for the second- and third-year assignments and participated in the closing seminar organised exceptionally as entirely virtual on MS Teams due to COVID-19. In the second-year assignment, an industry representative participated in the progress reviews along with the teacher team. The project management procedures following the discipline standards were implemented, as described in Section 3.2.1. In the third-year assignment, the DevOps platform was used collaboratively with GitLab.

4.5.2 Data Collection Methods

In sub-study III, the responses to the CoI instrument were refined with four open-ended inductive and partially deductive questions. These four questions were taken from Collins et al.'s (2004) study, in which they recommended asking in the context of the variables which areas of design have survived and are spreading and which are not related to the systemic variables described in Table 3. These questions are as follows: 1) Which challenges have you experienced during the online learning period this spring? 2) What worked well? What things or elements of the semester project would you keep in the future? 3) How would you develop the online learning/working approach? and 4) How did you feel about the remote reviews? These questions were a follow-up to the online questions of the CoI instrument presented in Appendix A.

4.5.3 Data Analysis

In sub-study III, survey data from students (N = 79) were passed on to the analysis step. The responses of the CoI instrument were analysed using the Rasch RSM (Andrich, 1978a, 1978b) for polytomous data. The analysis was performed with the same setup as in sub-study II, specifically using R version 3.6.2, RStudio version 1.2.5033 and TAM package version 3.7 for R (Robitzsch et al., 2021) and following a process similar to that in sub-study II. In analysing the data, three questions (TP4, SP19 and CP27) and 16, 12 and 16 persons in TP, SP and CP, respectively, were excluded based on the statistics of MNSQ being higher than 1.4.

In addition to the CoI questions, sub-study III included four open-ended questions. The analysis of three of these was described in the publication of sub-study III as following inductive and partially deductive reasoning. The analytical approach could also be considered as abductive reasoning, in which data and theory are fitted together iteratively (Timmermans & Tavory, 2012). Abductive reasoning according to Timmermans and Tavory (2012), allows the identification of hidden cause-and-effect relationships or even entirely new general descriptions aimed at explaining previous findings. The analytical process commenced with the identification of phenomena within the dataset, leading to the formulation of initial thematic constructs. Subsequently, these categories underwent iterative and recursive mapping to the underlying theoretical framework. The analysis framework used was the CoI by Garrison (2016). The structure of the final categories and their mapping to the analysis framework for each question is presented in the original article of sub-study III (Mielikäinen & Viippola, 2023). Question number 4 on the experience of remote reviews was coded by classifying each analysis unit as either positive, negative, missing or neutral. Validation for the classifications was conducted with the co-researcher to reach a consensus.

4.5.4 Summary and Contribution of the Results

The data analysis methods yielded the following results and responses to the research questions posed in sub-study III (question ID refers to the questions in the CoI survey presented in Appendix A):

5) How do students experience teaching, social and cognitive presence in an online environment?

It was encouraging to see that the reference to the difficulty rating scale model for the TP item suggests that the facilitation discussion category items of the facilitator keeping the project team engaged and maintaining dialogue (TP7) and the facilitator helping with the right choices and solutions (TP5) were the easiest for the students to agree with. The most difficult to agree with was the argument about providing individual feedback on the strengths and weaknesses in relation to the project objectives (TP12), with a large difference in a continuum from the other items. The most difficult to agree with was also seen in the clustered subjects regarding further facilitation of discussion and direct instruction in the following statements: instructors fostered a sense of community (TP10), instructors provided timely feedback (TP13), facilitators helped focus discussion on relevant topics and promoting learning (TP11), and instructors helped keep my project team on task (TP8). In the questions about SP, the students found it easiest to agree with being able to form a clear picture of the project team members (SP15), followed by acceptance of their own perspectives (SP21), disagreement without losing trust (SP20) and sense of belonging to a project team (SP14), which were all clustered. The most difficult item to agree with was the argument that online or web-based communication is an excellent medium for social interaction (SP16), which was also significantly separated on a continuum. Among the most difficult to agree with were the targets with arguments about online discussions helping to develop a sense of cooperation (SP22) and feeling comfortable having online conversations (SP17). The item difficulties of the last question set in the Rasch rating scale model regarding CP suggested that the easiest to agree with was the statement on the use of different data sources to solve the problem (CP26), which was also separated on a continuum from the following items. The next easiest item to agree with was that the project arouses curiosity (CP24) and motivates students to explore content issues and problems (CP25). The most difficult to agree with was the cluster of items on the application of the knowledge and skills acquired in the project (CP32) and the practical application of the solutions (CP33). Furthermore, one of the most difficult to agree with was an item claiming that brainstorming and finding relevant information helped resolve questions (CP27) and that learning activities helped with solution construction (CP30).

In the responses to the open-ended questions, students reported on the challenges in learning. The responses specifically highlighted the challenges associated with shared metacognition, such as problems with management and scheduling, the accumulation of tasks, a lack of daily routines and motivation issues. They suggested that online learning might not be suitable for students who feel that they are learning by doing things better in practice. Online learning was perceived to be more boring than FTF. They also felt that the online approach required more time and initiative. In the case of SP, the responses mentioned were related to communication problems and a lack of social contact. The responses related to TP reported problems such as a lack of use of equipment resources and the unavailability of guidance and support. The English language material was seen as a problem in one of the responses. When asked about successes, it was reported that chat support in the team collaboration platform facilitated the availability and reachability of instructors in the TP. Recording and sharing lectures were considered valuable solutions. In SP, team spirit was high, and cooperation worked mainly well. Management and scheduling were also considered successful in shared metacognition by some students due to the ease of planning and managing their own time using the online approach. The proposed improvements and areas worth preserving mainly pertained to TP. Specifically, requests were made to augment the availability of learning and support materials, and suggestions were put forward among all instructors to expand the adoption of beneficial practices, such as recording lectures. Teachers were expected to be better prepared and to provide more information and guidance. A closer interaction with the instructors was also suggested. The use of platforms should be further enhanced. Some respondents called for the promotion of group cohesion in the SP category by improving collaborative learning. The vast majority of students (78.5% of respondents in total) found the remote progress and sprint reviews positive, and 8.9% hoped they would be held on campus.

Table 12. describes the new requirements that emerged from the second cycle. The design requirements as preliminary design principles that have been previously approved for retention are no longer discussed here.

Table 12
Design Requirements as Preliminary Design Principles and Solutions Emerging from Sub-study III and Suggested to be Transferred to the Next Implementation

Key Results/Triggers	Design requirements emerging from sub-study III	CoI-related design principle	Strategy
CP27, CP30 A suggestion for adding learning and support materials	Provide sufficient digital material to support learning (Reformed later on to an online resource pool)	CoI-2 CoI-6	Open educational resources are suggested to be utilised.
CP32, CP33, SP16, SP22 Communication problems and a lack of social contacts	Blended learning approach	CoI-4	A blended learning approach is to be applied in the case of laboratory-related subjects.

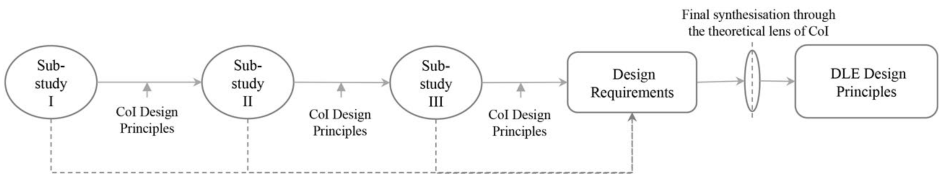
Note. ID in the key results refers to the questions in the CoI survey presented in Appendix A. Reprinted from 'ICT engineering students' perceptions on project-based online learning in Community of Inquiry (CoI)' by M. Mielikäinen and E. Viippola, 2023, *SAGE Open*, CC BY-SA 4.0.

The results of sub-study III suggest that the layout, according to the requirements as preliminary design principles, was also successful in a fully online environment and that common satisfaction with the learning experience increased with the subsequent year course. However, the results show problems in sociality and in the application of the knowledge and skills learned in practice, which reinforces a blended learning approach, including collaborative hands-on activities on campus in laboratory settings. Moreover, among these solutions in sub-study III, those that can be interpreted as successful in light of the objectives and results are retained.

5 DESIGN PRINCIPLES FOR A DIGITAL LEARNING ECOSYSTEM

This chapter combines and analyses theoretical perspectives, observations, results and contributions from the three sub-studies. Initially, all the design requirements identified as preliminary design principles that emerged from the sub-studies are compiled for discussion. Thereafter, the final design principles resulting from the design requirements are synthesised, taxonomised and refined through the theoretical lens of CoI. Sub-studies I, II and III have enhanced and advanced the exploration of the main research question. Figure 9 illustrates the cumulative contribution of each sub-study.

Figure 9.
Contribution and Positioning of the Sub-studies, Design Requirements and Design Principles for the Digital Learning Ecosystem (DLE) in Relation to Community of Inquiry (CoI) Design Principles in the Overall DBR Study



5.1 Design Requirements for a Digital Learning Ecosystem

The study yielded 16 design requirements (Req-1–Req-16) presented in Table 13. All requirements can be traced back to their origins in the sub-studies, although the wording has been refined and clarified. The origin of Req-1–Req-9 can be traced to sub-study I in Table 4, Req-10–Req-15 to sub-study II in Table 9 and Req-15 and Req-16 to sub-study III in Table 12.

Table 13

Pool of Design Requirements for the digital learning ecosystem

Requirement ID	Requirement
Req-1	PjBL should be applied in an integrated curriculum context.
Req-2	Collaboration should be supported by facilitating group cohesion.
Req-3	Authentic project management methods should be applied.
Req-4	A team collaboration platform (TCP) should be deployed.
Req-5	Collaboration and the involvement of industry representatives should be ensured.
Req-6	Particular attention should be paid to the integration of mathematical skills by establishing an instructor team.
Req-7	Competence-based assessment methods should be applied.
Req-8	The Industry X.0 concept should be implemented.
Req-9	Sustainable development goals (SDGs) should be implemented in context
Req-10	Learning management systems (LMSs) should be utilised.
Req-11	Group cohesion with risk-free expression and encouraging cooperation should be maintained.
Req-12	All stakeholders of the digital ecosystem should be activated in discourse, feedback and support activities.
Req-13	A discussion should be maintained on task-related questions, technologies and concepts.
Req-14	The DevOps philosophy and principles should be applied.
Req-15	An online resource pool for students should be established.
Req-16	A blended learning approach should be conducted.

Note. The abbreviation Industry X.0 refers to Industry 4.0 or a higher revision.

PjBL should be applied in an integrated curriculum context (Req-1). The research configurations of the sub-studies meet the requirements of both Thomas (2000) and Adderley et al. (1975, p. 1) for the five properties of project-based learning listed earlier in relation to the theoretical background, thus confirming the validity of the PjBL approach presented in this study. Learning in PjBL is based on collaboration, thus providing a purposeful inquiry (CoI-4) (Garrison, 2016, p. 112) with social constructivism as a learning theory. An adequate understanding and expertise in real-world problem solving require exposure to authentic problems. The significance of a substance is almost inevitably perceived as relevant due to its authentic adaptation to a real-world context. In terms of integration, the settings are mainly similar to the cross-course approach described in Chen et al.'s (2021) study, in which a series of related or multidisciplinary courses is combined to support a student project, often over one semester, at the curriculum level to form the backbone of the curriculum, with other traditional learning methods as supporting elements. The core of the results, and perhaps even the most significant outcome of this study, revealed PjBL to be a successful approach to engineering education. This finding is in accordance with previous empirical research (Berselli et al., 2020; Chang & Yen, 2021; Coronado et al., 2021; Huang & Yang, 2021; Mills & Treagust, 2003; Morais et al., 2021; Nugroho, 2021; Reis et al., 2020; Shpeizer, 2019; Souza et al., 2019). The solutions to the problems are usually ambiguous, allowing for several variations in the same assignment. Beier et al. (2019) observed that authentic experiences affect students' perceptions of their own STEM skills and the usefulness of courses in their future careers, positively influencing students' effectiveness and interest in a STEM career. The appropriate organisation of the orientation phase should be taken into account. As shown in the results of sub-study I, in the orientation phase, students construct an initial understanding according to constructivism using previously acquired knowledge and skills. Competence development and thinking are focused on the methods and technologies required for problem solving. Open and authentic problems respond to the requirement of pragmatically activating students' critical thinking and holistic understanding of broader concepts.

Collaboration should be supported by facilitating group cohesion (Req-2). As project-based learning naturally provides a context for learning by doing collaboratively, creating a related SP is one of the key challenges in any educational setting (Garrison, 2016, p. 116). The results of sub-study I indicate that students consider collaboration to be one of the significant factors in learning practical skills, giving reasons for further supporting collaboration and cohesion. Research on working life has also found that group cohesion is linked to job satisfaction, providing practitioners with insights into the need to promote cohesion by supporting the ongoing interactions of team members (Riasudeen et al., 2019). Interconnected work tasks require interaction, as a result of which partners get to know each other better and help develop a strong commitment (Bjørn et al., 2014). Applying a CoI approach from the perspective of group cohesion and collaboration in the case of traditional teaching methods and large groups also supports the positive role of PjBL in establishing SP. Self-efficiency and a sense of belonging are the most important motivating factors (Tinto, 2017). To measure the level of cohesion, a simple principle can be used to observe the expressions used by the student in project-focused questions—that is, whether the term 'we' or 'I' is used. Garrison (2016, p. 121) suggested facilitating SP and CoI with the instructor's style of participating in the conversation by expressing emotions with restraint and by being not too formal by using humour. An enthusiastic and interested instructor can enhance students' positive emotions and their interest (Hartikainen et al. 2022).

Authentic project management methods should be applied (Req-3). PjBL cannot be authentically applied without authentic project management methods. Analysing the significance of competency categories, Ada et al. (2021) found that project management skills were identified as the most important factor in the list of skills required of personnel in the Industry 4.0 era. Although there are numerous examples in the literature of the application of PjBL, they rarely specifically mention the use of authentic project management methods, such as iterative and incremental models. If methods have been used, they will be the main focus of the articles (Fioravanti et al., 2020; Pokharel, 2021). For students, project management, as a discipline standard, is part of the engineering portfolio. Presumably, these skills also develop students' coping skills and everyday management.

The design of the intervention must also take into account the needs of instructors' professional development (Collins et al., 2004), which is highlighted in this study in terms of project management competencies. Promoting a range of professional project management competencies is an advantage in the promotion and participation of the institution (Cerezo-Narváez et al., 2019).

In addition to the goal of utilising industry-based methods and concepts, the results of the present study also support the use of project management methods, for example, by bringing positive pressure to schedules and providing a review instrument for feedback, support and guidance. Regular reviews provide instructors with a unique opportunity to monitor the progress of both teams and individual students and to provide feedback on competence development. The advantage of the Scrum approach in PjBL is that regular feedback is received from the instructor (Fernandes et al., 2021); this also proved to be significant in this study. According to the results of sub-study I, particular attention should be paid to project management and the assessment of progress in terms of learning and equitable sharing of tasks. Students suggested increasing the number of feedback and reviews. Cubric (2013) noted that regular feedback from mentors in a project following the Scrum approach is a key factor in reinforcing the importance of TP and regular interaction in terms of motivation and group cohesion. Moreover, conducting reviews as peer reviews followed and facilitated by instructors could further enrich the learning experience.

A TCP should be deployed (Req-4). The use of team collaboration platform facilitates communication and promotes accessibility. Magni and Maruping (2019) mentioned in their study that, according to Gartner, over 50% of team communication occurs through collaboration platforms. The figure is likely to be even higher today, and TCP is now an inescapable de facto of modern working life. The most general rationales for adapting TCP in technology-intensive organisations are virtual collaboration, openness and transparency and interoperability with external services (Anders, 2016).

ICT students can easily adopt new tools, so the threshold for using them to communicate is low. The goal of using TCP could be to achieve a high level of autonomy presence, as proposed by Lam (2015), in which students replace the role of the teacher, such as in initiating and directing the discourse. Although sub-study II shows that the majority of students are passive communicators on the public channel (i.e. publishing their ideas for the 'general public' to read), the high SP results suggest that communication within the project team works well. TCP should be chosen to support the functionality required for collaboration, such as video calls, screen sharing and integration possibilities. Leppänen et al. (2016) encouraged instructors to choose a communication tool that students would like and accept. Discord, which is used by gaming communities, received a few suggestions from first-year students in sub-study III, but it could be a good idea to use the choices commonly used by the industry as selection criteria.

Collaboration and involvement of industry representatives should be ensured (Req-5). Thus far, the data have not provided clear evidence of the impact of industry involvement on the approach. In any case, according to the findings of sub-study I, the students felt it was insufficient. However, the literature contains numerous results in which collaboration with industry or external stakeholders has been identified as a strongly positive factor in engineering education at the course level (Llopis & Guerrero, 2018; Nugroho, 2021; Ståhl et al., 2022; Valentine et al., 2022). In addition to providing authentic project topics, cooperation has several beneficial aspects, such as providing employment opportunities for students in a partner organisation, providing up-to-date presentations of various topics important to professional engineering practice, promoting staff development and job satisfaction and helping to maintain an up-to-date curriculum (Goldberg et al., 2014).

Particular attention should be paid to the integration of mathematical skills by establishing an instructor team (Req-6). The findings of sub-study I reveal teachers' challenges in integrating mathematics and natural sciences into a context consistent with the PjBL approach. Although Rani et al. (2020) argued that mathematics is the most challenging subject to teach in HE, it nonetheless plays a significant role as part of an engineer's toolkit for problem solving. The emerging application areas, such as AI, ML and data analytics, as well as robotics and autonomous vehicles, are based on mathematical algorithms. This is the concrete solution to authentic problems through mathematics that can also affect the meaningfulness of the learning experience in mathematical skills. There is also evidence of the successful application of mathematics with the PjBL approach in the case of a single course level (Rani et al., 2020; Razali et al., 2020).

Competence-based assessment methods should be applied (Req-7). In DP-7 of the CoI, Garrison (2016, p. 112) called for ensuring that the assessment would be congruent with the intended processes and outcomes. Rewarding learning shapes the approach to learning (Garrison, 2016, p. 127). In the case of project-based learning, as an authentic assessment task, it requires the integration of cognitive and social skills (Care & Kim, 2018). Concerns about the challenges of assessing the competence and contribution of individuals, shown by the findings of sub-study I, lead to a redesign phase of the assessment methods. Sidharan et al. (2019) also state that the problem with teamwork is that teachers are not able to ensure the contribution of individual students, which has been sought to be addressed through peer assessment, although teachers often do not want to attribute significant importance to this grade. Peer review can also prove challenging due to students' reluctance to honestly evaluate their peers, as their actions may penalise non-contributing students (Sridharan et al., 2019). The transparency of workload follow-up in project management, acting as a kind of log file in relation to collaborative problem solving (Krkovic et al., 2018, p. 80) contributes to individual-level pressure on performance and can also be linked to individual evaluation criteria. From the standpoint of assessment, it should be possible to eliminate as many unwanted phenomena that occur in student teamwork as possible, including uneven workloads and hitchhiking. The development of evaluation methods, for example, the collaborative process of instructors, provides a more comprehensive perspective on individual performance. The perspectives provided by the authentic project management methods mentioned previously (Req-3) also help in the evaluation process. Project reviews offer instructors the opportunity to monitor competence, development and individual contributions to define an individual's cognitive profile. In competence-based assessment, learners are evaluated based on their production and integration, not on memorisation or reproduction (Birenbaum et al., 2006; Koenen et al., 2015).

The Industry X.0 concept should be implemented (Req-8). Industry 4.0 requires the synthesis and integration of knowledge and skills from experts in different fields (Raman & Rathakrishnan, 2019, p. 2) supporting the subject integration in a project-based learning approach. The thoughts on future aspirations left by industry representatives in sub-study I indicate the need to shape the curriculum with the principles of the Industry 4.0 concept. For example, they saw potential in new technologies, such as ML, AI, test automation, blockchain and IoT. In addition to the Industry 4.0 paradigm, a design must be forward looking, and anticipation should already be made from the perspective of Industry 5.0. Whereas Industry 4.0 is technology-driven, Industry 5.0 is value-driven (Adel, 2022; Xu et al., 2021), consisting of three interconnected pillars: human-centricity, sustainability and resilience (Wang, 2022). Thus, Industry 5.0 is also linked to SDG-compliant targets in Req-10. Industry 5.0, alternatively referred to as Society 5.0 (Deguchi et al., 2020; Skobelev & Borovik, 2017; Smuts & Smuts, 2022), pairs human and machines to utilise human brain power and creativity by creating a synergy between humans and autonomous machines (Nahavandi, 2019). Carayannis and Morawska-Jancelewicz (2022) urged universities to create appropriate structures and mechanisms to support the development and implementation of social and digital innovation, extend digital social innovation to all missions, embrace interdisciplinarity in research and education, foster multi-actor collaboration, strengthen mobility between industry and academia, promote intelligent learning and create new flexible, inclusive and adaptive learning systems.

SDGs should be implemented in context (Req-9). For the time being, engineering education is not enough to contribute to achieving the sustainable development goals, which are important alongside the technical skills of the next generation of engineers (Gürdür Broo et al., 2022). The proposal put forward by industry representatives in sub-study I to include visions such as a smart city in the curriculum underlines the growing importance of SDGs. Incorporating sustainability themes into the PjBL approach and engagement supports transformativeness and progressivity. It is therefore likely that involvement in solving real-world problems that require critical thinking could also develop competences related to sustainability (Ratinen & Linnanen, 2022). Mishra and Mishra (2020) recommended organising at least one sustainability course for software engineers, including sustainability theory, requirements and analysis, sustainability issues in software architecture and design, sustainable system modelling and engineering process, testing, quality assurance and the sustainability management process with tools and a capstone project. These topics are relevant, and due to the integrated PjBL, the systemic approach to include SDG themes in the programme for each semester project throughout the degree is worth considering. Even the allocation of a single semester assignment to the theme of sustainability could promote engineering students' understanding of social and climate responsibilities.

LMSs should be utilised (Req-10). Although it is in accordance with industry practice that project communication takes place mainly in the team collaboration platform, it is natural to report the official course completion criteria, assessment criteria and course schedules using traditional methods and learning management systems, such as Moodle, Edmodo, Canvas or Schoology. In sub-study II, the instructors provided this information on Moodle, which the students felt was successful according to the results, thus encouraging the use of the LMSs in the intervention. Without a collaborative learning experience, LMSs also provide a practical channel for sharing resources for self-regulated learning. LMSs offer features that specialise in returning individual personal assignments with learning analytics. Student academic success can be predicted using this tracking data (Fahd et al., 2021; Macfadyen & Dawson, 2010; Tamada et al., 2022; Zhang et al., 2020), which, combined with TCP and LMS data, may also help to solve the problems described in the context of the design principle DP-7.

Group cohesion with risk-free expression and encouraging cooperation should be maintained (Req-11). Providing team collaboration platform to distributed teams does not always mean success (Magni & Maruping, 2019). The Rasch RSM estimates the difficulty of each item with which students agree. The results of sub-study II showed that the most difficult items for students to agree with were the instructors' role in creating a sense of community and the role of online discussion in fostering a sense of collaboration. However, the rating scale showed a higher level of agreement for questions about whether they formed an image of the other members of the project team, the respondents were comfortable disagreeing with the project team and the individual's own proposals would be accepted by the project team. Therefore, even though it was easier for students to agree with questions about group cohesion in sub-study II, from the students' perspective, the role of the facilitator as the maintainer of the project team cohesion might not be necessarily obvious if the interaction was based solely on communication over the TCP's public channels. According to Garrison (2016), the design should be flexible and adapt to unforeseen and individual learning needs as they arise. Creating the right tone at the right time is challenging. Specifically, creating an SP (Garrison, 2016, p. 116) requires instructors to participate in the internal communication of the project team. This perspective should be facilitated by the participation of the instructors on the private channels of the project teams. According to Garrison (2016, p. 116), the TP should develop an SP that creates a sense of trust, control, belonging to the community, a willingness to engage in discourse and a questioning attitude. Establishing a community, cohesion and a plan for critical reflection and discourse as design principles of CoI (Garrison, 2016, p. 112) can be facilitated by providing instructors from the outset with insights and opportunity to monitor and address the project team-specific situation.

All stakeholders of the digital ecosystem should be activated in discourse, feedback and support activities (Req-12). Isomöttönen et al. (2019) pointed out that while challenging tasks can increase self-confidence, a lack of support can be discouraging (Isomöttönen, 2011). Similarly, high-quality interaction with the faculty and receiving support have been found to be significant for the satisfaction in terms of the learning experience (Isaeva et al., 2023). The results of sub-study II indicate that there may be improvements to be made, such as in the instructors' timely feedback. However, support from the perspective of availability and accessibility may prove insufficient, especially in complex problem solving. Project development professionals in industry and university have valuable competence, the sharing of which should be encouraged. In the same digital ecosystem, discourse is natural and can prove beneficial for all parties. The CoI could be extended to include these external stakeholders as active participants in data construction. From the students' point of view, the setup offers experience in authentic professional networks, and communication experience enables the demonstration of one's competence. The roles change dynamically, in which students at times act as teachers in relation to their peers and even to other representatives of the ecosystem. This works especially well in Finnish culture due to the low hierarchy. For instructors, the development of competence through studying substances alongside the students supports the professional development of the personnel. Correspondingly, from an industry perspective, improving successful recruitment opportunities, finding new and fresh perspectives and possibly having a welcome variation in day-to-day work can facilitate participation. However, university–industry cooperation is not a new phenomenon (Ashruf et al., 2021). Even complete degree programmes have been established in cooperation between industry and the university (Xue et al., 2018).

A discussion needs to be maintained on task-related questions, technologies and concepts (Req-13). In their study on the participation of undergraduates in distance learning universities in a large forum, Baxter and Haycock (2014) found that most students participated as occasional posters and that academic interaction is considered more valuable than social. Students also proved to be passive messengers on public channels in sub-study II, even though it was a relatively small-scale forum. The epistemic uncertainty of students participating in general discussions about the assignment on problem solving and critical thinking should be addressed as a pedagogical challenge. Furthermore, in sub-study II, the Rasch RSM showed a higher level of agreement for questions about the facilitation of discourse-related items to keep discussions and project assignments conducive to learning. Conversely, a lower level of agreement (i.e. more difficult to agree with) was found in items concerning the importance of online discussions in valuing different perspectives and of reflection for understanding fundamental concepts. Even following the discussions alone is important for the students' cognitive development and individual engagement, which already contributes to the challenges to the discourse maintained in the community. Progress towards educational goals requires attention to both CP and SP, such as following the posts and taking into account the timing and nature of the responses (Garrison, 2016, p. 74). As Cascurlu et al. (2020) observed a moderately strong positive relationship between TP and both student satisfaction and learning experience, instructors should be encouraged to participate in discussions by adding comments and providing guidance, additional information and critical questions (Aljahromi, 2020). TP is also essential to ensure movement towards the integration and resolution phase (Garrison, 2016, p. 117), which may happen at different times in the case of problem solving of project teams. Some of the discussions certainly fall under the concept of technological support, which was proposed by Wang et al. (2021) as an additional category to assessment in TP based on factor analysis among Chinese university students majoring in educational technology. Creating a culture of knowledge sharing and peer-to-peer discussions and support also moves the intervention one step closer to the DevOps philosophy.

The DevOps philosophy and principles should be applied (Req-14). There are several similarities in the philosophy and principles of DevOps with respect to CoI. Both are based on social perspectives, which are founded on collaboration and recognise trust as one of the core values. In addition to the culture of trust (de França et al., 2016; Freeman, 2019, p. 7; Mishra & Otaiwi, 2020), de França et al. (2016) listed the following characteristics of DevOps' social aspects: collective performance evaluation, effective communication, mutual learning, openness to change, personal responsibility, relevance of cultural aspects and respect among team members. The basic principle of DevOps, which is the culture of sharing (de França et al., 2016; Faustino et al., 2022; Mishra & Otaiwi, 2020; Rafi et al., 2022), is about sharing personal knowledge, learning and project data. The Rasch RSM in sub-study II highlighted the students' difficulty in agreeing with the statement that they feel the interaction with the other teams' members is comfortable. Encouraging students to collaborate and interact across team boundaries, among other things, follows the DevOps principles and also prepares students for emerging industry paradigms. Although DevOps is a process of continuous integration and delivery, the rest of its principles can be integrated into the learning process and the educational context where applicable. These principles include measurement, automation, quality assurance, leanness, meaning (e.g. rapid feedback), holistic or systemic view and even the elimination of waste (de França et al., 2016), with reference to the SDG perspective.

An online resource pool for student use should be established (Req-15). With digitalisation, the number of open educational resources is increasing rapidly. It is no longer necessary for instructors to lecture personally and comprehensively, as students can be given access to the necessary resources, and learning takes place on an individual basis. The results of the Rasch RSM analysis in sub-study II reveal that, in the case of CP, the statement that they use a variety of information sources to explore problems posed is one of the easiest to agree with. Among the most difficult items to agree with in sub-study III is the claim that the value of brainstorming is to help find relevant information to solve the problem, as well as learning activities with solution construction. The students also proposed additional learning and support materials in the open-ended questions of sub-study III. These results encourage practitioners to offer, diversify, increase and pre-filter learning materials that are more relevant to students. The PjBL's authentic and open assignments also challenge instructors to produce necessary and useful material and even differentiate it to support the individual solutions of each project team. In these cases, the establishment of a common OER pool to support learning, reviewed and selected by instructors, is justified. Although OERs, in this case MOOCs, have been found to suffer from a lack of collaborativeness and interactivity (Gamage et al., 2020), they are well suited as support material or self-regulated learning (Gürdür Broo et al., 2022). The supply now covers the latest technologies and methods, and production is of high quality. The inclusion of this design requirement can also be justified by the national utilisation of common data resources included in the objectives of the Digivisio 2030 project (Digivisio 2030, n.d.).

A blended learning approach should be used (Req-16). Although sub-study III finds that it is possible to successfully implement PjBL online, as observed by Mulyani and Arif (2021), it is more meaningful to consider the needs of students' social contacts. A key feature of blended learning, in which students are involved in a meaningful way in situations where either FTF or online is not possible (Garrison, 2016, p. 101), is justified in laboratory-intensive activities. In sub-study III, the Rasch RSM reveals that the most difficult items to agree with are the statements that they can apply the knowledge and develop solutions in practice when it comes to CP in an online setting. Working in the laboratory is also part of learning, as expressed by students in the context of sub-study I, including finding the necessary components, configuring the test setup, verifying and debugging the functions of the equipment and documenting any measurement event, which are skills more challenging to learn virtually. Although the laboratory functions of engineering education have often been virtualised in the context of the blended learning approach (Al Arefi, 2021; Deepa et al., 2021; Purnamawati et al., 2021), laboratories should be provided with a natural way for socio-emotional interaction (Hu et al., 2021) at the peer-to-peer and peer-to-instructor levels. This point of view is supported by the findings in sub-studies II and III, in which students experienced the most difficult item to agree with: a sense of collaboration fostered by online discussions and the excellence of online communication for social interaction. Furthermore, in the open-ended questions of sub-study III conducted entirely online, the students highlighted communication problems and a lack of social contact.

5.2 Design Principles for a Digital Learning Ecosystem in Engineering Education

Based on the previously described and discussed requirements, the next step involves further synthesis and adaptation of the design requirements to a more generalised form, aligning them with the design principles of CoI outlined by Garrison (2016, p. 112). This synthesis enabled the addressing of the main research question of this study.

What are the design principles and characteristics of a digital learning ecosystem that align with the needs of stakeholders and policies in ICT engineering education?

The design requirements derived from the various cycles of this DBR are used to synthesise the final design principles. Table 14 illustrates the design requirements and the corresponding design principles of CoI, synthesising the final design principles for the DLE. Following Table 14, each design principle is individually discussed to provide a comprehensive understanding of its implications. Finally, a visual model illustrating the theoretical framework is presented.

Table 14
Design Principles Synthesised from the Requirements and Mapped to the Design Principles of CoI

Design Principle for DLE	**Related Design Principle of CoI**	**Requirements**
DP-1: Deploy a team collaboration platform (TCP)	CoI-1: Plan for the creation of open communication and trust CoI-2: Plan for critical reflection and discourse CoI-3: Establish community and cohesion	Sub-study I: Req-2, Req-4, Req-5 Sub-study II: Req-11, Req-12, Req-13, Req-14 Sub-study III: Req-16
DP-2: Activate all stakeholders in cooperation	CoI-1: Plan for the creation of open communication and trust CoI-2: Plan for critical reflection and discourse CoI-3: Establish community and cohesion CoI-6: Sustain inquiry that moves to a resolution	Sub-study I: Req-3, Req-4, Req-5, Req-6, Req-7, Req-8 Sub-Study II: Req-11, Req-12, Req-13, Req-14
DP-3: Create a culture of ecosystem	CoI-1: Plan for the creation of open communication and trust CoI-2: Plan for critical reflection and discourse CoI-3: Establish community and cohesion CoI-5: Sustain respect and responsibility	Sub-study I: Req-2, Req-4 Sub-study II: Req-11, Req-12, Req-13, Req-14
DP-4: Employ blended learning methods	CoI-4: Establish inquiry dynamics (purposeful inquiry)	Sub-study I: Req-2, Req-4 Sub-study II: Req-11 Sub-study III: Req-16
DP-5: Establish an instructor team	CoI-4: Establish inquiry dynamics (purposeful inquiry) CoI-7: Ensure assessment is congruent with the intended processes and outcomes	Sub-study I: Req-1, Req-3, Req-4, Req-5, Req-6, Req-7, Req-8, Req-9 Sub-study II: Req-10, Req-12, Req-14
DP-6: Establish an online resource pool	CoI-2: Plan for critical reflection and discourse CoI-6: Sustain inquiry that moves to a resolution	Sub-study II: Req-10, Req-15
DP-7: Apply project-based learning (PjBL) methods	CoI-2: Plan for critical reflection and discourse CoI-3: Establish community and cohesion CoI-4: Establish inquiry dynamics (purposeful inquiry) CoI-5: Sustain respect and responsibility CoI-6: Sustain inquiry that moves to a resolution	Sub-study I: Req-1, Req-2, Req-3, Req-5, Req-6, Req-8, Req-9 Sub-study II: Req-11, Req-12, Req-13
DP-8: Apply industry-based methods and concepts	CoI-2: Plan for critical reflection and discourse CoI-3: Establish community and cohesion CoI-5: Sustain respect and responsibility CoI-6: Sustain inquiry that moves to a resolution	Sub-study I: Req-3, Req-4, Req-5, Req-8 Sub-study II: Req-12, Req-13, Req-14 Sub-study III: Req-15, Req-16

Note. The requirements are listed in Table 13. The related CoI design principles refer to Garrison's (2016, p. 112) design principles.

Deploy a team collaboration platform (TCP) (DP-1). To ensure collaboration and interaction throughout the entire ecosystem, DLE should be supported on a team collaboration platform to support both open interaction and a collaborative constructivist approach for the creation of open communication and trust (CoI-1) and for professional system development (Req-13, Req-14). Enabling critical reflection and discussion (CoI-2) on a flexible platform in terms of time and place frees students from independent and individualised learning. Platform members contribute to establishing a community whose access to team workspaces and channels requires belonging to certain levels of the ecosystem, contributing to and facilitating a sense of cohesion (CoI-3, Req-2). Stakeholders communicate, collaborate (Req-5, Req-11, Req-12) and contribute to the community through a TCP as a communication medium (Req-4) and, where applicable, through integrated developer platforms and tools. A TCP should be selected based on the widest possible range of features, such as screen and audio/video sharing, to support a blended learning approach (Req-16). Both team-specific and private work areas and channels, as well as public ecosystem-wide forums, should be considered, taking into account the starting points, needs and objectives of micro-, meso- and exo-level ecosystems.

The platform is expected to support all core elements of CoI: SP, TP and CP. From an SP perspective, the platform should support *cohesion* and provide students with a sense of belonging, trust and security to facilitate open communication (Garrison, 2016, p. 114). Trust is considered one of the key factors in teamwork success (Breuer et al., 2016; Choi & Cho, 2019). Technology makes it possible to create emotional connections to combat the effects of social distance (Logemann et al., 2022). Instructors are also encouraged to personalise the interaction, which, according to Logemann et al. (2022), has improved the development of SP in virtual classrooms. Indeed, the fully digital environment transforms the role of the instructor into a coach and mentor, which has been found to create a greater sense of inclusion in the interaction between the faculty and the student (Logemann et al., 2022). In supporting CP, the TCP plays an active role as a tool for the collaborative construction and reflection of information through exploration, integration and resolution. The digital infrastructure, including TCP, should be used as a shared and guided information retrieval gateway by incorporating professional development tools into the platform's activities to enable effective monitoring and early intervention as support for ecosystem conversations and team development. However, from the standpoint of CP design, Garrison (2016, p. 118) warned against overburdening students with excess content, which can signify the goal of assimilating information over applying information or other higher-order learning outcomes. Instructors must constantly manage and monitor the learning experience from the perspective of TP, striking a balance between too little and too much intervention (Garrison, 2016, p. 120).

Activate all stakeholders in cooperation (DP-2). In addition to students, teachers, R&D personnel and industry representatives were considered stakeholders. From the perspective of students, the employees of university units, such as the staff of laboratories and projects, could also be considered representatives of industry and business. Activating these stakeholders as active actors (CoI-3, Req-5) in the digital ecosystem can enrich and diversify (Req-6) the learning experience for critical reflection (CoI-2) and open discourse (CoI-1). Authentic project management methods (Req-3) and TCP-supported interaction and *collaboration* (Req-4) provide an authentic and goal-oriented context (CoI-6) for the learning experience in which all actors are naturally involved in the collaboration and assessment (Req-7). It is important to provide not only students but also every representative from the stakeholder group with the opportunity for risk-free expression, participation in discussions and possible support activities, thus fostering a sense of community and group cohesion at all levels of ecosystems (Req-11) in accordance with working life practices (Req-14). The versatile inclusion of new technologies (Req-8) and the professional discussions related to their development and utilisation (Req-13) require a multidisciplinary approach to research and education, as well as knowledge of various topics (Korhonen-Yrjänheikki et al., 2007), in which case the contribution of all stakeholders is valuable. The results of the study by Muukkonen et al. (2022) also highlighted the significance of systematic support for collaborative knowledge creation and teamwork in the development of students' competencies. Individual instructors may also benefit from cooperation from the perspective of competence development, as competence profiles do not always cover all subjects. Furthermore, the findings of Vesikivi et al. (2019) also reinforce the idea that team teaching fosters the professional development of teachers. Furthermore, the support activities, discussion and feedback are carried out in cooperation among stakeholders (Req-12) and thus do not burden the limited time resources of the individual instructor.

The CoI should aim to be both inclusive and critical, finding a balance between academic and social factors (Garrison, 2016, p. 37). From the perspective of SP, participants recognise that a group's academic purpose and personal relationships should evolve from these interactions (Garrison, 2016, p. 40). Indeed, according to Garrison (2016, pp. 48–49), a strong SP provides a basis for respectful questioning and also serves as a mediating variable in terms of CP and TP. Strengthening SP and CP online has been found to facilitate learning of the skills required for a substance to a level equivalent to that of performance in on-campus approaches (Beneroso & Robinson, 2022), with TP acting as a unifying element in a virtual and *collaborative* setting (Garrison, 2016, p. 70).

To activate and motivate ecosystem-wide cooperation, the specific interests of each party should be taken into account and ensured from different perspectives. Collecting and publicising a reference collection of previous successful forms of cooperation can serve as a motivator for stakeholders, demonstrating the value and meaningfulness of collaboration at each level of the ecosystem. Collaboration also provides industry with a perspective and influence on the content, not only indirectly at the curriculum level but also directly during the implementation phase, which advocates the widest possible inclusion at all levels of the ecosystem.

Create a culture of the ecosystem (DP-3). The methods and philosophies adopted by industry, such as DevOps, have several goals related to the organisational culture similar to the CoI principles, which are based on open communication (CoI-1), critical discussion (CoI-2), community and cohesion (CoI-3) and the common idea of trust and responsibility (CoI-5). Both are based on cooperation, which can be supported by facilitating group cohesion (Req-2) on an appropriate platform (Req-4). In addition to the climate of cooperation and trust (Req-11) underlying the methods used by the industry and CoI principles, cultural values (e.g. DevOps method) also include effective communication and *sharing* of learning and project information with professional discussions recognised by the CoI framework (Req-12, Req-13, Req-14), which are strongly recommended values to be embedded in the DLE. Furthermore, if the practice of these values can be shown to be part of the engineering skills and culture of the profession in the field followed and applied in the industry, their importance in promoting SP and CP is emphasised from the students' point of view. Garrison (2016, p. 147) noted that in the context of educational institution leadership, effective leadership develops shared commitment and productive relationships in a culture of shared purpose and collaboration. In the DLE, this may be considered part of the TP element.

Employ blended learning methods (DP-4). A blended learning approach (Req-16) is used to provide technical competencies that require laboratory facilities and the occasional FTF social interaction of students (Req-2, Req-11) to promote inquiry dynamics (CoI-4). The blended learning approach should be supported with an appropriate platform (Req-4).

From the point of view of the collaborative process in a digital environment, students should have the opportunity to influence not only the content but also the implementation approach (Garrison, 2016, p. 73), which seems to strongly support the blended learning approach in this study. Furthermore, starting conversations is better in the FTF environment, but it requires special attention to TP to achieve resolution (Vaughan & Garrison, 2005). It is crucial to harness the benefits of blended learning in the context of comprehensive online education. The ultimate purpose of e-learning is not only to connect individuals remotely but to create *virtual* communities (Garrison, 2016, p. 2). The blended learning approach has been observed in relation to the CoI framework, such as in reducing the time needed to develop group cohesion, promoting the achievement of a higher level of inquiry by freeing up time for the integration and resolution phases and satisfying more students by offering more versatile communication methods (Akyol et al., 2009). From the perspective of SP, Guo et al. (2021) speculated that the willingness to enter into personal relationships could be emphasised, especially among first-year students, and that this process could be supported by a blended learning approach. According to Garrison (2016, p. 106), developing SP online takes time.

Establish an instructor team (DP-5). Management of comprehensive culture-appropriate (Req-14) learning, congruent competence-based assessment methods (CoI-7, Req-7) and general community dynamics (CoI-4) on the team collaboration platform (Req-4) and learning management system (Req-10) requires a team of instructors working closely together to establish the foundation and structures for all activities in digital learning ecosystem, activating all stakeholders at all levels (Req-12). For integrated courses, a joint project assignment requires interaction (Req-1), planning, facilitation between instructors, cooperation and even a teaching presence through a partnership with industry representatives (Req-5). Cross-cutting topics, such as mathematics (Req-6), should also be systematically included in Industry X.0 (Req-8)- and sustainable development goals (Req-9)-based assignments through different subjects. The instructor team forms a network of experts comprising not only teachers but also other stakeholders in the ecosystem where possible. This meso-level social network within the ecosystem represents a contribution to the CoI, to which the principles of the three core presences of the framework may also be applied. The integrated implementation of the semester can also be equated to a project for instructors. This is why the instructor team is strongly recommended to project the implementation of the semester using authentic project management methods (Req-3), such as agreeing on the schedule, communication and responsibility issues.

The processing of the assignment in the integration phase of cognitive presence involves the construction of meaning and the *integration* of ideas (Garrison, 2016, p. 56), which requires deep cooperation from the instructor team in the context of the integrated semester project assignments. The different nature of teaching enriches the entire ecosystem. An instructor who models a strong academic approach is likely to raise the CP indicator; correspondingly, an instructor with a strong SP raises the level of SP in the entire ecosystem (Garrison, 2016, p. 43), which may also be true for all active stakeholders. In terms of achieving the goals, a strong and collaborative leadership (Garrison, 2016, p. 148) included in the teaching presence is important (Garrison, 2016, p. 78) justifying and empowering the instructor team for collaborative development.

Establish an online resource pool (DP-6). The open problem paradigm emphasises the importance of diverse learning materials. The progression of the problem-solving process to the resolution phase (CoI-6) requires a critical discussion (CoI-2) and evaluation of options, which can be accomplished with various support materials as a knowledge base (Garrison, 2016, pp. 51–52) offered, recommended and delivered, for example, through the learning management system (Req-10), in addition to the instructors' actual lecture materials. These resource-rich online environments (Req-15) have been found to facilitate students' self-regulated learning strategies (Dowell & Small, 2011), supporting lifelong learning skills. The materials in the open course materials, internet material and commercial services are of high quality and free up the instructors' time to reinforce TP, facilitation and maintaining activities. The online resource pool as a *toolkit* should also include a collectively maintained body of development applications offered by the organisation, as well as possible lists, recommendations and experiences of the open-source tools.

In critical thinking, such as cognitive presence, the individual constructs meaning and strengthens it through critical discussion (Garrison, 2016, p. 50). In this exploration phase of CoI, ideas are explored collaboratively as individuals attempt to search for relevant information and understand what Garrison (2016, p. 56) refers to as the core of thinking and learning as a recursive process. In this sense, however, Garrison (2016, p. 69) cautioned about allowing students to have excessive discretion in deciding on objects of interest (e.g. for internet materials) and emphasised the role, responsibility and expertise of TP to achieve transactional balance. As a cognitive process, shared metacognition requires awareness and the ability to take responsibility for regulating the thinking and learning process as an individual and in collaboration (Garrison, 2016, p. 60). These skills can be assumed to develop by enabling self-regulated learning with an appropriate knowledge base and bringing students' individual contributions to the discussions of the project group.

Apply project-based learning (PjBL) methods (DP-7). In collaboration with industry (Req-5), transferring learning to authentic development projects by integrating courses (Req-1) and using Industry X.0 technologies (Req-8) with incorporated SDG topics (Req-9) fosters early adaption to professional *problem solving* as purposeful inquiry (CoI-4). Collaborative learning in project groups develops group cohesion (CoI-3, Req-2) and critical reflection and discussion (CoI-2) in effective small groups. Through collaboration and small group activities, the potential for influencing approaches and solutions can be assumed to shift learning from surface approach to deeper learning, as also inferred by Rämö et al.(2023). As PjBL is based on the integration of subjects, cross-cutting perspectives, such as mathematics (Req-6), can be more easily included in the contents, requirements and solutions of authentic and open problems. In integrated semesters, the contribution of all stakeholders in the ecosystem in the form of discussions, feedback and support activities (Req-12) is naturally activated. This encourages cooperation (Req-11) in realising the need for multidisciplinary perspectives on the ecosystem and maintaining task-related professional discourses (Req-13). Finally, with the methods of authentic project management (Req-3), both the learning and professional development processes are subjected to determined, controlled and goal-oriented progress (CoI-6), following a culture of respect and responsibility (CoI-5).

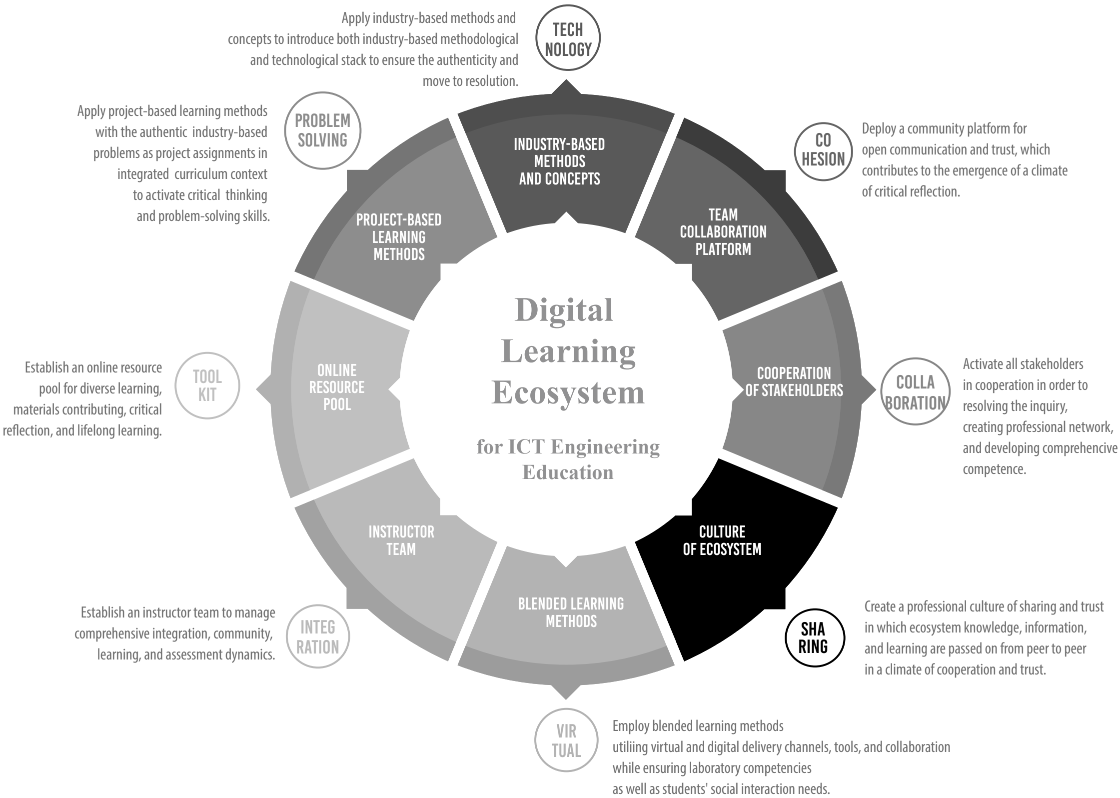
Garrison (2016, p. 51) argued that critical thinking is more effective in purposeful research groups. Project-based learning with authentic project management methods is suitable for generating this determination. Furthermore, Garrison (2016, p. 46) posed the challenging question of how to establish social presence to support thinking and learning collaboratively in blended and online learning environments in CoI. Based on the results of this study, this question is also answered using the PjBL method conducted in the digital learning ecosystem. Cognitive presence focuses on purposeful learning, including reflective thinking, critical discourse and higher-order learning outcomes (Garrison, 2016, p. 116). Authentic content through authentic project management methods (Req-3) engages participants in CP. For Garrison (2016, p. 148), all members of a community must participate in the leadership function by facilitating and directing the process. Alongside clear content goals, metacognitive maps support an understanding of the meaning of responsibilities (CoI-5) and the progress of tasks (Garrison, 2016, p. 119). Authentic project management can also be considered a metacognitive roadmap for learning.

Apply industry-based methods and concepts (DP-8). Finally, the technologies, concepts, practices and methods of industry's working life should be adopted during education, exposing students to professional discussions (CoI-2) at an early stage as part of respectful and responsible (CoI-5) daily interactions. Industry is largely based on teamwork (CoI-3), with cultural values being prioritised (Req-14). In both industry and education, the goal of methods and concepts is to solve an authentic problem. From the point of view of this common goal, it makes sense to use emergent methods, concepts and technologies (Req-8) that have solid evidence and are constantly being developed and usually moving towards resolution (CoI-6). It is also easier for industry representatives to participate (Req-5) in the process, whether management follows generally accepted methods (Req- 3) and utilises commonly used teamwork platforms (Req-4). Participating in professional discussions is part of the industry's working life practices (Req-12, Req-13) and utilises all parties in the ecosystem. Open or internal resource pools (Req-15) within organisations are also a modern approach for moving away from the 'silent knowledge' of individual experts. Industry also implements a blended learning approach (Req-16) for social relations, cohesion and on-site activities in organisations.

Providing professional development and supporting learning should be included in the institutional policy of introducing a blended or online approach (Garrison, 2016, pp. 143–144). A collaborative learning experience implemented with appropriate industry-based methods and *technologies* naturally promotes not only the students' but also the personnel's competencies. Thus, the term 'learner' refers to all participants in the ecosystem, not just students. The application of standards is placed on the outer ring of the CoI framework, along with communication medium, applications and educational context (Garrison, 2016, p. 25), indicating the interaction with each of the three core elements: TP, SP and CP.

Figure 10 illustrates a visualised model of the design framework of the DLE of ICT engineering education. The design requirements and characteristics have been condensed and integrated into design principles utilising Garrison's (2016, p. 112) CoI framework.

Figure 10.
The Design Framework for the Digital Learning Ecosystem (DLE) of ICT Engineering Education



Note. Reprinted from 'ICT engineering students' perceptions on project-based online learning in Community of Inquiry (CoI)' by M. Mielikäinen and E. Viippola, 2023, *SAGE Open*, CC BY-SA 4.0.

6 DISCUSSION AND CONCLUSIONS

This chapter briefly summarises the design principles discussed in the previous chapter, followed by a discussion of the validity, reliability and limitations of the research process and results, providing the reader with critical reflection, considerations and evaluation. After evaluating the ethical perspectives, the theoretical and practical implications of this study are discussed, and possible directions for further research are provided.

6.1 Discussion on the Design Principles for a DLE in Engineering Education

Education needs to adapt to rapid global changes in economic and technological developments towards more flexible cross-sector teaching and learning ecosystems (Ralls et al., 2020). Digital convergence enables dynamic partnerships with a digital learning ecosystem as a socio-technical system (Jeladze et al., 2017; Laanpere et al., 2014; Valjataga et al., 2020) to deliver a high-quality learning experience. In digital transformation, stakeholders are required to work together in a more interdisciplinary manner towards the common goal of solving an open problem. The solution to the problem translates into competence, presumably with a positive effect on metacognition. Constructivist approaches have been found to be well-suited for developing 21st-century skills, such as creativity and innovation, critical thinking, problem solving, metacognition and lifelong learning (Teo et al., 2021). Furthermore, the transition from a teacher-centred approach to a learner-centred approach is critical (Ralph et al., 2022).

The eight design principles for a DLE are the most important contribution of the present study, as they provide a design framework for DLE implementation in ICT engineering education. With these design principles, this study provides a new understanding of and insights into the characteristics of a DLE in engineering education. A DLE in engineering education has the following design principles: *1) Deploy a TCP, 2) Activate all stakeholders in cooperation, 3) Create a culture of the ecosystem, 4) Employ blended learning methods, 5) Establish an instructor team, 6) Establish an online resource pool, 7) Apply PjBL methods,* and *8) Apply industry-based methods and concepts*, as shown in Figure 10. These design principles of a DLE can be considered to largely follow the core components proposed by Ramírez-Montoya et al. (2022) in connection with Education 4.0, such as a competency-based framework, teaching–learning methods, stakeholders, technologies and infrastructure. In a recent study, the eight characteristics of a DLE can be synthesised from the design principles, thereby establishing a connection between the concept and the emerging ideologies of the current era: *1) cohesion, 2) collaboration, 3) sharing, 4) virtual, 5) integration, 6) toolkit, 7) problem solving* and *8) technology*.

According to the design principles, the characteristics of a DLE are summarised as follows: A successful DLE enriches the entire ecosystem through collaboration. Therefore, a DLE should be placed on a digital platform for shared communication, collaboration and cohesion. The platform supports the dynamics of the instructor group's ecosystem and the joint planning of the integrated semester, starting from the planning phase. Integration with team development platforms and tools can be considered a selection criterion for team collaboration platform and learning management system in which tracking analytics at the team and individual levels through data platforms is made easier. As a pedagogical method, the project-based learning approach is applied in the integrated curriculum. An individual's expectations for the learning experience are taken into account in the adaptive characteristics of a DLE, which, through integrated learning entities and authentic projects, provides students with competence for problem solving and authentic readiness for an engineering career during their degree. Learning is collaborative among project teams that are supported by a toolkit of learning resources, freeing up instructors' resources to manage teaching, social and cognitive processes. Thus, sufficient and, in a positive sense, individualistic isolation is guaranteed, and social needs for the development of continuous learning and the availability of learning opportunities can be ensured.

In cooperation with industry representatives (e.g. through partnership), the project-based learning approach promotes a quality supply of Industry X.0-based, authentic and open assignments and provides students with valuable and suggested working life contacts. An iterative, agile and experimental approach supports the perspectives of continuous, lifelong and lifewide learning. First, PjBL is an iterative process, which involves repeating and refining steps. This aligns with the perspective of continuous learning as a combination of lifelong learning and lifewide learning (Laitinen-Väänänen, 2020), which emphasises the ongoing nature of learning. Second, project-based learning is also an agile approach that responds flexibly to changing circumstances. This is also in accordance with the view of continuous learning, which emphasises the importance of the ability to adapt and learn throughout life. Finally, PjBL is an experimental approach, which means that it encourages students to explore and test ideas through practical and inquiry-based activities. This aligns with the perspective of the lifewide learning component of continuous learning, which highlights the importance of learning from a variety of sources and contexts by allowing students to draw on their own experiences and interests to guide their learning and connect it with real-world issues and challenges. Overall, the iterative, agile and experimental approach of PjBL supports the perspectives of continuous, lifelong and lifewide learning by fostering a flexible, adaptable and inquiry-based approach to learning that is well-suited to the demands of the modern world.

In light of the findings of this study, Cronje's (2020, p. 120) revised definition of blended learning can be supported: 'The appropriate use of a mix of theories, methods and technologies to optimise learning in a given context'. When the Industry 4.0 strategy is based on digitalisation (technologies) and digital transformation (organisational and infrastructure change) (Ralph et al., 2022), the university field must take both aspects into account. Therefore, it is not enough for education to cover key technologies; authentic operating models and practices must also be introduced as discipline standards. From the perspective of mutual benefit, it is worthwhile for university institutions to integrate their own experts into the ecosystem. The SDGs are integrated as a theme in learning to improve the ability to think creatively and critically about complex problems and to develop innovative solutions that address the root causes of these problems. Fostering creativity and critical thinking by integrating SDG themes into authentic PjBL assignments can help students identify and implement solutions to complex global problems and can play a key role in advancing progress in the SDGs. Furthermore, the integration of mathematical skills is emphasised, and implementation is considered in the context of semester projects, with the subject teacher as part of an instructor team that collaboratively designs the context for the assignment. In addition, a separate semester is suggested to be dedicated to an innovative project assignment in accordance with the theme of sustainable development. The physical and virtual resources of campus labs support project teams and students' self-regulated learning. A blended learning approach can be suggested, for example, by organising joint laboratory activities to enable FTF social contact in the virtual community.

Monitoring the iterative process, which involves authentic project management and reviews following discipline standards, ensures progress and quality. The participation of industry representatives provides cognitive and constructivist perspectives for instructors as a team. This approach also takes into account factors such as team cohesion among students. In terms of reviews, instructors can monitor individual-level competence in accordance with the competence-based assessment criteria through demonstrations and discussions, regardless of the nature of the teamwork. The dynamics of the instructor team formed by supervisors have a crucial impact on the success of the overall endeavour. As noted by Romeu et al. (2016), teachers see collaboration in the online environment as increasing collective reflection, providing collective support and developing professional competence, which in the long run extends to improving the quality of the learning experience offered. Each semester should end with a presentation of project outputs at a public event, further activating students' sense of purposeful inquiry and completion culture and promoting soft skills.

Through cultural factors, the DevOps principles can be reflected across the entire DLE. Efficiency considerations are largely based on the DevOps thinking in the industry. The design principles of a DLE emphasise its human-centred aspects that benefit and strengthen individuals. The main contribution of the DevOps mindset to a DLE is its human-centric cultural perspectives, such as communication, collaboration, sharing and respect. In addition, certain analogies can be found in the educational context and in the goals of the value-driven and human-centric contributions of the DevOps approach. First, according to Park et al.'s (2015) taxonomy, the benefits of the DevOps mindset include improved deployment frequency, which can be seen as an analogy to the overall goal of education for better deployment and adaptation of skills and knowledge. A DLE contributes to this by adapting the PjBL approach and agile methods and by seeking to free up the rational use of time by instructors for supporting TP, CP and SP. Second, DevOps promises a faster time to market (Park et al., 2015), a goal that can be equated with a quicker transition to employment in terms of education and as an immediate opportunity to apply skills without deep competence gaps. A DLE and its design principles offer a lifelong learning perspective supported by OCW/MOOCs, authentic assignments and learning environments, authentic project management methods and problem solving based on Industry X.0 technologies, all of which contribute to advanced capabilities and an easy transition to working life. Third, new releases have a lower failure rate (Park et al., 2015). In the case of education, these failures can be seen as dropouts, the reduction of which is one of the most important tasks of HE institutions. In a DLE, the continuous monitoring of the progress of studies and a community based on comprehensive cooperation, including the collective support of all stakeholders, contribute to the impact and number of factors leading to dropouts. To support learning and focus instructors' attention on significant issues, automated learning analytics should be developed in accordance with the principles of measuring and monitoring in DevOps. Measurement is part of DevOps' core principles as improvement is only possible through measurement (Jabbari et al., 2018). Therefore, the implementation of automation has been proposed, such as the continuous measurement and observation of events in team collaboration platform, learning management system, git repository and developer platforms through data platforms. Furthermore, DevOps has been claimed to shorten the lead time between fixes, which can be sought in education from the perspective of faster intervention. The digital capabilities of a DLE provide a framework for versatile and purposeful data collection, monitoring and analytics. According to the DevOps principles, measurement is proactive and allows for real-time decision making (Forsgren & Kersten, 2018). Finally, DevOps' faster mean time to recovery (Park et al., 2015) can be equated with early actions and intervention, support and guidance in an educational context. The collaborative approach taken by all stakeholders of a DLE towards a shared community TCP results in quicker access to support, ultimately leading to enhanced metacognition among individuals.

From the perspective of this study, following Bronfenbrenner's (1979) ecological systems theory, cultural elements situated at the macrosystem periphery should not be disregarded either. In the development of design principles for DLE, it is essential to take into consideration, the significance of industry-specific business and operational cultures. From the standpoint of DLE, stakeholders contribute their individual insights, experiences, and expertise to a larger communal context, thereby enhancing the richness of the learning process. In project-based learning, the cultural context and communal interaction are reflected through projects in which students engage with their environment, industry practices, as well as community practices and culture. This parallels Bronfenbrenner's (1979) macrosystem periphery, which emphasizes the broader cultural and societal influences on an individual's development and learning. According to Lemmetty (2020), the individual is part of a larger sociocultural entity, where self-directed learning in the workplace is connected to the frames of the environment and the community through the group. Well-designed activities motivate and inspire active participation, while also fostering critical thinking and lifelong learning skills (Wang, 2011).

6.2 Overall Methodological Evaluation and Reflection

In this section, the methodological choices are described and discussed, starting from perspectives related to design-based research. Nieveen and Folmer (2013) listed four quality criteria for interventions: 1) relevance: there is a need for the intervention, and its design is based on state-of-the-art (scientific) knowledge, 2) consistency: the intervention is 'logically' designed, 3) practicality: the intervention is expected to be usable in the setting for which it has been designed and 4) effectiveness: using the intervention is expected to result in the desired outcomes. This DBR is situated in an authentic engineering education context by iterating using mixed methods and fostering collaboration between researchers and practitioners. It promotes understanding of the context, improving practices and planning and testing the intervention. These aspects also correspond to the parameters proposed by Anderson and Shattuck (2012) for high-quality DBR research. Lincoln and Cuba (1985, p. 290) presented four fundamental issues for the trustworthiness of research: 1) truth value: confidence in the truth of a finding, 2) applicability: application of the results to other contexts or subjects, 3) consistency: repeatability with the same or similar context or subject and 4) neutrality: determination of the results based on the subject of the study, the respondents or conditions, and not by the researcher's biases, attitudes, motivations or perspectives. The strength of this research can be attributed to the use of mixed methods. The simultaneous use of qualitative and quantitative research paradigms produces more comprehensive knowledge that is necessary to inform both theory and practice (Johnson & Onwuegbuzie, 2004). The following paragraphs reflect on the perspectives of this study in relation to the quality criteria.

The choice of a DBR as the research method for this dissertation was largely based on its ability to develop solutions to complex and practical educational design problems (McKenney & Reeves, 2019, p. 6). From the beginning of the research process, the goal was to form design principles for the development of ICT engineering education, for which DBR, as a producer of design principles (Amiel & Reeves, 2008), provided the process and framework. Van den Akker's (1999, p. 9) heuristic statement on design principles:

> 'If you want to design intervention X [for the purpose/function Y in context Z], then you are best advised to give that intervention the characteristics A, B and C [substantive emphasis], and to do that via procedures K, L and M [procedural emphasis], because of arguments P, Q and R'.

guided thinking throughout the process. In this DBR, the following characteristics of the intervention, as intended by van den Akker, were revealed based on iterations: cohesion, collaboration, sharing, virtual, integration, toolkit, problem solving and technology, as described earlier in relation to design framework. Intervention should be done via procedures, i.e., by following eight design principles. The arguments were presented in connection with the background and theoretical framework of the first chapters and then discussed, justified and synthesised through the lens of the theoretical framework.

However, the DBR chosen as the research method also involves some threats, criticisms and limitations that should be considered in this study. For example, the complexity of real-life situations and the large amounts of data arising from the combination of ethnographic and quantitative analyses pose challenges to designing research (Collins et al., 2004; Wang & Hannafin, 2005). DBR has been criticised for being poorly defined (Easterday et al., 2014). Easterday et al. (2014) found that understanding the phases is a prerequisite for better planning and communication. They described several theorists' notions about forms of research in DBR. They noted that it had been questioned whether the design was a science at all and how it differed from the design used in industry. The authors described DBR as useful only if it can reliably produce useful interventions and effective theories compared with other methodologies, which require a clear description of the process. Herrington et al. (2007) were even cautious about using DBR in dissertations because of the long term and intensity it requires (Goff, 2017). However, according to Goff (2017), the DBR approach can be used in a shorter term and in less intensive contexts to successfully design context-based solutions to educational problems in collaboration with researchers and practitioners. Based on the experiences of this study, DBR is a natural way to approach a problem for a researcher in engineering education. As an iterative process, DBR strongly resembles agile product development methods, including cycles and phases. In agile methods, the results of the iteration rounds or cycles are carried over to the next cycle, where applicable, to be supplemented with the tasks allocated to the respective iterations. Based on the previous analogy, DBR research can roughly be considered agile. In the context of this study, agility proved to be especially advantageous, given that the outcomes of the cycles could be promptly operationalized.

According to Wang and Hannafin (2005), DBR reports should include purpose and goals, framework, settings and processes, outcomes and principles. The reporting in this study includes the previously described elements. The implementation process, methods used, data collection, phases and methods of processing and analysis have been described as precisely as possible to increase the quality of this DBR. Following Wang and Hannafin's (2005) instructions, the first chapters of this study state the purpose of the design, explain the goals of the design and present the literature related to the design. In the research design section, the research setting, data collection, and analysis methods are described. The findings are linked to the research process and presented with contextual information, providing some guidance to support reading.

It is also worth noting that one of the strengths of design research is working collegially with practitioners and co-constructing knowledge (Shavelson et al., 2003). However, Barab and Squire (2004) examined the role of the researcher in the conception, design, development, implementation and research of a pedagogical approach and found that it was challenging to ensure the credibility and reliability of claims. By nature, DBR strives for idealism. Researchers are involved in manipulating the intervention to understand reality, as in this study, in which the researcher served as the designer, instructor and researcher. The instructors worked closely with the researcher to design the interventions. The success of the collaboration is probably directly proportional to the simultaneous role of the researcher as a teacher. In this case, the partnership is natural, and the role of the researcher does not stand out in particular. However, the role of researchers as context manipulators may undermine the credibility of the arguments (Barab & Squire, 2004). However, in interpreting the results, researchers' perceptions are paramount and influenced by epistemological aspects. Although the research process strongly aims at the neutrality criterion of trustworthiness, as defined by Lincoln and Cuba (1985, p. 290), the influence of the researchers' epistemological philosophy on the results cannot necessarily be completely excluded in this study either. It is assumed that this valuable partnership will also be maintained in the development of the intervention after this study, which is important because maintaining the partnership between researchers and teachers affects the success of the innovation (Design-Based Research Collective, 2003).

During the first phase of the initial DBR cycle (sub-study I), the researcher independently carried out all the actions and activities. However, upon completing the individual work, the qualitative content analysis was presented to an instructor colleague to reach a consensus on categorisation and coding. In the remaining phases of the first DBR cycle (sub-study II) and the second cycle (sub-study III), the researcher collaborated with practitioners to design the setting. In sub-study II, the researcher provided support as an instructor, while in sub-study III, she served as an instructor for first-year students and a supporting instructor for upper-year students. Furthermore, the researcher led a team of instructors in each cycle. Data collection and final analysis were performed by the researcher across all sub-studies I, II and III. In sub-studies II and III, the analysis relied on visual presentations of the Rasch RSM results, which were prepared by a statistician. The statistician served as the second author in both sub-studies. Following the Rasch analysis, the results were reviewed and discussed with an instructor colleague and the statistician in sub-study II. Similarly, in sub-study III, the results were examined with a statistician before being presented to an instructor colleague to ensure validity.

The researcher was the first author of all three international scientific publications incorporated in this dissertation. For the initial publication of sub-study I, the researcher independently wrote the manuscript, carrying out all facets of the writing and publishing process. In the second publication of sub-study II, the researcher assumed the responsibilities of writing and publishing, occasionally seeking feedback from two co-authors, a statistician and a colleague. In the third publication of sub-study III, the researcher collaborated with a statistician as a co-author, following the same procedures as in sub-study II.

In the case of qualitative research based on Gibbs (2007), Creswell (2014, p. 251) defined validity as the verification of the accuracy of the results by employing certain procedures and reliability as consistency across different researchers and different projects. Validity in research can be categorised into internal validity, which pertains to a study's ability to explain a specific event or problem based on the data, and external validity, which concerns the extent to which the findings can be generalised to broader populations, cases or situations (Cohen et al., 2007, pp. 132–136). It is a straightforward approach to start the analysis of validity of qualitative research sections to evaluate the truth value (Lincoln & Guba, 1985, p. 290) in this study using Creswell's (2014, pp. 251–252) seven validity strategies: triangulation, member checking, rich and thick description, clarifying the bias of the researcher, presenting negative or discrepant information, spending prolonged time in the field, peer debriefing and use of an external auditor. The concept of triangulation has traditionally been used in positioning geometry to determine locations using two stable reference points. In research, triangulation refers to the use of more than one approach to study a research issue (Heale & Forbes, 2013). In this study, triangulation was used to ensure the validity of the qualitative research sections. Patton (1999) defined four different types of triangulation: 1) variety of data collection methods as methods triangulation, 2) consistency of different data sources as triangulation of sources, 3) use of multiple analysts to review findings as analyst triangulation or investigator triangulation (Archibald, 2016; Bans-Akutey & Tiimub, 2021) and 4) use of multiple perspectives or theories to interpret the data as theory/perspective triangulation. For this study, the data were collected from multiple sources in the case of all three sub-studies; thus, the method triangulation was implemented. Triangulation of sources was also applied in this study, in which a common rationale for the themes—the design principles—was developed by examining evidence from different data sources (Creswell, 2014, p. 251). The results of the sub-studies were presented to colleagues as participating stakeholders throughout the process, and they assessed and commented on the results using Creswell's (2014, p. 251) member checking validity strategy. Colleague opinions were used in content analysis to reach a consensus and enhance validity through analyst triangulation. In this study, several methods, perspectives and theories from industry and engineering practices and social sciences research were used to reinforce validity from a theoretical triangulation perspective.

Although triangulation has been criticised (e.g. it assumes that data from two distinct studies are comparable) (Heale & Forbes, 2013), this study sought to view the results of the sub-studies as separate entities and developed a common rationale previously identified from the findings. Efforts were also made to use a rich and detailed description of the settings to convey the findings, which is expected to increase the validity of the findings (Creswell, 2014, p. 251). Negative and contradictory evidence was presented to add credibility to the account. An in-depth understanding of the phenomenon under study was gained in the field, and the analysis used the researcher's long experience in setting and stakeholders, which can also be assessed to increase the credibility of the study (Creswell, 2014, p. 252). Creswell (2014, p. 252) argued that peer debriefing and external auditor processes, which were applied in the current study, supervisory professor reviews, targeted questions and learning seminars could increase the validity of the study.

In addition to the designed elements, the learning experience is influenced by many other factors, such as the atmosphere and the classroom culture (Ryu, 2020). Therefore, interpreting and explaining causality can be challenging in complex DBR interventions involving different decisions made by different practitioners (Design-Based Research Collective, 2003). The results of sub-studies II and III were positive, but the phenomenon studied in them could not be isolated. Thus, the effects of other factors or phenomena referred to by Ryu (2020) could not be completely excluded. In sub-study III, the reasons for the phenomenon were sought to be clarified in more detail with open questions that revealed at least some of these underlying factors.

The research material described real answers given by real students. However, the possibility that the students' answers could have been influenced by authority factors and other hidden factors could not be excluded. Incomplete observations can pose serious challenges to causal discovery and inference. The existence of latent confounders, unobserved common causes that affect two or more observed parts of a system (Hyttinen, 2013, p. 6), is still possible from the point of view of this study. In addition to the intervention itself, several other factors influenced the intervention, one of the most important of which was the COVID-19 pandemic at the time of this study. Moreover, there was no randomisation in the sampling, and it could not be considered an experimental design, which limits the making of causal inferences (Stone-Romero & Rosopa, 2008), especially without using causal inference methods. Randomisation in this study could be implemented by dividing the population into experiment and control groups through random sampling (Cohen et al., 2007, pp. 110–117) and by following the online approach for one subpopulation and the blended learning approach for the other. Randomised controlled trial (Deaton & Cartwright, 2018), which is considered the highest level of research (Slavin, 2002) and has a convincing way of making causal inferences (Bikner-Ahsbahs & Norma Presmeg, 2014), can be challenging in similar DBR studies that are situated within a single degree programme development paradigm.

The CoI survey, which is validated and widely used in educational research, provided a research instrument for collecting students' learning experience data for this DBR. However, the English questionnaire was translated into Finnish before delivery, which may have had an impact on the results. The translation into Finnish was done because the students are native Finnish speakers in a Finnish-language education. Although the translation was performed with particular care in an effort to minimise possible differences in nuances typical of languages by reviewing the translations with two instructor representatives, the translation could still affect the nuances of the features and meanings from the respondents' point of view. These unintended effects could have been mitigated through the application of a systematic back-translation (Beaton et al., 2000; Borsa et al., 2012) process, where the translated version is completely blind translated back to the original language by at least two persons and the results are checked for validity (Beaton et al, 2000).

According to Beaton et al. (2000), it is crucial that the translation maintains semantic, idiomatic, experiential and conceptual equivalence. Semantic equivalence involves checking if words signify the same thing or have multiple meanings depending on the context. Idiomatic refers to linguistic features or expressions that need consideration when adapting the instrument. Experiential equivalence refers to the need for questionnaire items to accurately capture comparable daily life experiences in different cultural or geographical contexts, ensuring that tasks are relatable and meaningful across diverse populations, and conceptual equivalence pertains to the different meanings of concepts in different populations. Borsa et al. (2012) emphasizes that in back translation, it is crucial not to maintain literal identicalness with the original but rather to preserve conceptual equivalence. In this study, two parameters of the CoI instrument were modified, replacing the 'course' concept with the 'semester project' concept and the 'instructor' concept with the "instructors" concept. Semantic equivalence has been altered, which may affect comparability. Although two instructors went through the translation of the instrument and did not notice specific or problematic linguistic expressions or differences in meaning, back translation could have better ensured idiomatic equivalence. In this context, for instance, the term 'brainstorming' could have come up. The brainstorming concept as such does not necessarily belong to the general conceptualization used by this population in the sense of experimental equivalence either, instead the term innovation or ideation is generally used for it. At the beginning of the questionnaire, students were provided with guiding text: 'By 'project', we refer to the semester-long project and the integrated study units. 'Instructors' refer to the responsible teachers for the semester and support personnel.' In the students' responses, these concepts are presumed to have been understood as intended by the questioner based on the instructions, which could be considered to have preserved at least some degree of conceptual equivalence. More precise consideration and validation of the equivalences described by Beaton et al. (2000) could have influenced the results, potentially even reducing items and person later deemed possible misfits in the Rasch analysis such as, for example, the question about brainstorming, which will be brought up again later in this chapter. Although, in this study, the results have not been compared to previous CoI studies conducted using Rasch analysis due to a gap identified in the literature, subsequent research may provide the opportunity to do so. Comparisons of psychometric analyzes using this same analysis method would have contributed to enriching the understanding of the assessment of the psychometric properties of the original and the translated CoI instrument, such as accuracy, reliability and validity. Preserving the validity of the carefully adapted instrument would enable more reliable comparisons across different populations in future studies (Borsa et al., 2012).

The data collection was carefully tested before the actual distribution. The respondents' subjectivity, opinions, attitudes and views can be considered to influence bias (Cohen et al., 2007, p. 133). For a deeper understanding of the data produced by the CoI instrument, qualitative data were collected in sub-study III to support the analysis. This can be considered to contribute to the correctness of the conclusions. The dataset was small, but the entire possible population was invited to the study in terms of the students of the target group. Therefore, the data were suitable, sufficiently comprehensive and justified in terms of the phenomenon and the research problem under investigation.

According to Edelson (2006), DBR should lead to a theory that can be generalised. However, DBR can be seen as context-bound (Plomp, 2013; Sebbowa & Ng'ambi, 2020), with the context being a core part of the story and not an extraneous variable to be trivialised (Barab & Squire, 2004). Replicating settings, even in ICT engineering education despite accurate descriptions, can prove challenging, which may reduce the generalisability value of the study. That is, DBR emphasises adapting the design to the local context (Dede, 2004, 2005). In terms of external validity (Cohen et al., 2007, pp. 135–136) and Lincoln and Guba's (1985, p. 290) applicability and consistency criteria, the results of this study also have some limitations and threats. Although, in accordance with the research question, the study focused on the context of engineering education, and even though DBR does not, in principle, aim for context-free generalisations due to its context-bound nature (Plomp, 2013), efforts were made to generalise the design principles to be as independent as possible from the discipline. To accept the results in more contexts, the design principles should be replicated in multiple cases in various contexts and achieve the same results (Plomp, 2013), which Yin (2009, p. 39) calls analytical generalisability.

Furthermore, according to Cohen (2007, p. 133), the validity of quantitative data can be improved through careful sampling, appropriate instruments, data and statistical treatment. The Rasch model is based on the assumption that there is a latent variable whose level varies from person to another—in the case of this study, from one student to another. The CoI framework is based on three latent variables (SP, CP and TP), and the Rasch model is well suited for analysis. The Rasch techniques enable the conversion of nonlinear raw data into a linear scale. They also offer tools for evaluating the measurement properties of instruments, such as model fit and separation reliability.

Psychometric models, such as Item Response Theory (IRT) and one of its models, Rasch, can be used to analyze response data from surveys (Bailes & Nandakumar, 2020; Boone et al. 2011; Edvards & Alcock, 2010). Although IRT would have offered flexibility to incorporate parameter values more diversely, the Rasch model was chosen since the specific goal was to create a truly linear and equidistant measurement scale, and it is deemed sufficient (Stemler & Naples, 2021). The choice of the Rasch RSM over the other IRT models, such as the partial credit model (PCM; Masters, 1982), is supported by the fact that each item shares the same scale (Wright, 1998; Yamashita, 2022). While PCM would have allowed the use of response categories other than the employed 5-point scale, it was not deemed necessary in this context. Furthermore, for example, Bayesian IRT would have allowed the incorporation of parameter estimates from previous observations into the model (Bürkner, 2020). The decision to utilize the RSM was made to maintain the simplicity and consistency of the measurement scale. Other possible models could have provided different perspectives and enriched the understanding of the phenomenon.

There are also several software packages developed for implementing models in R. Bürkner (2020) lists examples of these IRT specific R packages, including TAM

(Robitzsch et al., 2021), eRm (Mair & Hatzinger, 2007), ltm (Rizopoulos 2006), mirt (Chalmers, 2012), and sirt (Robitzsch & Robitzsch, 2017), among others. In this study, the Rasch RSM analyses were conducted using the TAM package, although other alternatives were available. The choice of the TAM package was made due to its suitability for the needs and the presence of clear documentation and instructions (e.g., Katz et al., 2021).

Rasch models assume unidimensionality (Bond et al., 2021, p. 253), measuring a single underlying construct, which means that if a question or item does not align with the underlying structure of the test, it should be excluded from the test, and such exclusion also enhances the test's construct validity (Tavakol & Dennick, 2013). When the order of items aligns with the theory, it can be seen as evidence of the instrument's validity and reasonable fit of data to the Rasch model (Planinic et al., 2019). The Wright maps significantly assist in examining the order of test items according to difficulty (Planinic et al., 2019), as was done through visualizations similar to Wright maps in Sub-studies II and III. When analysing the results, it can be observed that they align with the expectations of claims, benefits, and anticipated challenges identified in the context of the key concepts and theoretical framework in chapter 2, such as the lack of support and interaction in online environments. In sub-studies II and III, Infit and Outfit MNSQ statistics have been calculated to indicate how well or accurately the test data fit the Rasch measurement model. Furthermore, according to Tavakol and Dennick (2013), items should be independent, meaning the probability of responding correctly to one question—or, in the case of this study, how easy it is to agree with a statement—should be independent of the responses to other items. These inter-item correlations were not measured in this study, but they could have been used to ensure, among other things, the impact of the mutual order of items on responses. However, reliability has also been examined in sub-studies II and III by exploring separation values, which are associated with person's latent traits and the difficulty levels of items where person separation indicates how well the test distinguishes students based on their latent traits.

The standard errors calculated from the observed scores were 0.25–0.29, 0.32–0.35 and 0.30–0.31 in sub-study II and 0.23–0.25, 0.20–0.28 and 0.22–0.27 in sub-study III in TP, SP and CP, respectively. In a similar study by Abbitt and Boone (2021), the standard error of the estimates of the three CoI elements varied between 0.06 and 0.08. This difference can be partly explained by the sample size. Abbitt and Boone's sample size was 704, which is significantly larger than the sample in this study.

Boone (2016) suggested evaluating the quality of measurement instruments using the 'fit' of items, in which the identification of misfit items can be reviewed using fit statistics (MNSQ Item Outfit and MNSQ Item Infit) and the misfitting items are excluded (Boone & Noltemeyer, 2017; Linacre, 2002). Another technique for evaluating instrument quality is to review the consistency of responses using person-fit statistics (Boone, 2016). Person-fit measures the consistency of a person's responses with their other answers, and item-fit measures the consistency of the item's answers. For example, in the case of an individual person, the misfit may have been caused by a subsequent cessation of concentration during the response session or by answering at random (Boone, 2016).

Various fit statistic threshold values for significantly deviating data are defined in multiple sources. Bond et al. (2020, pp. 244–245) gives a reasonable MNSQ ranges for rating scale in cases of Likert/survey as 0.6–1.4 but point out that 'fit statistics should be used to assist in the detection of problem item and person performances, not just to decide which items should be omitted from a test.' Boone (2016) suggested using an Outfit MNSQ > 1.3 for misfit items, while Wright and Linacre (1994) recommended reasonable item MNSQ range 0.6–1.4, which has also faced criticism (e.g. Seol, 2016), as acceptable for rating scale surveys and 0.5–1.5 as productive for measurement. Abbitt and Boone (2021) used also an acceptable MNSQ range of 0.5–1.5, as recommended by O'Connor et al. (2016, as cited in Abbitt & Boone, 2021). According to Tavakol and Dennick (2013) values between 0.70 and 1.30 are indicating a good fit.

A fit value of 1.4 was used as an upper limit for Infit and Outfit MNSQ in sub-studies II and III. Values deviating from the expected value of 1 indicate either overfitting or underfitting of the data to the model: overfitting, with MNSQ values < 1, suggests that the data is more predictable than the model expects and they do no harm, while underfitting, with MNSQ values > 1, indicates that the data is less predictable than the model assumes (Wright & Linacre, 1994). Overfitting items or persons may not necessarily be advisable to eliminate due to the risk of losing important data (Bond et al., 2020, p. 245). In both of the sub-studies II and III, during the removal of misfit items, related responses were also omitted, resulting in the discovery of new items surpassing the threshold MNSQ value 1.4 during the subsequent run.

In Sub-studies II and III, the lower threshold for acceptable fit was not defined. Determining this lower limit may have influenced the results. It is observed that in Sub-study III, responses to item CP32, 'I can describe ways to test and apply the knowledge created in this project,' make it the most challenging item to agree with. Meanwhile, its outfit MNSQ value is 0.56 and infit MNSQ 0.59, indicating a 44% and 41% mismatch between the model and the data. Thus, if a fit range of 0.6–1.4 had been used in the fitting, this item would have been considered for excluded as overfit. Using the lower threshold defined by Connor et al. (2016) at 0.5, this item would have fit the model. The next most difficult to agree with, in terms of infit and outfit MNSQ values, were 0.93 and 1.06, significantly closer to the value of 1. This observation would have provided a more fitting item for closer analysis and reporting. Similarly, in sub-study II, item TP10 'Instructor's actions reinforced the development of a sense of community among project team members' has been reported as the item where students found hardest to agree with the statement, with an outfit MNSQ value of 1.41 and an infit MNSQ of 1.42. These values exceeded the theoretically acceptable fit threshold of 1.40, leading their potential exclusion as underfitting values. However, this item TP10 has been retained in the model, reported, and analysed, even though, for example, the next 'harder to agree with' item TP13 'The instructors provided feedback in a timely fashion' had MNSQ values of 0.79 and 0.81. These values are within the fitting range indicating only a 21% and 19% mismatch.

Excluded persons may be of interest for further examination as their responses differ from the rest of the study population. When analyzing the person fit for the model in Sub-study II, it was observed that, compared to other students, those excluded from the Rasch model based on Outfit MNSQ had a higher proportion of negative responses. The misfit was also confirmed by calculating the standard deviations ($Z = 2.9$, $p < 0.05$) in TP, ($Z = 3.4$, $p < 0.05$) in SP, and ($Z = 3.7$, $p < 0.05$) in CP, where values exceeding 2.0 indicate less compatibility with the model (Bond et al., 2020, p. 242). These person misfits have been analyzed in the discussion of sub-study II, suggesting that negative experiences may have resulted from factors such as students not feeling as included in the group as other respondents or perhaps problem-based learning (PjBL) and blended learning were unsuitable learning methods for them. In sub-study III, a similar phenomenon can be identified from students' responses; their responses deviated particularly in the case of negative responses. Possibly, they may have also had specific deficiencies in the sense of belonging to the group and in the suitability of online learning as a method for them.

Based on the initial run, items were excluded as misfit for the model in both sub-studies: in Sub-study II, the items CP23 'Problems posed increased my interest in project issues,' CP27 'Brainstorming and finding relevant information helped me resolve content-related questions,' and CP29 'Combining new information helped me answer questions raised in project activities' were removed. Similarly, in Sub-study III, TP4 'The instructors clearly communicated important due dates and time frames for learning activities,' SP19 'I felt comfortable interacting with team members from other teams,' and the same item CP27 as in Sub-study II were excluded. An examination of the distributions within the CP category indicates that, for item CP27, there is a significant number of Disagree responses (N=7), with the second-highest being N=2. These responses are most likely due to the fact that brainstorming was not consciously used as a method in project teams during the semesters under consideration for these two iterations. If the method was used, it was not necessarily described with this term, which in turn reflects the item's inappropriateness for the study, as reflected by the misfit. For CP23, the distribution examination corresponds with the distribution of the other items. However, the item may have been too broad after translation and adaptation to the project context, covering all integrated courses throughout the semester instead of the original context of a single course. One possible explanation is also that the responses of a single person do not align with the other responses. Furthermore, when examining the distributions of responses within the CP category, CP29 stands out as the only item for which Strongly Disagree responses were given (N=2), potentially leading to misfit.

In sub-study III, after the exclusions, the item TP2 'The instructors clearly communicated important course goals' has a marginal infit MNSQ value of 1.46 indicating underfitting. The questions have been reformulated from original course- and instructor related questions to project- and instructors-related questions, which may have distorted the meaning and understanding, particularly in the case of this question. The wording of the question may have been unclear to respondents, for example, causing uncertainty whether the respondent was unsure whether the instructor communicated all goals or only some. Furthermore, the respondent may have considered whether this refers to the objectives of the instructor's own course or the learning objectives for the entire integrated semester. However, there doesn't appear to be significant differences in the distribution of responses across different answer options. In Sub-study II, for TP4, the outfit MNSQ value was 1.5, and the infit value was 1.47; for TP10 'Instructor's actions reinforced the development of a sense of community among project team members', the corresponding values were 1.41 and 1.42. In the case of item TP4 'The instructors clearly communicated important due dates and time frames for learning activities', the misfit may have been due to the same reasons described above as in the case of TP2. Item TP10, 'Instructor's actions reinforced the development of a sense of community among project team member,' in its original form, was directed toward the entire student group. When applied to the project context, the target audience for the question has narrowed to encompass project team members. Respondents may also have been uncertain whether each of the instructors acted according to the statement or only some of them. In Sub-studies II and III, the items interpreted as misfit were not the same as in Abbitt and Boone's (2020) study, where CP28 and TP13 were identified as misfit items. In this context, a potential gap in the literature may exist, as no additional studies on CoI surveys analyzed with the Rasch RSM model have been identified.

Wright and Stone (1999, p. 151) defined person separation as an index of how efficiently a set of items can separate the persons measured and item separation as an index of how well a sample of people can separate the items used in the test. Expressing the former as reliabilities yields values between 0.0 and 1.0 (Wright & Stone, 1999, p. 151). The separation reliabilities yielded values of 0.92–0.94 for TP, 0.85–0.90 for SP and 0.90–0.91 for CP in sub-study II and 0.88–0.90 for TP, 0.86–0.90 for SP and 0.87–0.88 for CP in sub-study III. The values are interpreted in that the closer they are to 1.0, the better the separation and the more precise the measurement (Wright & Stone, 1999, p. 151), thus indicating a reliable measurement for the Rasch analyses of sub-studies II and III. Rasch analysis can be performed with small datasets (Planinic et al., 2019). Linacre (1994) took a stance on sample size, specifying a minimum sample size of 27–61 and at least 50 for most purposes, with a 99% confidence interval in polytomous Rasch analyses. In sub-studies II and III, the sample size varied between 56 and 79.

A small sample size also affects generalisability (Ercikan & Roth, 2014). In this study, nonetheless, the sample size is both appropriate and sufficient to represent the entire population (Cohen et al., 2007, p. 144). However, only a small part of the industry representatives as ecosystem stakeholders participated in the research and only in sub-study I. In this sense, the data can be considered limited. A more versatile and critical examination of these perspectives could lead to better generalisability. Therefore, replicating the DLE is recommended beyond the sample surveyed. Agile methods in process and system development are generally and widely accepted in the field of ICT, but this is not always the case in other disciplines, making it difficult to apply the results. However, the similarity of the context can be considered to be applied in any open-ended assignment implemented in collaboration with the business world, the content of which is tailored to meet the goals of the study courses included in the curriculum.

When considering the generalisability and causality of the present study, it is also advisable to contextualise its significance within the chosen methodologies from the perspective of social constructivism, from which different perspectives have also been presented. According to Annand (2019), the generalisability of the research results in the social constructivist paradigm that the CoI framework represents (Kozan & Caskurlu, 2018; Swan, 2019; Swan et al., 2009; Tolu, 2013) is limited by the restrictive effects suggested by Lincoln and Cuba (1985): it is assumed that communication achieves intersubjective understanding despite the unique and individual experiences, the researchers' values affect the formulation of questions, and research in the paradigm deals with a unique network of dependencies in which it is difficult to establish cause-and-effect relationships. Referring to these, Annand (2019) highlighted the 'thickly described' experiences through interviews, in which the texts are analysed into small data units and grouped into larger categories of meaning to be transferred to the broader consideration of researchers between social contexts. He reflected this perspective on the creation of the CoI framework, in which the constructs of SP, CP and TP were developed based on the synthesis of coded and grouped data. Annand (2019) believed that the process in question, particularly the research using the CoI survey instrument, also used in sub-studies II and III in this DBR, is more similar to the objective–rational paradigm, in which transcript analysis is a common means of producing a theory grounded in data. Based on the research results of the worldview of the objective–rational paradigm, in which reality is known and individual, causality can be attached to the conditions (Annand, 2019). Conversely, social constructivism posits that realities are individual, many and subjective and that the situation is more challenging (Annand, 2019). In other words, the use of the CoI survey, the mathematical techniques to quantify the effects of the three main elements of the CoI and the assignment of correlations and causality suggest the assumption of a worldview according to the objectivist–rational paradigm (Annand, 2019). Thus, Annand (2019) argued that CoI research is closer to the objective–rational paradigm than to the social constructivist paradigm.

The final design principles resulting from the design requirements were synthesised, taxonomised and refined through the theoretical lens of CoI. However, when examining this final synthesis, for example, through Table 14, it can be observed that the connections between the final DLE design principles and CoI principles are not clearly visible anymore. Design principles have already been utilized in the iterations of design, meaning that the preliminary design principles have passed through the theoretical lens of CoI and are already integrated through sub-studies. This potentially makes it unnecessary to include them in the synthesis of final principles, except perhaps for the purpose of bidirectional validation.

Finally, the coverage review of related literature can initially be viewed through Cooper's (1988) main coverage taxonomies: a) exhaustive coverage, in which all relevant published and unpublished studies are included in the review to base conclusions and discussions on this all-inclusive information base, b) exhaustive coverage with selective citations, c) representing materials (i.e. the search for articles in a small number of top-tier journals in a field) and d) focusing on prior works being central or pivotal to a particular topic, including empirical studies or conceptual papers that initiated a line of investigation. In this study, the exhausting coverage strategy with selected references was partially followed. The searches focused on all the scientific and academic databases included in the Google Scholar search engine. The main subject-related databases used were SAGE Journals, ScienceDirect (Elsevier), ProQuest databases, IEEE/IET Electronic Library, ACM Digital Library, Taylor & Francis Online, Springer Journals and Emerald Journals. In terms of empirical research, this DBR mainly focused on the most recent studies. Some methodological principles and concepts were searched among the key and recognised sources of the subject.

The literature review highlighted the disparity between the volume of research on new technologies and concepts in engineering sciences and the volume of research on pedagogy and educational sciences. Academic research has not yet necessarily had enough time to catch up to new technologies and methodologies, whereas educational research is a more conventional discipline. Furthermore, the application of new technologies in learning has been addressed very little. The subject may not be a particularly popular or well-established research area, so there may not be many academic articles on the topic. The phenomenon may also be relatively new, in which case it may take some time for researchers to catch up and begin to study the topic more widely. Ultimately, the phenomenon may involve multiple disciplines, such as engineering and computer science, education and psychology, which may make it more difficult for researchers to publish their work in academic journals.

6.3 Ethical Evaluation

This research follows the ethical principles in the guidelines for an ethical review in the human sciences (TENK, 2019) and the guidelines for the responsible conduct of research (TENK, 2021) published by the Finnish National Board on Research Integrity, TENK. This study is largely situated in the area of human sciences, in which the fundamental starting point is the participants' trust in researchers and science (TENK, 2019). It aims to respect the human dignity and autonomy of participants in human research (Barrow et al., 2022; TENK, 2019). According to TENK's (2021) declarations, research must be conducted with integrity, meticulousness and accuracy using methods that are in accordance with scientific criteria and ethically sustainable. The results must be communicated in an open and responsible manner, taking into account the work and achievements of other researchers and following the standards set for scientific knowledge. The necessary research permits and a possible ethical evaluation must be completed. However, this study does not meet the criteria for a mandatory preliminary ethical review, which are intervening with physical integrity, research targeting minors under the age of 15, exposing participants to special stimuli or security risks and causing mental harm (TENK, 2019). All the participants were adults and were informed about their rights and the processing of their personal data in truthful and comprehensible language.

Initially, for research authorisation, a research permit was applied for at the Lapland UAS, and it was granted in February 2019. For sub-study I, the researcher presented the purpose and goal of the study orally in spring 2019 and invited students to participate in the interviews. The calendar entries for the project group-specific interview invitations were then delivered to the participants. At the beginning of the interview sessions, the researcher went through a written explanation with the participants about the purpose of the research and data management and collected the participants' signatures on the agreement on the conduct of the research and the processing of the data. For sub-studies II and III, the researcher visited the students at the beginning of the autumn semester 2019 and spring 2020 and informed them about the research orally and in writing. The students' signatures for their consent to participate in the study were then collected. In the case of online surveys in sub-studies I, II and III, background information on the study was provided in advance orally and in writing, and it was reiterated again during the response phase. In connection with the requests for research permits for all sub-studies, it was emphasised to the students that participation was voluntary, that they could withdraw their consent to participate in the research at any time and that their answers have no effect on the evaluation of their courses.

In sub-study I, the data collected from the interviews were pseudonymised. The individual participants were given an identification code, and the information was stored as coded in the research file. The data were analysed and coded, and the reporting of the results took place at the group level. The individual participants could not be identified without a code key. Only the researcher had access to the code key, which was used to identify the data and results of the individual participants. The participants responded anonymously to the survey carried out electronically (i.e. in the Webropol system in sub-studies II and III); thus, they could not be technically identified. Research materials were stored in the Dynasty10 case management system of the Lapland UAS, protected by an organisational username and password, as permanently stored confidential documents (see Finnish Act on the Openness, 24 § 21). The Dynasty10 case management service is a SÄHKE2-certified system that meets the National Archives (https://kansallisarkisto.fi/en/the-national-archives-2) SÄHKE2 norm requirements for the long-term storage of documents.

This dissertation consists of three sub-studies that were peer reviewed during the process. The reviews and feedback of the supervising professors of the University of Lapland, which were discussed earlier in connection with the methodological evaluation, contributed to the consideration of the ethical aspects of the overall research process. In addition to respecting the privacy of the participants, the source references implemented in the publications were made in an appropriate manner and with respect to the author. The phases and results of the research were reported honestly and openly, avoiding the possible epistemological influence of the researcher on the results. The data could not be made openly available for ethical and data protection reasons. TENK's (2018) recommendations for agreeing on authorship were followed in the publication of the sub-studies.

6.4 Implications and Future Studies

This dissertation has both theoretical and practical implications. It offers empirical observations about the PjBL approach to ICT engineering education in online and blended learning environments, enabling the development of practical design principles. This study combines the concepts of pedagogy, information technology and engineering. For the first time, this study presents a DBR situated at the intersection of engineering and pedagogy, resulting in the development of a design framework comprising eight design principles for a digital learning ecosystem in ICT engineering education. It is particularly useful in the development of engineering education by expanding traditional and course-specific methods by comprehensively taking responsibility for and integrating the participants into a functioning and adaptive digital community. Knowledge can be applied in practice, and the findings serve as a starting point for further development of the DLE.

To the best of the author's understanding, a comparable comprehensive approach to developing the design framework, along with the design principles of DLE within the ICT engineering education context, has not been utilised in any university to this extent. The concept has been formulated by synthesising university field manifestos, policies, stakeholder expectations and best practices. Furthermore, the successful implementation of the intervention necessitates a systemic approach that entails cultural transformation. It is important to note that almost all studies in the academic literature on e-learning have focused on individual e-courses (Abumandour, 2022), not on an integrated and holistic approach, which is a characteristic of this study. The DLE concept is applicable not only to ICT engineering education but also to universities in general by exchanging field-specific development tools and technology concepts to suit the respective fields. In practice, the intervention does not require special curriculum-level changes as it is mainly adapted to a completed curriculum. The design principles of DLE can be considered broadly in accordance with the model of continuous learning and business cooperation in higher education and the culture of open collaboration. The general acceptance and proliferation of virtual classrooms in HE, the possibilities of AI and other technical innovations and the funding constraints favour many-to-many communication instead of local and small-scale communication (Annand, 2019). In this regard, the potential and possibilities of the DLE to develop a communication culture based on being open and many-to-many without compromising the individual expectations and requirements of the different levels of the ecosystem should be recognised. It is critical to replicate the concept in engineering education in various fields, disciplines and multinational and international contexts.

The deeper understanding and design principles are intended to support industry players that plan and offer comprehensive integrated learning experiences in engineering education, aiming to establish a framework for the development of a DLE or to develop existing structures. In addition, this study benefits all readers who want to increase their own understanding of the current state, goals or requirements of engineering education. It also supports informed decision making, as it serves as an opening for a dialogue between representatives and decision makers from industry and educational institutions. Business, industry, decision makers and other entities that play a significant role in the promotion of engineering education can benefit from the research results and influence development through their own activities. One concrete action is that the CDIO consortium could manifest and promote the ideology of the DLE, as DLE's pragmatic implementation model does not conflict with the principles offered by the CDIO. Such a procedure is important not only for the dissemination of information but also because it emphasises the common state of the will of both industry and HE. Willpower is needed to blur the boundaries of study units, the roles of ecosystem members and the ownership of learning material and courses.

Moreover, this research is a new opening for an international discussion in the field of engineering education, with a particular focus on cooperation, community, methods and technologies commonly used in industry. Engineering education has largely worked with traditional methods based on the FTF approach in the classroom. As a result of digital transformation, this model is currently in disruption, although universities have been found to lag behind other organisations in this regard (Alenezi, 2021; Rodríguez-Abitia & Bribiesca-Correa, 2021). Authentic industry-based assignments ensure the development of engineers' competencies to be problem solving oriented and give students a taste and readiness for challenges after graduation. From the point of view of lifelong learning and continuous learning, the options have long been to offer individual study courses as virtual ones. Therefore, this study challenges the debate about integrating these individual courses into an ecosystem, providing a context for the authentic application of online resource learning.

The concept is adaptable to distributed ecosystems, supporting the Digivisio 2030 objectives (Digivisio 2030, n.d.) with principles of e-learning. The online resource pool, in alignment with the design principles of DLE, incorporates the joint study offering of Finnish HE institutions according to Digivisio's open learning ecosystem as part of the DLE outlined in this dissertation. It also interacts with companies and society by activating all stakeholders as active members. Similarly, the development of lifelong learners' competencies and the individual completion of studies from Digivisio's offer are made possible for all stakeholders in the ecosystem by utilising openness and offering a pragmatic connection to the context.

With the new theoretical support of this study, the ICT engineering education of the Lapland UAS has conducted a degree programme based on the design principles of a DLE, catering specifically to full-time students pursuing their degrees. Based on design principles, a separate academy activity has been made, separating the student team from the schedule of the rest of the study-year group and offering its customised semester based on the students' study plans. This activity aims at early employment through 'pre-recruitment', in which students complete the studies included in the degree and integrate them with the employers' authentic assignments, even across disciplines. Through the implementation of these developmental measures, the Lapland University of Applied Sciences has successfully realised its vision for ICT technology education. This approach enables personalised and individualised learning by utilising various study options, such as OER, and the opportunities provided by Digivisio's offerings while simultaneously fostering a community. Development continues actively, but it should be done even more systematically and comprehensively.

The design principles of a DLE follow the recommendations of ARENE (2022), the rectors' council of Finnish Universities of Applied Sciences, on common competencies. ARENE briefly lists the following competencies: 1) learning to learn: identifying the strengths of skills and learning methods and utilising the possibilities of community and digitalisation, 2) operating in a workplace: having working life competencies, 3) ethics: adhering to the ethical principles of the profession, 4) sustainable development: becoming familiar with the principles, promoting them and acting responsibly, 5) internationality and multiculturalism: operating in environments and networks and 6) proactive development: seeking and applying solutions that anticipate the future. A DLE combines informed, skilful and attitudinal competencies to form the foundation of students' professional expertise in accordance with the goals of ARENE. These objectives are also applicable to international engineering education.

Related to Industry 5.0 and the need for next-generation skills, Gürdür Broo et al. (2022) identified four strategies that could help HE institutions redesign their programmes: 1) lifelong learning and transdisciplinary education, which requires environments available with transdisciplinary environments where societal, engineering and sustainability-related decisions are discussed together; 2) sustainability, resilience and human-centric design modules in which ethical and social aspects related to systems should be integrated into existing curricula with the necessary methods and methodologies; 3) hands-on data fluency and management courses: data management, statistics, data visualisation, ML, data ethics and social implications of the future autonomous and intelligent systems should be integrated with the current engineering curricula; and 4) human–agent/machine/robot/computer interaction should challenge students' views through curricula to allow them to experience different ways of communication and collaboration with next-generation cyber-physical systems. Smuts and Smuts (2022) also called for interviewing software engineering experts about the skills needed in the Society 5.0 scenario.

As this research serves merely as a starting point for exploring the implementation of a comprehensive DLE in engineering education, more theoretical and empirical efforts are required. According to Garrison (2016, p. 106), the core challenge is to create and maintain a CoI in which TP, SP and CP are in a dynamic balance. The experiences of all stakeholders, including industry representatives and all instructors, from ecosystem dynamics and social and pragmatic perspectives can help deepen and further develop the concept in this respect. In the concluding remarks of this study, one can also align with Aldahdouh et al. (2023) in encouraging instructors' innovativeness and willingness to embrace change, which entails effective responsiveness, tolerance for uncertainties, and curiosity towards new ideas. The support from the management level is crucial in the functioning of the instructor team, encompassing active involvement and addressing instructors' concerns, such as the loss of autonomy, while also ensuring sufficient time and resource allocations (Vesikivi et al., 2019). In terms of future research, the ecosystem's stakeholders should include new cohorts, such as national and international partner universities. As stated by Bygstad et al. (2022), the digital learning space enabled by digital transformation offers universities the opportunity to cross physical and institutional boundaries and interact with the wider society. However, it is important to remember that although competence is built in collaboration according to the principles of social constructivism, the learning experience is still always individual.

An interesting research goal for the following DBR cycles may include real-time data analytics and possibly predictive analytics based on ML to monitor and support learning. As the industry uses advanced sensing and data analytical technologies to understand and monitor manufacturing processes, it is entirely possible to harness the same elements in the educational paradigm. To improve the efficiency and reliability of learning, statistical AI techniques, such as ML and data mining, are used to detect and predict potential anomalies in learning processes and experiences. According to Alnafessah (2021), AI/ML support can play a key role in the effectiveness of DevOps in distributed data-intensive environments. Integrated into the implementation and pedagogy of education, it contributes to the systemic automation of learning and education by providing solutions to the problems of supporting learning and monitoring the progress of studies in which AI and ML solutions are utilised. However, in this context, it is worth emphasising that AI solutions can be used with the help of humans, but humans still make the final decisions and use social and emotional aspects. Conversely, Elliot (2019, p. 200) challenges us to think in a new way: 'With the advent of a new global narrative of AI, along with Industry 4.0 and the Internet of Things, it may well transpire that our traditional theoretical frameworks for understanding social life are now approaching an end'.

This study also shows the need to examine the following pedagogical approaches, especially in terms of the DLE: team teaching, cooperative learning, learning analytics and competence-based assessment. The concept includes a design principle for establishing an instructor team to orchestrate people, methods and resources, but the team's dynamics and pragmatic approach to semester design should be critically examined. The pedagogical approaches used in this study essentially disregard collaborative learning, whose methodological and empirical aspects should also be considered when developing the concept. As far as learning analytics is concerned, the changing context causes challenges, which is why step-by-step development and application to generate sustainable solutions must be taken into account. Finally, the individual evaluation process, methods and criteria of the study courses in relation to the integrated authentic entities and the outputs of the project groups should be opened and examined critically. Too little attention has been paid to the actual assessment of student learning in CoI (Rourke & Kanuka, 2009). The traditional evaluations of competence performed by exams are replaced by competence-based assessment methods in the integrated PjBL approach, which evaluates practical process management and final outputs with the assistance of an instructor team rather than an individual instructor.

In summary, the results of this research, which combined engineering and educational sciences, have expanded the new knowledge of engineering education and produced a theoretically and empirically justified design framework for establishing a DLE for ICT engineering education. Eight design principles of a DLE have been presented as the main contributions of this study. In addition, the results have concretely developed the practices and content of engineering education in the ICT field. This study holds significant importance as it fills a gap in the international research landscape, providing a solid foundation for further discussions, research endeavours and advancements in the global digital transition. Moreover, it fosters collaboration between HE institutions and industry, facilitating the exchange of knowledge and expertise in this rapidly evolving field.

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APPENDICES

APPENDIX A.

Table A1

CoI Questionnaire

Survey item	Statement
TP1	The instructors clearly communicated important project topics.
TP2	The instructors clearly communicated important course goals.
TP3	The instructors provided clear instructions on how to participate in project learning activities.
TP4	The instructors clearly communicated important due dates and time frames for learning activities.
TP5	The instructors were helpful in identifying areas of agreement and disagreement on project topics that helped me learn.
TP6	The instructors were helpful in guiding the project team towards understanding project topics in a way that helped me clarify my thinking.
TP7	The instructors helped to keep project members engaged and participating in productive dialogue.
TP8	The instructors helped keep the project team on task in a way that helped me learn.
TP9	The instructors encouraged the project team to explore new concepts in this semester project.
TP10	Instructor's actions reinforced the development of a sense of community among project team members.
TP11	The instructors helped focus discussion on relevant issues in a way that helped me learn.
TP12	The instructors provided feedback that helped me understand my strengths and weaknesses relative to the project's goals and objectives.
TP13	The instructors provided feedback in a timely fashion.
SP 14	Getting to know other project members gave me a sense of belonging in the project team.
SP15	I was able to form distinct impressions about some project team members.
SP16	Online or web-based communication is an excellent medium for social interaction.
SP17	I felt comfortable conversing through the online medium.
SP18	I felt comfortable participating in my own project team discussions.
SP19	I felt comfortable interacting with members from other teams
SP20	I felt comfortable disagreeing with other project team members while still maintaining a sense of trust.
SP21	I felt that my point of view was acknowledged by other team members.

SP22	Online discussions help me to develop a sense of collaboration.
CP23	Problems posed increased my interest in project issues.
CP24	Project activities piqued my curiosity.
CP25	I felt motivated to explore content-related questions.
CP26	I utilized a variety of information sources to explore problems posed in this semester project.
CP27	Brainstorming and finding relevant information helped me resolve content-related questions.
CP28	Online discussions were valuable in helping me appreciate different perspectives.
CP29	Combining new information helped me answer questions raised in project activities.
CP30	Learning activities helped me construct explanations/solutions.
CP31	Reflection on project content and discussions helped me understand fundamental concepts in this project.
CP32	I can describe ways to test and apply the knowledge created in this project.
CP33	I have developed solutions to project problems that can be applied in practice.
CP34	I can apply the knowledge created in this project to my work or other non-school related activities.

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APPENDIX B.

Table B1

Interview Themes and Supporting Questions

Variable	Theme	Supporting questions
Climate (Renamed in the analysis phase as social climate, referring to the psychosocial environment of educational settings (Allodi, 2010))	Engagement	How do you feel about studying in the integrated curriculum and semester projects? Do you feel that project-based learning requires too much, too little or just appropriate commitment or engagement?
	Cooperation	How did the project conduct teamwork in RURAL IOT? (Communication? meetings? What percentage of the project work has been done face-to-face?). [RURAL IOT is the name of the current semester project.] Are there different roles in your project? Do you feel that some of you take more responsibility than others or not? Is this a problem? Everyone in the group is equal, but is decision making democratic? How do you resolve conflicts when there is no clear leader? Do you take responsibility for learning from each other? Should you? How much do you learn together and independently? Do you share your expertise with other project teams? What do you think about the size of the project team? How many members would be best?
	Risk taking	Are you using demanding and advanced techniques or familiar and safe ones? Will you stay in the familiar, safe and minimum requirements, or will you throw yourself into the new (strange and challenging)? What are the reasons for your selection?
	Student control	How do you experience deadlines? Is tight control good or bad? Do project management and tight scheduling promote your learning or time management in learning? The project team is free to design its own schedule. How do you deal with it?
Learning	Content knowledge	The aim of your degree programme is to use the latest emerging technology. How do you feel about the situation in which the technologies are new and weird for both students and instructors or supervisors? What do you think about the content and techniques of the ongoing semester project? What are the possible benefits of semester projects and the integrated curriculum for the student/teacher/institution/employer? How would you fix the previous one? Do you feel like everyone in the project is learning, or do you feel that only some of the areas are being learned while others are overlooked? Do you feel that you are learning things deeply or superficially? Do you feel that the current integrated project-based method supports learning goals? If not, what should be done?
	Skills	How challenging do you experience the techniques and technologies used in this semester project? Do you know that the skills you have learned are useful in your worklife? Do you think this PjBL is an effective way to learn and apply practical skills? Does PjBL develop meta-skills, such as communication skills, problem-solving skills, language skills, teamwork skills, etc., and if so, how and if not, why not? What do you think about the tools, equipment, techniques and technologies utilised in the degree programme?
	Dispositions	Will your level of motivation change in any direction if the implementation of the semester project; teamwork, teaching, supporting and mentoring are mainly online? (I feel more motivated/I feel less motivated/No effect on level of

		motivation) How should semester projects be implemented in a way that is motivating but could be done while working (evening only)/online (no opportunity to work on campus)?
	Metacognitive strategies	Do you independently study things that you find useful? In PjBL, is independent learning effective? Would you follow your workload if they were not within the requirements of the project study? What other factors affect and take time out from learning? Does PjBL offer students enough freedom to learn the way or in the schedule they want? Or does project learning restrict freedom of choice?
	Learning strategies	What kinds of study method do you prefer? Have you noticed that students in your team have different learning methods? Could semester projects be implemented online or as blended learning? What parts of the RURAL IOT case could be transferred online and what should be face-to-face? Which sections in RURAL IOT require guidance (online or face-to-face), and which can be studied independently? If project learning were implemented online or blended, what kind of learner would benefit the most? Imagine a situation in which you work every day from 8 AM to 4 PM. How would you manage to complete the RURAL IOT semester project in a meaningful way? In general, do you think there is anything that requires face-to-face learning and should not be done online?
Required resources and support for implementation		How do classrooms and laboratories on campus serve PjBL? What about Moodle and other platforms? Do you think the degree programme has contributed enough to teaching, equipment and technology? Do you think they are up-to-date? What kind of facilities would you prefer to complete a semester project? Do you use your own tools (e.g. laptop)? Why do you use your own devices? What kind of tools do the institution not offer that you may need? What kind of support do you need during your semester project? Is there sufficient technical support available? What facilities should the institution provide for online learning at home? What kind of support should be available in the case of online or blended learning? How should support be achieved? How well do you know your degree programme institution as an organisation? Would you like to know the organisation structure, the staff and instructors better? What kind of tools and equipment would you like to use in the semester projects conducted online or blended in general?
Systemic	Costs	Do you feel that the students' personal financial situation affects learning and outcome?
Nature of learners		In terms of PjBL and semester projects, do you think they hinder or promote flexibility in graduation and personal learning path? Is this teaching and learning method fair to everyone?

Note. Derived from Collins et al.'s (2004) variables. It should be noted that the affective aspects, such as motivation, are categorised in the dispositions theme, while they are classified under metacognitive strategies in sub-studies II and III, according to the CoI framework.

APPENDIX C.

Table C1

Online Survey Questions for Personnel and the ICT Advisory Board

Systemic	Sustainability	*) How do you see the role of ICT education as a producer of experts in the province? What do you think the curriculum and its implementation model would be like in 2024? Do you think the current curriculum is up-to-date and sustainable? Is the structure of the curriculum sustainable so that it can be used flexibly in the coming years? Are the titles, contents and scope of the studies up-to-date and sustainable? The scope of the curriculum is 240 credits, which means that adding to it may cause others to be removed. What content do you think should be added there? What could be excluded?
	Spread	*) How will the ICT ecosystem of the regional actors change over the next few years? *) What are the most important drivers of the ICT sector in the province?
	Scalability	How can the ICT industry in Lapland grow? *) How do you think the R&D project activities of Lapland UA should be developed? How would you increase interaction and cooperation between the industry and students?
Learning	Skills	What kind of capabilities and competencies would you like engineers graduating from the ICT engineering education in 2024 to have?
Settings		What do you think about the current project-based integrated curriculum? What are its benefits or advantages compared with the 'traditional model' (separate courses)? What problems have come up?
Implementation path		Which subjects should be organised to learn face-to-face? Please justify. If it is possible to offer students the opportunity to choose individual study paths and methods, how should they be organised in practice? How can an integrated model of project learning be offered in accordance with the principle of continuous learning? If you think the model should be changed, how? Consider each target group separately: • As additional training offered to companies • As a study offered at the Open UAS • As a paid service activity • Others. What? How should the interaction between the project teams and the supervising personnel be organised? How should project supervision and technical support be organised? Which subjects/contents should be transferred to online teaching and in what ways? Please justify.

Note. Derived from Collins et al.'s (2004) variables. The questions presented only to the members of the ICT Advisory Board are marked with the symbol *).

APPENDIX D.

Coding categories in sub-study I following inductive reasoning and ending with the categories in the theory of characterised variables by Collins et al. (2004).

- **Nature of Learners**
  - Professional specialisation options
- **Required resources and support for implementation**
  - Learning materials
    - Lecture recordings
  - Virtual learning environment
  - Process and technical support
    - Synchronous interaction
      - Team communication platforms
        - Real-time chat services
    - Initial orientation
- **Setting**
  - Industry cooperation
    - Working life context
      - Application in practice
- **Climate**
  - Engagement
    - Task allocations
    - Taking responsibility
  - Cooperation
    - Social communication
    - Meeting routines
    - Communication tools
  - Risk taking
    - Various solution options
  - Student control
    - Reviews
      - Process reviews
      - Technical reviews
      - Learning control
    - Managing schedules
      - Deadlines and milestones
- **Learning**
  - Content knowledge
    - Selection of tools and technologies
  - Skills
    - Problem solving
    - Collaboration and teamwork skills
    - Communication skills
    - Critical thinking
  - Dispositions
    - Motivation
  - Metacognitive strategies
    - Concentration
  - Learning strategies
    - FTF
    - Self-oriented learning
    - Learning by doing
- **Systemic**
  - Sustainability
    - Competence profile
  - Spread
  - Scalability
  - Ease of adoption
  - Costs
- **Professional Development**
  - Professional skills of teachers
- **Financial requirements**
- **Implementation path**

APPENDIX E.

Table E1

Data Description Table for the Variables and Data Types of the GitLab Log Data

Variable	Description	Data type
id	Commit ID number	String
title	Title of the activity	String
message	Commit message	String
committer_name	Name of the committer from AD (Active Directory)	String
committer_email	Email of the committer from AD	String
committed_date	Commit timestamp	Date time string, ISO 8601 formatted

Table E2

Data Description Table for the Variables and Data Types of the Mattermost Log Data

Variable	Description	Data type
id	Message ID number	String
create_at	Message timestamp	Integer, in milliseconds since the Unix epoch
user_id	Mattermost user ID	String