

KÜLLI KALLAS

Development, validation and
application of the Digitest



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TABLE OF CONTENTS

LIST OF FIGURES	7
LIST OF ABBREVIATIONS	8
LIST OF ORIGINAL PUBLICATIONS	9
1. INTRODUCTION.....	10
1.1. Research problem	11
1.2. Focus of the research	15
2. THEORETICAL FRAMEWORK.....	17
2.1. Digital competence.....	17
2.1.1. Definition of digital competence	17
2.1.2. Dimensionality of digital competence.....	22
2.1.3. Student profiling based on digital competence	24
2.1.4. Digital competence development	25
2.2. Assessment of digital competence.....	27
3. RESEARCH METHODOLOGY	31
3.1. Research design	31
3.2. Research context.....	32
3.2.1. Digital education in Estonia	32
3.2.2. DigiEfekt study	34
3.3. Sample	35
3.4. Data collection and data analysis.....	36
3.4.1. Data collection	36
3.4.2. Data analysis	36
3.5. Ethical considerations.....	37
4. RESULTS.....	38
4.1. Development and applicability analysis phase of the Digitest	38
4.1.1. Development and validation of the Digitest.....	38
4.1.2. Usability of the Digitest for assessing students' digital competence for learning	40
4.1.3. Applicability of the Digitest for designing digital learning processes	41
4.2. Application phase of the Digitest	43
5. DISCUSSION.....	45
5.1. Implications	47
5.1.1. Implications for practitioners	47
5.1.2. Implications for policymakers.....	48
5.1.3. Implications for further research	49
6. CONCLUSIONS	51
7. LIMITATIONS OF THE STUDY	53

REFERENCES	54
SUMMARY IN ESTONIAN	59
ACKNOWLEDGEMENTS	63
PUBLICATIONS	65
CURRICULUM VITAE	158
ELULOOKIRJELDUS.....	160

LIST OF FIGURES

Figure 1. DigComp framework (From Cosgrove & Cachia, 2025, p. 17).....	20
Figure 2. The overall design of the doctoral thesis.....	31
Figure 3. Student clusters based on their level of DCL (CREAT – creating digital materials, PROG – programming digital content, PROT – protecting oneself and others in the digital world, RULE – following the rules in the digital world, COMM – communicating in the digital world, OPER – performing operations with digital tools, AT_BATT – behavioural attitudes, AT_PC – perceived control, AT_SA – social aspects, AT_BINT – behavioural intention (see Article II)	41
Figure 4. Mean scores of the attitude dimensions assessed with the Digitest, presented on a percentage scale with 95% confidence intervals (from Article IV)	43
Figure 5. Mean scores of the digital skills dimensions assessed with the Digitest, presented on a percentage scale with 95% confidence intervals (from Article IV)	43

LIST OF ABBREVIATIONS

- ICT – information and communication technology
- DC – digital competence
- DCL – digital competence for learning

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which are referred to in the text using Roman numerals.

- I. Pedaste, M., Kallas, K., & Baucal, A. (2023). Digital competence test for learning in schools: Development of items and scales. *Computers & Education*, 203, 104830. <https://doi.org/10.1016/j.compedu.2023.104830>
- II. Kallas, K., & Pedaste, M. (2022). How to Cluster Students Based on Their Digital Competence for Learning? In: Sridhar IYER, Ju-Ling SHIH, Weiqin CHEN, Mas Nida MD KHAMBARI (Ed.). *Proceedings of the 30 th International Conference on Computers in Education*. (709–714). Asia – Pacific Society for Computers in Education.
- III. Kallas, K., & Pedaste, M. (2022). How to Improve the Digital Competence for E-Learning? *Applied Sciences*, 12(13), 6582. <https://doi.org/10.3390/app12136582>
- IV. Kallas, K., & Pedaste, M. (2025). Estonian students learning related attitudes towards digital technologies and digital skills. *Eesti Haridusteaduste Ajakiri. Estonian Journal of Education*, 13(1), 94–118. <https://doi.org/10.12697/eha.2025.13.1.05>

Author contributions:

- Article I: composing the theoretical framework, formulating the research questions, developing the instrument, collecting the data, conducting the data analysis and writing the article as one of the main authors.
- Article II: composing the theoretical framework, formulating the research questions, conducting the study, conducting the data analysis and writing the article as the main author in cooperation with the co-author.
- Article III: composing the theoretical framework, formulating the research questions, collecting the data, conducting the data analysis and writing the article as the main author in cooperation with the co-author.
- Article IV: composing the theoretical framework, formulating the research questions, developing the instrument, collecting the data, conducting the data analysis and writing the article as the main author in cooperation with the co-author.

1. INTRODUCTION

Rapid global developments in information and communication technology (ICT) have made digital technologies widely accessible and deeply embedded in everyday life. Its widespread integration into society has driven significant changes in both the workplace and educational systems, where digital competence (DC) is now a foundational requirement for teachers, students and educational institutions.

DC affects teaching quality, student learning and engagement, assessment and system-wide digital transformation. Research shows a positive relationship between digital skills and academic self-efficacy (Javier-Aliaga et al., 2024). Digitally skilled students engage with learning technologies more autonomously, more frequently and more deeply (Heidari et al., 2021). Moreover, DC is essential for online learning readiness where there is a need to navigate learning management systems platforms, participate in synchronous classes, manage independent online learning and troubleshoot technical issues (Chaves, 2021).

Furthermore, as the digital revolution has changed how we work, DC is also viewed by students as a key for careers and readiness for emerging digital jobs (Zhou et al., 2023). It also plays a complex role in entrepreneurship, as it can both strengthen the link between expected outcomes and entrepreneurial intention while simultaneously weakening the influence of self-efficacy, demonstrating that higher competence does not automatically translate into stronger entrepreneurial drive (Lam et al., 2025).

In practice, this means that students need structured opportunities to build advanced digital skills already before becoming university students, shifting focus to the importance of developing DC in primary and secondary education. Importantly, DC does not develop naturally or automatically through exposure to technology alone, but requires systematic, guided and purposeful support within educational settings. In these educational levels, it is essential to integrate DC systematically across curricula, starting in early primary grades and building competencies beyond mere tool use, focusing also on problem solving, safety and critical evaluation. Without such intentional integration, students may remain passive users of technology rather than developing the deeper competences required for learning and participation in digital environments.

Here, researchers, experts and policy-makers agree on the importance of developing digital skills, as on the European Union level the European Commission defines DC as one of the eight key competences of lifelong learning. Furthermore, most European countries have integrated DC into school curricula, either as a cross-curricular competence, a separate subject or a combination of both approaches.

Contemporary frameworks such as DigComp conceptualise DC as a combination of knowledge, skills and attitudes related to the critical, creative, safe and responsible use of digital technologies (Cosgrove & Cachia, 2025). However, the existence of comprehensive frameworks does not guarantee the successful

development of these competences in practice, as implementation depends on educational contexts, teaching practices, support structures and assessment opportunities. At a global level, it means unequal access to internet and devices.

In educational systems where access to digital technologies is largely ensured, a different challenge emerges. Schools are increasingly expected to support students' DC development, yet educators often lack reliable information about students' existing competence levels. Without valid assessment instruments, it is difficult to identify learning needs, monitor progress or evaluate the effectiveness of educational interventions.

Despite growing attention to DC development, considerably less attention has been devoted to how it can be assessed in a reliable and educationally meaningful manner. If DC is considered a key competence and is expected to be systematically developed in schools, it is equally necessary to measure and evaluate its development in a reliable and valid way. Without appropriate assessment, it is difficult to determine students' actual competence levels, monitor their progress or provide targeted support for further development.

Assessment therefore needs to provide more than an overall competence score. It should help to identify meaningful differences between learners and generate information that can support instructional decision-making. As a solution, the current thesis aims to address these challenges by providing an assessment method for assessing students' DC in learning settings and identify common combinations of students' digital skills and knowledge in order to teach more efficiently. More specifically, the thesis focuses on combining multidimensional assessment of digital competence for learning (DCL) with the identification of student competence profiles and the analysis of internal relationships between DCL dimensions, creating a basis for more informed and effective instructional decision-making.

1.1. Research problem

Despite the growing importance of DC in education, significant challenges remain regarding how it should be assessed, interpreted and used to support learning.

In the international education sphere, research about DC has been ongoing for decades and covers many educational levels, including teacher education and more recent developments related to COVID-19 and digital learning environments (Ma & Ismail, 2025). At the same time, there are still many issues where further research is needed. Among them, (1) how to develop DC in specific subjects, including the need for more intervention programmes for enhancing DC in specific disciplines; (2) targeting younger students, as there is a lack of evidence about the current state of DC among primary and secondary school students; (3) assessing DC, as we try to find research methods that can address the limitations of self-assessment in assessing DC and conduct longitudinal studies for monitoring DC development over time, gaining accurate and comprehensive data

in the process (Ma & Ismail, 2025). These issues all point to a need for an empirically validated DC assessment instrument, which can provide evidence and direction for addressing the aforementioned shortcomings.

In addition, there is a growing recognition that digital competence should not only be assessed as a general societal competence, but also in relation to students' participation and performance in learning processes. Previous reviews on DC assessment have highlighted that schools increasingly need assessment approaches that capture how students use digital technologies in authentic educational contexts and learning-related activities, rather than only assessing general ICT use or self-perceived abilities (Godaert et al., 2022; Siddiq et al., 2016). This highlights the need to focus more specifically on DCL, which captures the knowledge, skills and attitudes required for using digital technologies effectively in educational contexts.

However, this shift from general DC to DCL also introduces an important conceptual challenge. Many existing frameworks define DC as a broad competence required for participation in digital society, encompassing work, communication, leisure and civic engagement (Ferrari, 2012; Ilomäki et al., 2016). Learning, however, represents only one specific context within this broader construct. Consequently, it cannot be assumed that individuals who are digitally competent in everyday life are equally competent in digitally supported learning situations. Students may be proficient users of social media, entertainment platforms or digital communication tools while simultaneously lacking the competences required for information evaluation, self-regulated learning, knowledge construction or collaborative problem solving in educational settings. This creates a conceptual tension between general DC and DCL, suggesting that educational research may require more context-specific approaches to competence assessment and development.

Attempts to assess DCL have been made with international and regional surveys. For example, Pedaste et al. (2021) analysed data from previously conducted DC assessments (EU Kids Online and the Estonian Digital Competence Test) and distinguished nine dimensions that can form a basis for assessing DCL. These include operational skills, communication, content creation, programming, safety, legal behaviour, self-assessment and attitudes towards technology. This work provides an important example of how DC can be operationalised in a multi-dimensional manner, demonstrating that assessment is possible but also highlighting the complexity of the construct.

Although the need to assess DC in learning contexts is widely recognised, existing assessment approaches still face substantial conceptual and methodological limitations. Previous studies of DC assessment instruments highlight many issues. Siddiq et al. (2016) analysed 38 studies of assessment instruments for measuring primary and secondary school students' ICT literacy. Their review concluded several conceptual limitations and brought forward important areas for further development. First, the content of assessment instruments varies considerably across studies. Some tests focus on general, context-independent activities (e.g. writing emails or organising school trips), whereas others are embedded

within specific subject domains, such as science or mathematics, requiring students to retrieve digital information or solve subject-related problems. This variation limits comparability and raises questions about what is actually being measured – general DC or subject-specific applications. Greater conceptual clarity and alignment of test content would strengthen the field. Second, although the DigComp competence area of information is widely covered, other areas, particularly safety and problem solving, are underrepresented. Content creation, communication and technical-operational skills receive moderate attention, but the uneven distribution across competence areas suggests that current instruments may not capture DC in a balanced way. More systematic development is needed to ensure comprehensive coverage of all competence domains. Third, most available instruments target lower secondary students. There is a clear shortage of validated tools designed for primary and upper secondary learners. This gap indicates the need to develop age-appropriate assessments that reflect developmental differences across educational stages. Finally, the majority of existing assessments rely on multiple-choice formats or interactive tasks in which students select predefined responses. While such formats allow for efficient large-scale testing, they may insufficiently capture higher-order, creative or critical aspects of DC. Expanding the range of task designs, potentially including more authentic, open-ended or performance-based assessments, would contribute to a more comprehensive assessment of learners' DC.

Furthermore, several methodological issues emerged from the review made by Siddiq et al. (2016), as the authors conclude that transparency in reporting test items is often limited. In fewer than one third of the reviewed studies were all test items explicitly presented. The remaining studies either described test content only indirectly by referring to competence areas or provided only selected examples of tasks. This lack of full disclosure restricts the possibility of evaluating content validity and replicating instruments. Moreover, cross-country comparative studies remain limited. As a result, current assessment approaches often fail to provide a comprehensive and transferable understanding of students' DC.

Godaert et al. (2022) conducted a systematic review targeting studies where the DC of primary school students was assessed. The authors located 14 suitable studies and reported future directions of assessment based on previous attempts. First, only a small number of studies explicitly include primary school pupils, and many combine primary and secondary samples (average age around 12), which makes it difficult to draw clear conclusions about assessment tools specifically designed for younger learners. There is a clear need for instruments that are developmentally appropriate for primary education and that reflect pupils' cognitive and social characteristics at this stage. Second, most instruments assess DC through self-report questionnaires, often using Likert-type scales. Objective assessments and performance-based tasks are less common, and fully authentic assessments are rare. Although many studies combine formats, scoring is frequently limited to dichotomous correct/incorrect responses. This approach may not adequately capture the complexity of pupils' DC. Future instruments should include more performance-based and open-ended tasks to assess applied and

higher-order skills. Third, some competence areas are significantly under-represented, and important sub-competences such as managing digital identity, online citizenship, copyright, programming and identifying gaps in one's own DC are rarely assessed. This imbalance suggests that current tools do not provide a comprehensive picture of primary pupils' DC. More balanced frameworks and test blueprints are needed.

In addition, Godaert et al. (2022) further highlight issues with the transparency and methodological quality of conducted studies. They state that in several studies, full item sets are not presented, and in some cases only examples are provided. This reduces transparency and makes it difficult to evaluate content validity and comparability across studies. Clearer reporting of test matrices, item descriptions and scoring procedures would strengthen the field and support replication. Furthermore, the authors point out issues with methodology, as most studies report reliability coefficients and describe data collection procedures, but not all provide detailed information about test development or validation. Advanced validation approaches are also inconsistently applied, especially regarding construct validity and age-appropriate difficulty levels. Further development should focus on stronger evidence of validity, especially construct validity and age-appropriate difficulty levels.

Overall, taking these reviews into account, research on DC assessment in primary and secondary education remains fragmented. There is a need for more age-appropriate, transparent, comprehensive and methodologically valid instruments that assess the full range of DC and provide actionable information for educators.

However, even when such assessment instruments are developed, an additional challenge emerges: DC is often treated as a single aggregated construct. In reality, students differ not only in the level of their competence but also in how different competence components combine within individuals. As a result, average scores may conceal meaningful differences between learners and limit the usefulness of assessment results for teaching.

To address this limitation, there is a need to move beyond aggregate measurement and adopt approaches that capture learner diversity. Student clustering and profiling offer a way to identify groups of learners with similar competence patterns, enabling a more nuanced understanding of student needs and supporting differentiated instructional design.

On the other hand, we can argue that because DC is essential for academic success, then we should specify which aspects of DC directly support learning processes. There is often an assumption that students can use technology effectively for learning. However, students may be confident users of applications meant for everyday communication – like social media tools or artificial intelligence chatbots – but ineffective learners, and access does not equal meaningful use.

This leads us to the importance of supporting the development of students' DCL, which focuses on their ability to use digital tools to understand subject content, manage information overload, engage in inquiry and problem solving,

collaborate and regulate one's own learning in digital environments. And as we need assessment for tracking the growth of abilities in all subjects to provide supportive feedback, DCL is also something we should be able to assess.

In addition, DCL should not be understood only as a set of separate dimensions, but also as a system of interrelated components. It is likely that some competences support or precede others, for example, basic operational skills may enable more advanced activities such as content creation or collaboration in digital environments. Without examining these relationships, assessment results remain descriptive and do not provide insight into how competence develops.

Therefore, there is a need to analyse the internal connections between different dimensions of DCL. Such structural analysis can provide insight into competence development and support the design of more effective and logically sequenced learning processes.

Taken together, these challenges highlight the need to combine multidimensional assessment, learner profiling and structural analysis of DCL. Addressing these aspects forms the central focus of this doctoral thesis.

1.2. Focus of the research

The aim of this doctoral thesis is the development, validation and application of the instrument for assessing DCL: the Digitest.

The research is divided into two phases. The first phase is **Development and applicability analysis**, which focuses on development and validation of a test for measuring DCL and exploring the applicability of the test. The sub-phases of the Development and applicability analysis phase are as follows:

- a. to create a test for assessing the DCL of primary and lower secondary school students;
- b. to evaluate the quality of the test;
- c. to determine how the test can cluster students based on their DCL; and
- d. to determine how the different factors involved in the development of students' DCL are related to each other.

The research questions for the Development and applicability analysis phase are as follows:

1. What evidence supports the use of the Digitest for assessing the digital competence for learning of primary and lower secondary school students?
2. How can assessment results from the Digitest be used to support the design of the digital learning process?

The second phase is **Application**, which focuses on using the developed instrument for gathering insights on students' competence. The aim of the Application phase is to determine the digital skills and learning-related attitudes of Estonian primary and lower secondary school students.

The following research question is posed for the Application phase:

3. What are the levels of Estonian primary and lower secondary school students' learning-related digital knowledge, skills and attitudes towards digital technologies?

The research questions are addressed in the following original publications:

Article I addresses research question 1 by focusing on the development and validation of the Digitest as an instrument for assessing students' DCL. The study evaluates the psychometric quality of the test and examines its suitability across different age groups.

Articles II and **III** contribute to answering research question 2. In **Article II**, student clusters are identified based on their DCL, providing insight into how the test can support differentiated instruction and learning design. **Article III** investigates the internal relationships between different dimensions of DCL, offering a basis for structuring learning processes according to developmental pathways.

Article IV addresses research question 3 by applying the validated Digitest in school settings to assess Estonian primary and lower secondary school students' levels of digital skills and learning-related attitudes, providing an empirical overview of students' DCL.

Taken together, the four empirical studies provide complementary perspectives on how children's DCL can be assessed, validated, described and meaningfully interpreted using the Digitest, demonstrating its applicability as a multi-dimensional assessment instrument, a tool for identifying student profiles and structural relationships between competence dimensions and a means for generating empirical insights into students' competence levels in practice.

2. THEORETICAL FRAMEWORK

The following chapters provide the theoretical outline of the thesis. First, an overview explaining the nature of DC and DCL is provided, followed by an overview of studies assessing DC.

2.1. Digital competence

In this section, the central concepts of the thesis, DC and DCL, are defined and conceptually clarified. Particular attention is given to distinguishing between general DC and its application in learning contexts, highlighting why DCL is a more specific and educationally relevant construct in this research. In addition, the section elaborates on the multidimensional nature of DC and DCL, explaining how these constructs can be understood through different interrelated dimensions such as knowledge, skills and attitudes. Furthermore, the section introduces the idea of clustering, describing how learners can be grouped based on their competence profiles, thereby providing a basis for understanding variability among students and supporting more differentiated approaches to analysis of competences and instructional design based on the clusters. Finally, the necessity and uses of examining interactions between the dimensions of DC is also discussed.

2.1.1. Definition of digital competence

In order to understand DC, it is first necessary to clarify what is meant by competence more broadly. Competence has been conceptualised in multiple ways across educational and psychological research, which has contributed to the lack of a single universally accepted definition (Weinert, 2001). Rather than referring only to what an individual knows or is able to do, competence is generally understood as a combination of knowledge, skills, attitudes, motivational tendencies and the ability to apply these successfully in specific contexts. As Weinert (2001) argues, competence refers to the prerequisites necessary for successfully mastering complex demands and tasks, and these prerequisites often include both cognitive and motivational components. Accordingly, competence can be viewed as the integration of what individuals know (knowledge), what they are capable of doing (skills) and their willingness or readiness to act (attitudes and motivational tendencies) in order to perform effectively in a given context (Weinert, 2001; Westera, 2001).

The Council of the European Union (2018) defines competence as a combination of knowledge, skills and attitudes. Knowledge consists of “facts and figures, concepts, ideas and theories which are already established and support the understanding of a certain area or subject”; skills represent “the ability and capacity to carry out processes and use the existing knowledge to achieve results”; and attitudes involve “the disposition and mind-sets to act or react to ideas, persons or situations” (The Council of the European Union, 2018, p 7).

One of the main terms used to describe the knowledge, skills and attitudes that are required to function in a digital society is DC. The phrase has been increasingly used since the launch by the European Commission of the Digital Competence Framework (DigComp), which is a series of framework documents continuously updated to reflect changes in the digital landscape (most recent version DigComp 3.0, Cosgrove & Cachia, 2025). Furthermore, DC has been recognised by the European Parliament and the European Council as one of the key competences for lifelong learning and fundamental basic competence (European Commission, 2019). DC is a complex construct drawing elements from several disciplines: media studies, technology studies, literacy studies and library studies. It is also often used as a synonym or partially overlapping concept alongside terms such as “digital literacy”, “new literacies”, “media literacy” and “multiliteracies” in literature (Ilomäki et al., 2016). Ferrari (2012) proposed a definition of DC based on several theoretical frameworks (ACTIC, Becta’s review of Digital Literacy in 0-16-year-olds, Centre of Media Literacy framework, Digital Competence Assessment framework, DigEuLit, ECDL, eLSe Academy, eSafety Kit, Eshet-Alkalai’s conceptual framework for survival skills, IC3 Internet and Computer Core Certification, iSkills, NCCA: ICT framework for schools in Ireland, Pedagogic ICT licence, Information literacy project – Scotland and UNESCO ICT Competency Framework for Teachers) as “the set of knowledge, skills, attitudes (thus including abilities, strategies, values and awareness) that are required when using ICT and digital media to perform tasks; solve problems; communicate; manage information; collaborate; create and share content; and build knowledge effectively, efficiently, appropriately, critically, creatively, autonomously, flexibly, ethically, reflectively for work, leisure, participation, learning, socialising, consuming, and empowerment” (p. 3). Synthesising a wide range of frameworks, Ferrari (2012) conceptualises DC as a combination of knowledge, skills and attitudes that enable individuals to use digital technologies effectively, critically and responsibly across contexts such as learning, work and participation in society. This definition is particularly important for the present study, as it explicitly emphasises that DC is not limited to technical ability but also includes cognitive, social and motivational components.

Ilomäki et al. (2016) define DC as “consist[ing] of the skills and practices required to use new technologies in a meaningful way and as a tool for learning, working and leisure time, understanding the essential phenomena of digital technologies in society as well as in one’s own life, and the motivation to participate in the digital world as an active and responsible actor.” (p. 670). They divide the concept into four elements: (1) technical skills and practices using digital technologies; (2) abilities to use and apply digital technologies in a meaningful way as a tool for working, studies and leisure time; (3) abilities to understand the ethical issues, limitations and challenges coming with digital technology use; and (4) motivation to participate and engage in the digital culture. This approach reinforces the idea that DC extends beyond isolated skills and should be understood as a holistic and context-dependent construct, particularly in relation to learning.

UNESCO's report on digital literacy skills uses the term "digital literacy", which is defined as "the ability to access, manage, understand, integrate, communicate, evaluate and create information safely and appropriately through digital technologies for employment, decent jobs and entrepreneurship. It includes competences that are variously referred to as computer literacy, ICT literacy, information literacy and media literacy." UNESCO's definition of digital literacy complements DigComp and Ilomäki et al.'s perspectives by focusing on the ability to access, manage, evaluate and create information using digital technologies. While framed in terms of "literacy," it similarly encompasses a broad set of competences, including cognitive and practical abilities, as well as responsible and safe use.

All definitions are in a way different and focus on different aspects in their core: UNESCO's framework is more suitable for understanding workforce-oriented skills development; Ilomäki et al.'s (2016) approach provides deeper educational grounding; and Ferrari's (2012) proposed definition focuses on curriculum alignment and assessment. In developing the student DC assessment instrument, DigComp (based on Ferrari, 2012) was selected as the conceptual foundation in this thesis, as it provides a structured, multidimensional model that integrates knowledge, skills and attitudes across clearly defined competence areas. Unlike UNESCO's definition, which primarily frames DC in relation to employability and economic participation, DigComp offers a broader educational perspective that encompasses critical thinking, ethical awareness, collaboration and creative engagement. Compared to Ilomäki et al.'s conceptualisation, which emphasises meaningful participation and motivation in digital society, DigComp offers greater operational clarity and domain structure, making it more suitable for systematic assessment design. While Ilomäki's approach enriches the theoretical understanding of digital agency, DigComp enables the translation of DC into assessable components without reducing it solely to technical skills. Thus, DigComp provides both conceptual comprehensiveness and practical applicability, supporting the development of an assessment instrument aligned with educational goals rather than purely functional or labour-market-oriented outcomes.

In more detail, DigComp divides DC further into five sub-categories, as shown in Figure 1 (DigComp 3.0; Cosgrove & Cachia, 2025):

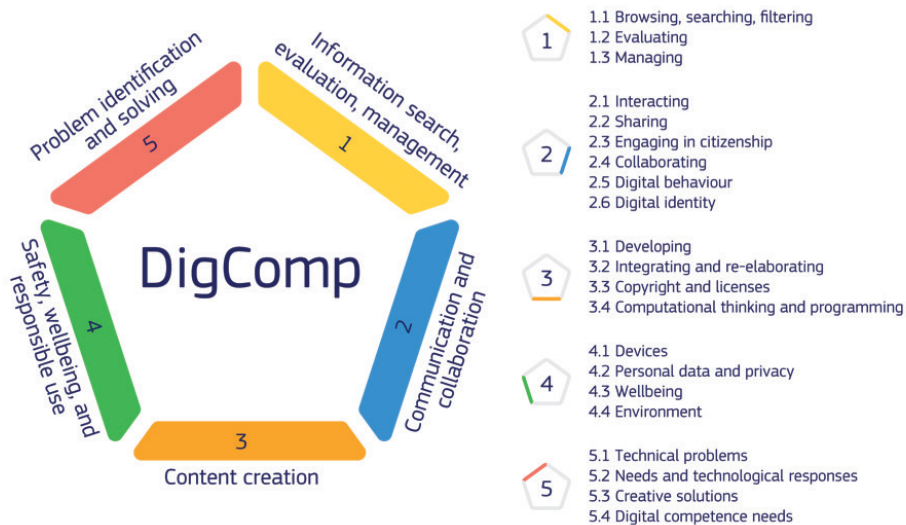


Figure 1. DigComp framework (From Cosgrove & Cachia, 2025, p. 17)

- 1) information search, evaluation, management (browsing, searching, filtering, evaluating and managing information) – this area refers to the ability to identify information needs, locate relevant data in digital environments, critically assess its credibility and relevance and organise it effectively. In practical terms, for citizens and students this means being able to use search engines strategically, distinguish reliable sources from misinformation, compare perspectives, manage references or files systematically and use information ethically for decision-making, learning and everyday problem solving.
- 2) communication and collaboration (interacting, sharing, participating, collaborating and managing digital identity) – this area concerns using digital technologies to communicate effectively, collaborate with others, participate in society and manage one's digital presence. Practically, this means engaging respectfully in online discussions, working in shared documents or platforms, understanding netiquette, adapting communication to different audiences, protecting personal data and maintaining a responsible and coherent digital identity across platforms.
- 3) content creation (developing, integrating and re-elaborating digital content; understanding copyright and licenses; programming) – this area involves producing and editing digital content in various formats and understanding the legal and technical frameworks that shape its use. For citizens and students, this means creating presentations, videos, reports or code; remixing existing materials responsibly; citing sources correctly; understanding intellectual property rights; and, at more advanced levels, developing simple digital solutions or scripts to meet specific needs.

- 4) safety, wellbeing and responsible use (protecting devices, personal data, privacy, health, wellbeing and the environment) – this area focuses on using digital technologies in ways that are secure, healthy and socially responsible. In practice, this means recognising online risks (e.g. scams, cyberbullying), applying privacy settings, using strong authentication practices, managing screen time, understanding the psychological and social impact of digital media and being aware of the environmental footprint of digital technologies.
- 5) problem identification and solving (identifying digital needs and problems, selecting appropriate tools, creatively using technologies and developing DC) – this area refers to recognising when and how digital tools can address specific challenges and adapting technologies to new situations. For citizens and students, this means choosing appropriate apps or platforms for tasks, troubleshooting technical issues, learning new tools independently, critically assessing whether a digital solution is appropriate and reflecting on one's own digital skill gaps and development needs.

These five areas are further divided into 21 sub-competences. Additionally, DigComp 3.0 describes how artificial intelligence plays both an explicit and implicit role in DC learning outcomes.

In this thesis, DC is conceptualised as a multidimensional construct that integrates knowledge, skills and attitudes, drawing on established definitions and frameworks in the field. Building on Ferrari's (2012) synthesis, DC is understood as the capacity to use digital technologies effectively, critically and responsibly across different contexts, including learning. This perspective is further supported by Ilomäki et al. (2016), who emphasise not only technical proficiency but also meaningful use, critical understanding and motivation to engage in digital environments. Together, these approaches highlight that DC extends beyond functional skills and includes cognitive, social and attitudinal dimensions.

The conceptualisation in this thesis is also aligned with the European DigComp framework, which structures DC into key areas such as information and data literacy, communication and collaboration, digital content creation, safety and problem solving. These areas reinforce the idea that DC consists of interconnected dimensions that reflect both individual and social aspects of technology use. Importantly, DigComp also acknowledges the role of attitudes, responsibility and critical thinking alongside practical skills.

Taking these perspectives together, in this thesis DCL is defined as a comprehensive and structured set of competences required for effective participation in digitally mediated learning processes. The focus of the thesis, DCL, is a narrower concept and has not been widely studied. Therefore, the thesis relies on the definition of DC to define DCL as the attitudes, skills and practices required for using digital technologies in a meaningful way for learning (see Article I).

An important distinction between DC and DCL is that being digitally competent in everyday life does not automatically mean being digitally competent for learning. Students may confidently use social media, messaging applications or

other digital tools, yet still struggle to find reliable information, evaluate sources, collaborate effectively or use technology to support learning. Therefore, DCL can be understood as a context-specific form of DC that focuses on the purposeful use of digital technologies for achieving learning goals. This also means that instruments assessing general DC may not provide sufficient information about students' readiness to learn with digital technologies.

Because general digital competence does not necessarily reflect competence for learning, the Digitest was designed to assess DCL as a multidimensional construct. It combines performance-based assessment of students' skills and knowledge with measures of their attitudes towards digital technologies, providing a more comprehensive picture of their capacity to learn in digital environments.

2.1.2. Dimensionality of digital competence

In order to assess different aspects of DC, the question of its dimensionality must be also raised. It is still not clear from previous research whether the concept of DC (or in our case DCL) should be considered unidimensional or multidimensional (see Article I). DC is widely conceptualised as a multidimensional concept in curriculum frameworks and most assessment instruments are designed to evaluate DC as a set of sub-competences. However, the results of empirical studies are mixed, reporting DC to be in most cases a unidimensional construct and in some cases a multidimensional one.

Several frameworks describe DC as multidimensional. For example, DigComp divides DC into five competence areas which are further divided into 21 sub-competences (DigComp 3.0; Cosgrove & Cachia, 2025), and The International Computer and Information Literacy study (ICILS) divides the DC (described in the study as computer and information literacy) into four categories – (1) understanding computer use, (2) gathering information, (3) producing information and (3) digital communication – further dividing each into two sub-areas (Egan et al., 2021; Fraillon & Duckworth, 2023). Ihme et al. (2017) analysed the data from ICILS to investigate whether item formats for assessing computer and information literacy (non-interactive/constructed response tasks, simulation tasks and authoring tasks) measure the same construct, and concluded that the empirical evidence supported multi-dimensionality regarding the item types (or types of knowledge). At the same time, high factor correlations also justify using a unidimensional model. Results from ICILS from 2013 showed that student responses to the assessment were best explained by a single underlying dimension – Computer and Information Literacy (CIL) – indicating that the construct functioned empirically as unidimensional rather than as a set of independent competencies (Gebhardt & Schulz, 2015). Following this cycle, and in collaboration with national research teams, the ICILS consortium revised the conceptual structure of the CIL framework for ICILS 2018 (Fraillon, 2018). The revision aimed to improve the clarity and communicability of the construct and to reduce overlap between strands, without implying a change to its psychometric structure. Subsequent analyses of ICILS 2018 data confirmed that, despite the

refined conceptual organisation, CIL continued to operate as a single latent dimension (Ockwell et al., 2020).

As the ICILS example shows, in empirical studies it has been more challenging to show and assess DC as a multi-dimensional concept. Aesaert et al. (2014) developed a test to assess primary-school students' proficiency in digital information processing and communication with tasks for real-life information searching, processing and communication activities. The authors had assumed that information searching and processing, on the one hand, and digital communication on the other, were two theoretically different ICT competences, together with their underlying technical skills. However, as they tested the unidimensional and two-dimensional structures, they concluded that the unidimensional model fit the data best. The unidimensional result for DC assessment aligns with the results of Claro et al. (2012). In their study of 15-year-old students, ICT skills were divided into information fluency (sourcing and processing) and effective communication (communication, collaboration and virtual interactions). However, the analysis revealed a single factor encompassing all items, rather than the expected two-factor structure.

In the hope of achieving multidimensional assessment ability, Jin et al. (2020) and Pan et al. (2025) measured digital literacy across ages and over time using a performance-based instrument for assessing students' ability in five areas: information and data literacy, communication and collaboration, digital content creation, safety and problem-solving skills. However, the assessed DC was found to be a unidimensional model in both cases.

In contrast, when assessing students' abilities to handle digital information and to communicate and collaborate during problem solving, Siddiq et al. (2017) found that a multidimensional model fit the data better than a unidimensional one. Because the assessment instrument yielded four distinct dimensions, the data strongly supported the multidimensional design of the DC concept. While DC is overwhelmingly conceptualised as a multidimensional construct identifying distinct yet interrelated components, previous research among students has struggled to empirically validate this in practice. This creates a clear tension between theoretical frameworks and empirical evidence, as multidimensionality is widely assumed but not consistently demonstrated. At the same time, even studies supporting unidimensionality often acknowledge that DC consists of qualitatively different aspects, suggesting that the construct may be more complex than what is captured by a single latent dimension.

This discrepancy raises a more fundamental question regarding the nature of DC itself. If theoretically distinct competence areas repeatedly collapse into a single latent factor in empirical analyses, it becomes necessary to ask whether DC should be interpreted primarily as a general competence or as a constellation of partially independent competences. From an educational perspective, this distinction is important because a single overall score may conceal meaningful differences between learners. Two students may obtain identical overall scores while demonstrating very different strengths and weaknesses across competence dimensions. Consequently, the question is not only whether DC is statistically

multidimensional, but also whether multidimensional assessment provides more educationally meaningful information than a single score.

Therefore, there is a need for assessment approaches that are explicitly designed to capture the multidimensional nature of DC and to empirically test whether such dimensionality can be identified in practice. In the context of this thesis, DCL is conceptualised and assessed as a multidimensional construct, and this assumption is systematically examined through empirical analysis. By doing so, the study helps clarify whether the theoretically proposed dimensions of DC can be meaningfully distinguished and assessed in educational settings.

2.1.3. Student profiling based on digital competence

Research on students' use of digital technologies has consistently shown that learners cannot be treated as a homogeneous group. Instead, studies applying person-centred approaches (e.g. cluster analysis, latent profile/class analysis) have identified distinct profiles of students, differing in their patterns of technology use, skills and engagement (Karakoyun & Başaran, 2021; Pedaste et al., 2017; Scherer et al., 2017; van den Beemt et al., 2011; Xiao & Sun, 2021). These findings provide an important basis for the current study, which aims to cluster students based on assessed DCL.

One of the key studies by van den Beemt et al. (2011) demonstrated that young people's use of interactive media is characterised by diversity rather than uniformity. The authors identified four user profiles – Traditionalists, Gamers, Networkers and Producers – each reflecting different patterns of engagement, from basic information use to active content creation. Importantly, this study challenged the notion of a uniform “digital native” generation and highlighted that students differ not only in how much they use technology but also in how and for what purposes they use it. For educational practice, this implies that digital learning environments should account for these differences rather than assume equal readiness among learners.

Focusing more specifically on learning contexts, Pedaste et al. (2017) examined students' use of mobile devices in science and mathematics education. Their results showed that students can be grouped into multiple profiles, ranging from non-users and beginners to more active users, including those focused on information use, communication or content creation. Notably, only a small proportion of students demonstrated advanced, versatile use of digital tools. The majority primarily used technology for information access, suggesting that higher-level competences such as collaboration and creation are less developed. These findings indicate that DC in learning contexts is structured and unevenly distributed, reinforcing the need for targeted pedagogical support.

Large-scale studies using international datasets have provided further evidence of student profiling. Scherer et al. (2017), using ICILS data, identified two main ICT user profiles differing in the frequency and consistency of ICT use across contexts. Their findings showed that profiles were associated with motivational

factors, such as self-efficacy and interest, but not strongly with achievement outcomes. This suggests that patterns of ICT use reflect differences in engagement and confidence rather than competence alone. Similarly, Xiao and Sun (2021) identified two profiles among U.S. students: moderate users and entertainment-oriented users. Students with more balanced ICT use performed better academically, indicating that purposeful and moderate use of technology is more beneficial than excessive or entertainment-focused use.

Other studies have also highlighted the complexity of ICT use profiles and their relationship with learning outcomes. Karakoyun and Başaran (2021), analysing PISA data, identified four profiles based on ICT use at home and school. Their results showed that students with the highest levels of ICT use formed a relatively small group and, importantly, that higher levels of ICT use did not necessarily correspond to higher academic achievement. In fact, intensive use, especially for non-academic purposes, was associated with lower performance. These findings emphasise that the quality and context of ICT use are more important than frequency alone.

Taken together, previous studies show that student profiles differ in patterns of technology use, levels of engagement and underlying motivational factors, and that these differences have implications for learning. However, a key limitation across many of these studies is their reliance on self-reported data about ICT use, which may not accurately reflect students' actual competences.

The current study builds on this by using an assessment tool (Digitest) that assesses students' skills, knowledge and attitudes. This allows for creating profiles based on actual competence, not just reported competence. This provides a stronger foundation for designing differentiated digital learning processes, where instruction can be tailored to students' actual competence profiles rather than assumed levels of digital ability.

2.1.4. Digital competence development

Previous research on DC has predominantly focused on identifying external predictors of competence levels rather than examining how different dimensions of DC interact and influence each other. Empirical studies consistently show that students' DC is shaped by background and contextual factors such as socio-economic status, academic achievement, goal orientation and access to technology (Barboutidis & Stiakakis, 2023; Hatlevik et al., 2015; Kim et al., 2014). These findings provide important insights into how DC develops, yet they offer limited understanding of how competence develops across its dimensions, which is crucial for designing effective learning processes.

In the context of DC, theoretical models suggest that positive attitudes towards digital technologies increase behavioural intention, which in turn promotes actual technology use and competence development. Empirical studies support this mechanism. For example, students who perceive digital technologies as useful and feel confident in using them are more likely to engage in digital learning activities, thereby creating opportunities for skill development (Adov et al., 2017;

Rahman et al., 2023). However, the relationship between attitudes and competence is often more complex. Attitudes do not necessarily translate directly into skills but rather influence engagement and usage patterns, which then affect competence development. This distinction is important, as it suggests that attitudes alone could be insufficient predictors unless they lead to sustained interaction with digital tools.

Beyond external and motivational predictors, theoretical models consistently emphasise the hierarchical structure of DC. Operational and technical skills are widely recognised as the foundation of DC, enabling individuals to interact with digital tools and environments (Iordache et al., 2017). Without these basic skills, the development of more complex competences, such as content creation, communication and problem solving, is constrained.

Empirical evidence supports this hierarchical perspective. Foundational competences such as information literacy and basic technical skills have been shown to predict higher-order competences, including content creation and digital problem solving (Nhi & Long, 2026; Trigueiro et al., 2026). These findings suggest a cascading effect, where the development of advanced skills depends on prior mastery of basic competences.

However, while DC is widely conceptualised as multidimensional, empirical research on the interrelations between its dimensions remains relatively limited. Existing studies indicate that competence dimensions are moderately to strongly correlated, suggesting that they form an interconnected system rather than independent components (Trigueiro et al., 2026).

Structural models further suggest that DC follows a hierarchical and interdependent structure, where foundational competences (e.g. operational skills, information literacy) support intermediate competences (e.g. content creation, programming), which in turn enable more complex competences (e.g. collaboration, problem solving, creativity) (Iordache et al., 2017; Nhi & Long, 2026; Trigueiro et al., 2026).

Furthermore, recent findings also highlight the role of specific dimensions as key predictors. For example, information literacy and digital communication have been identified as foundational competences that support analytical, collaborative and creative performance (Nhi & Long, 2026). This reinforces the view that competence development occurs through integrated learning processes, where multiple dimensions co-develop rather than evolve independently.

When viewing competences developed individually and those requiring collaborative interaction, important distinctions occur in the literature. Research on collaborative learning suggests that effective collaboration depends on the presence of sufficient individual competence. However, studies show that learners with limited prior knowledge may not benefit from collaboration due to cognitive overload and coordination difficulties (Nokes-Malach et al., 2012). Conversely, individuals with stronger prior knowledge are more likely to benefit from collaborative processes, as they can engage in meaningful interaction, explanation and co-construction of knowledge.

Similarly, research on expertise and teamwork demonstrates that individual capabilities strongly influence group performance (Williams Woolley et al., 2006). Collaboration is most effective when participants possess complementary or sufficiently developed skills relevant to the task. In contrast, collaboration among individuals lacking foundational competence may lead to ineffective outcomes or even hinder performance (Meade et al., 2009). These findings support the assumption that individually developed competences serve as prerequisites for collaboratively developed competences. In other words, the development of communication, collaboration and socially situated digital skills depends on prior acquisition of basic and intermediate competences.

Taken together, the literature indicates that DC is not a set of isolated abilities but a dynamically connected system in which motivational, cognitive and social dimensions interact, although empirical evidence on the precise predictive relationships between these dimensions remains limited.

2.2. Assessment of digital competence

Competences may be decomposed into contributing sub-competences, and assessment of competence will likely determine the areas of competence where the subject is incompetent (Westera, 2001). In the context of DC, this implies that assessment should not only provide an overall score but also identify specific strengths and weaknesses across different competence components.

Previous research suggests that DC can be assessed using three main approaches: self-assessment, knowledge-based tests and performance-based assessment. Each of these approaches captures different aspects of competence and has distinct strengths and limitations (Kluzer & Pujol Priego, 2018). Self-assessment focuses on perceived competence and supports reflection, but it might not provide us with an objective assessment of actual performance. Knowledge-based tests assess declarative and procedural knowledge through structured scenarios, offering more objectivity but often lacking authenticity. Performance-based assessments require learners to complete real or simulated digital tasks, thereby measuring competence as demonstrated action, but they are typically more resource-intensive to design and implement.

Because of these limitations, recent research increasingly emphasises the need to combine multiple assessment approaches in order to obtain a more comprehensive and valid representation of DC (Vuorikari et al., 2026; Mattar et al., 2022). Mixed-method assessment models, which integrate self-report, objective testing and performance-based tasks, are considered more suitable for capturing the multidimensional nature of DC, particularly when aiming to assess knowledge, skills and attitudes simultaneously. Recent developments also highlight the importance of balancing comprehensiveness and practicality: while large-scale instruments often aim to cover multiple competence areas, they may become too complex or time-consuming, leading to the development of shorter, more targeted tools that still retain the multidimensional structure of DC (Vuorikari et al., 2026).

Despite these methodological options, assessing DC in educational contexts remains challenging. A key issue is the continued dominance of self-assessment instruments, which are widely used due to their scalability and ease of administration (Ulfert-Blank & Schmidt, 2022; Martzoukou et al., 2022). However, evidence consistently shows that self-reported competence reflects perceived rather than demonstrated ability and is therefore only a partial indicator of actual DC. Studies show that learners tend to overestimate their digital abilities, and this bias can be influenced by factors such as age, confidence and prior experience (Černochová et al., 2019; Vonkova et al., 2021). For example, Vonkova et al. (2021), using the overclaiming technique, demonstrated that students report familiarity even with non-existing ICT concepts, particularly when they perceive themselves as more competent, indicating systematic inflation in self-reports. Similarly, Černochová et al. (2019) showed that self-assessment outcomes are strongly affected by reporting styles and contextual factors rather than actual skill levels, leading to inconsistencies across individuals and groups. As a result, self-assessment alone does not provide a reliable basis for evaluating students' DC.

Research focusing specifically on self-efficacy and self-perception further highlights these limitations. Ulfert-Blank and Schmidt (2022), in their review and scale development study, found that although self-efficacy measures can capture multiple dimensions of DC, they require validation against objective performance data to ensure criterion validity. Their findings suggest that even theoretically grounded, multidimensional self-report instruments cannot fully substitute performance-based evidence. Similarly, Martzoukou et al. (2022), using a self-assessment survey with university students, showed that learners tend to position themselves at intermediate levels across most competence areas while simultaneously demonstrating clear gaps in key domains such as digital creation, innovation and critical use of technologies. These findings indicate that self-assessment may capture awareness of competence to some extent, but it does not accurately reflect actual capability or readiness for learning and professional contexts.

Performance-based approaches address some of these limitations but introduce new challenges. While objective tests allow efficient large-scale measurement, they often rely on simplified task formats that do not fully reflect real-world digital practices (Aesaert & van Braak, 2015; Fraillon, 2018). Performance-based assessments, on the other hand, provide more authentic evidence by observing learners' actions in digital environments, but they are difficult to scale and require complex technical solutions for logging and analysing user behaviour (Aesaert et al., 2014; Bartolomé & Garaizar, 2022). This creates a tension between authenticity and scalability, which remains one of the central challenges in DC assessment. As highlighted by Bartolomé and Garaizar (2022), although interactive simulations and performance-based formats provide more valid representations of complex competences, their development and maintenance require substantial resources, limiting their widespread use in large-scale educational settings.

Another important issue concerns the coverage of competence dimensions. Although frameworks such as DigComp emphasise a broad set of competences, empirical studies show that assessment instruments often focus on a limited subset of these areas (Godaert et al., 2022). In particular, safety, ethical use and problem-solving competences are consistently underrepresented, while technical and information-related skills are more frequently assessed. This imbalance limits the ability to capture DC as a holistic construct.

In addition, many assessment instruments focus primarily on skills, while knowledge and attitudes receive less attention, despite being recognised as essential components of competence (Godaert et al., 2022; Muñoz-Repiso et al., 2020). Holistic models of DC emphasise that effective digital behaviour depends not only on technical ability but also on understanding, motivation and responsible use of technology (Guitert et al., 2021; Vuorikari et al., 2026). Therefore, assessment approaches that neglect these dimensions may provide an incomplete picture of learners' competence. Muñoz-Repiso et al. (2020), for example, demonstrated through the development of the INCODIES model that comprehensive assessment requires systematic inclusion of all three components, yet such comprehensive instruments tend to become complex and extensive, creating additional challenges for practical implementation.

A further challenge relates to the lack of age-appropriate assessment instruments, particularly for primary and lower secondary education. Most validated tools have been developed for older students or adults, leaving a gap in understanding younger learners' DC development (Godaert et al., 2022; Siddiq et al., 2016). This is problematic, as DC is expected to develop progressively from early stages of education, and assessment tools must be adapted to learners' cognitive and developmental characteristics. At the same time, designing such instruments is particularly challenging, as it requires balancing authenticity, accessibility and psychometric quality while ensuring that tasks remain meaningful and developmentally appropriate for younger students.

Methodological concerns also persist. A recurring issue identified in the literature is the insufficient reporting and inconsistent application of psychometric validation procedures, including reliability, validity and dimensionality analyses (Casillas-Martín et al., 2020; García-Ruiz et al., 2023). As many studies rely on self-developed instruments – often without comprehensive validation or transparent reporting – it becomes difficult to evaluate their measurement quality, ensure comparability across contexts or interpret findings with confidence (García-Ruiz et al., 2023). Recent research therefore emphasises the need for more rigorous and systematic validation practices. These include the use of exploratory and confirmatory factor analysis to verify construct structure, reliability estimation (e.g. Cronbach's alpha, composite reliability) and advanced approaches such as item response theory or Rasch modelling to examine item functioning and measurement precision (Avinç & Doğan, 2024; Cabero-Almenara et al., 2020). However, evidence suggests that such comprehensive validation procedures are not consistently applied in practice, particularly in studies targeting

younger learners or using newly developed instruments, which limits generalisability of findings.

Taken together, these findings indicate that current approaches to assessing DC remain fragmented. There is a clear need for assessment instruments that are: (1) multidimensional, capturing skills, knowledge and attitudes; (2) based on authentic and meaningful tasks; (3) psychometrically transparent; (4) adaptable to different age groups and contexts; and (5) capable of providing sufficient feedback for educators.

At the same time, assessment is not only a measurement issue but also a pedagogical one. Research has shown that what is assessed influences what is taught and learned, meaning that the design of assessment tools has direct implications for teaching practices and learning outcomes (Godaert et al., 2022). Therefore, improving DC assessment is essential not only for measurement accuracy but also for supporting meaningful learning processes.

In this context, the development of the Digitest in the present study aims to address these challenges by providing a multidimensional, performance-oriented assessment of DCL, combining different assessment approaches and aligning them with a comprehensive conceptual framework.

3. RESEARCH METHODOLOGY

The following section provides an overview of the Digttest development and validation process, research design, research context, sampling strategy, data collection and data analysis procedures, as well as ethical considerations of the doctoral thesis. The section describes how the four empirical studies were designed and carried out in order to address the research questions. In addition, an overview of the DigiEfekt project is also given, which was setting the frames within which the data collection of the thesis was conducted.

3.1. Research design

In the Digttest development and application process, two versions of the test can be distinguished, which were the basis of four studies included in the thesis. The initial version of the Digttest was used in a pilot study of the DigiEfekt project and provided data for studies 2 and 3 of the thesis. The second version of the Digttest was used for the main study of the DigiEfekt project and provided data for studies 1 and 4 of the thesis. As the changes between the two versions were marginal and did not change the way DCL can be assessed, we found it suitable to use the data from both versions of the test for drawing the conclusions of the thesis (the changes made in each version of the Digttest can be found in the results section of the thesis). The overview of the studies, data and methods used in the thesis can be found in Figure 2.

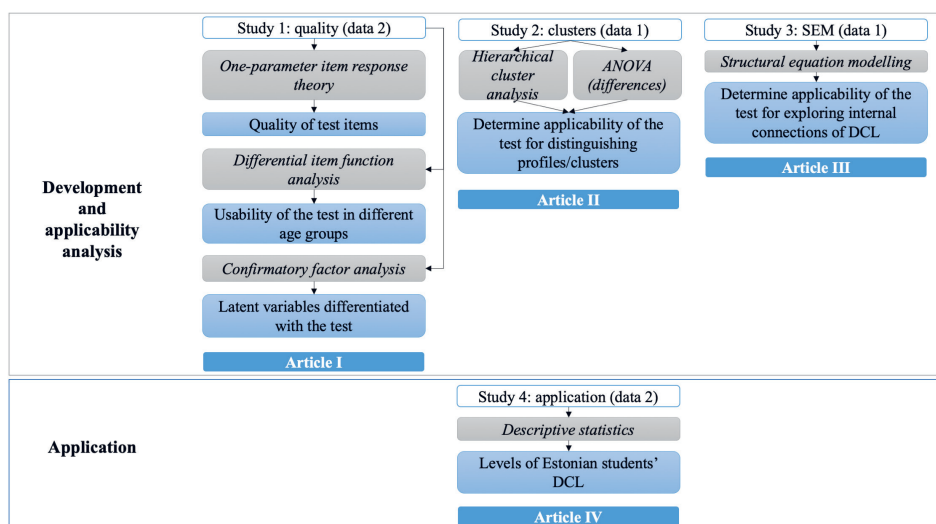


Figure 2. The overall design of the doctoral thesis

The thesis consists of four empirical studies, each addressing a distinct but complementary aspect of the Digitest development, applicability analysis and application phase. Together, the studies contribute to a coherent investigation of how students' DCL can be assessed in a way that is most beneficial for supporting teaching and learning processes.

The research design follows a multi-study approach. This allows addressing the research problem from different perspectives, combining instrument development, validation, profiling and structural analysis of DC. Rather than treating these as separate research strands, the studies are interconnected and collectively contribute to both a theoretical and practical understanding of DCL.

The thesis adopts a quantitative, empirical research design, supported by psychometric and statistical modelling approaches. The core of the research is the development and application of a performance-based assessment instrument (Digitest), designed to measure students' DCL across multiple dimensions.

Study I focuses on the development and validation of the Digitest, examining the quality of test items, fairness across grades and the dimensional structure of DCL. This study provides the methodological foundation for the subsequent analyses.

Study II investigates student clustering based on DCL, identifying distinct learner profiles. This study shifts the focus from variable-centred to person-centred analysis, enabling a deeper understanding of how competence manifests in different groups of learners.

Study III examines the internal relationships between DCL dimensions, using structural modelling to explore how different components of DCL interact. This study contributes to understanding the developmental structure of DCL.

Study IV provides an overview of students' levels of DCL, analysing differences across dimensions and grade levels. This study situates the findings within the broader educational context.

3.2. Research context

This section provides an overview of the national educational and policy context in Estonia, as well as the pedagogical and institutional settings of the studies, in order to situate the empirical findings of this doctoral thesis.

3.2.1. Digital education in Estonia

Estonia is widely recognised as a highly digitalised society, often described as a “digital education nation” (see Forsman et al., 2023; Mehisto & Kitsing, 2022, Pedaste & Bardone, 2023). This reputation is supported by strong national infrastructure, widespread access to digital technologies in schools and high student achievement in international assessments such as PISA. Digital technologies are well integrated into the education system, supported by national strategies, digital learning environments and long-term investments in educational technology.

In schools, digital tools are commonly used in everyday teaching and learning activities (Raave et al., 2024). Teachers and students have access to various digital platforms, learning management systems and online resources, which enable flexible organisation of learning, access to materials and opportunities for feedback and monitoring. DC is also emphasised as a general competence in the national curriculum, highlighting its importance across subjects and educational levels. DC is defined in the national curriculum as:

1. the ability to use evolving digital technologies to function in a rapidly changing society in learning, as a citizen, and in communication within communities;
2. to find and store information using digital tools and to evaluate its relevance and reliability;
3. to participate in digital content creation, including creating and using texts, images and multimedia;
4. to use appropriate digital tools and methods for problem solving; to communicate and collaborate in different digital environments;
5. to be aware of risks in digital environments and to protect one's privacy, personal data and digital identity;
6. and to follow the same moral and value principles in digital environments as in everyday life (Põhikooli riiklik õppekava, 2025).

At the same time, the Estonian context reflects ongoing development in how digital technologies are used pedagogically. While digital tools are widely adopted, their use varies across classrooms and teachers, depending on experience, confidence and instructional approaches. Recent developments, including the increased use of digital learning during the COVID-19 pandemic and the emergence of artificial intelligence in education, have further accelerated the role of digital technologies in learning processes.

In parallel with these developments, Estonia has initiated a large-scale national programme, the AI Leap (TI-Hüpe), which reflects a strategic shift toward integrating artificial intelligence into education. Launched in 2025 as a public-private initiative inspired by the earlier Tiger Leap programme, AI Leap aims to provide upper secondary students and teachers with access to AI-based learning tools alongside systematic professional development (Aru & Laak, 2025; Forsman et al., 2023). A central component of the initiative is the development of an AI-supported learning environment designed to scaffold students' learning processes, for example by supporting self-monitoring, retrieval practice and persistence, which could be considered one of the key mechanisms associated with effective learning. In addition, the programme includes continuous teacher training and collaborative support structures, emphasising adaptation, co-creation and critical engagement with AI in educational contexts. At the same time, the implementation of AI tools remains flexible and largely dependent on teachers' professional autonomy, resulting in variability in how and to what extent such

technologies are integrated into teaching and learning. This highlights the importance of systematic research and assessment approaches to better understand the actual impact of AI-driven innovations on students' learning processes and outcomes within the Estonian education system.

Overall, Estonia provides a well-established and forward-looking context for studying digital education, combining strong digital readiness with continuous development in teaching practices and educational innovation.

3.2.2. DigiEfekt study

The DigiEfekt study (May 2020-April 2023), led by the University of Tartu and funded by the Estonian Ministry of Education and Research (project code DIGIVARA5), was a national research and development initiative aimed at investigating the uses and aims of digital learning materials in Estonian general education schools as well as exploring the use of digital devices in the learning process. The study focused on understanding how digital tools are used in teaching and learning, how they support students' development and what factors influence the effectiveness of digital learning.

Within the DigiEfekt project, one important component was the development and validation of an assessment instrument for assessing students' DCL. This instrument, later referred to as the Digitest, was designed to assess different aspects of students' DCL in a systematic and scalable way. The primary aim within the project was to ensure that the instrument was psychometrically valid and suitable for large-scale data collection, allowing it to be used for analysing relationships between DC and various student, teacher and school-level factors.

The author of this doctoral thesis joined the DigiEfekt research team at a stage where an initial version of the Digitest had already been developed and piloted in schools. The author's role in the project focused on the further development, analysis and validation of the instrument, as well as contributing to the preparation of the final version used for data collection. Based on the collected data, the DigiEfekt project examined how students' DC is related to different background variables (e.g. characteristics of students, teachers and schools), and how it predicts other important educational outcomes, such as subject-specific competences (mathematics, science, language) and students' social-emotional skills.

While the validation of the Digitest was part of the DigiEfekt project, the broader research aims of this thesis extend beyond the scope of the project. In the DigiEfekt study, the focus was primarily on using the assessment instrument to support large-scale analysis of DC and its relation to other variables. In contrast, this doctoral thesis builds on the same data and instrument but addresses additional research questions that were not part of the original project design.

More specifically, the doctoral thesis focuses on three additional aspects: (1) examining the multidimensional structure of DCL; (2) identifying student profiles based on combinations of digital skills, knowledge and attitudes (clustering); and (3) analysing the internal relationships between different competence dimensions using structural modelling approaches.

These aspects, particularly student clustering and the analysis of internal connections between competence dimensions (SEM analysis), were not part of the DigiEfekt project but were developed as part of the doctoral research. Thus, the thesis represents both a continuation and an augmentation of the DigiEfekt study: it uses the same empirical basis but deepens the analysis by focusing on the structure, differentiation and development of DCL.

In summary, the DigiEfekt project provided the empirical foundation and validated measurement instrument, while the doctoral thesis builds on this foundation to contribute new theoretical and methodological insights into the assessment and understanding of DCL.

3.3. Sample

This thesis is part of a large-scale DigiEfekt study, which had several waves of data collection, using data from the pilot study and the first main study.

During the pilot phase, data was collected via a convenience sample of 426 students across four Estonian schools. The students were aged 9–15 years, including 224 males and 202 females. The sample consisted of 16 students from the third grade, 112 from the fourth grade, 56 from the fifth grade, 87 from the sixth grade and 155 from the eighth grade. The pilot study dataset is referred to as “Data 1” in this thesis and is used in Studies 2 and 3.

In the main study phase, the project had a purposeful sampling strategy in order to ensure maximum variation across schools. The school selection was based on three criteria: (1) students’ academic performance in national examinations and standard-determining tests; (2) school satisfaction as measured by a national survey; and (3) digital readiness that was assessed using multiple sources, including a national standard-determining DC test, schools’ self-evaluation data and relevant school satisfaction survey responses from staff and parents. These indicators were combined using a predefined selection matrix to ensure maximum variation across key characteristics relevant to the study. This approach enabled the inclusion of schools representing diverse profiles in terms of academic achievement and digital readiness. For two extreme categories within the matrix (the ones where all three indicators were all either at a very high or a very low level), two schools were selected in order to allow a more focused examination aligned with the objectives of the study.

In the main study, 836 students from 13 Estonian schools participated. Of these, 316 students were from the third grade (aged 9–10 years), 291 from the sixth grade (aged 12–13 years) and 229 from the ninth grade (aged 15–16 years). The data from this main study is referred to as “Data 2” in this thesis and is used in Studies I and IV.

3.4. Data collection and data analysis

This thesis comprises four empirical studies, conducted between September 2021 and March 2022. This section outlines their respective data collection and analysis procedures.

3.4.1. Data collection

Studies I and IV involved large-scale data collection using the DigiTest as part of the DigiEfekt study. The test was administered in the national Examination Information System (EIS) during regular school time using various digital devices (desktop computers, laptops, tablets). Students completed a multidimensional test consisting of different item types (e.g. multiple-choice, sequencing, open-ended tasks). The procedure allowed skipping difficult items, which revealed patterns such as lower engagement with programming tasks among younger students and some missing responses in later sections (especially attitudes), partly due to time constraints and declining motivation.

In studies II and III the test was administered electronically during regular lessons without external incentives, and completion time was approximately one lesson (45 minutes). The instrument assessed ten dimensions of DC through a combination of knowledge/skills tasks and Likert-scale attitude items. As in Studies I and IV, students could not return to previous questions but could skip difficult ones.

3.4.2. Data analysis

Study I applied a multi-phase analytical approach. First, item quality was evaluated using the Rasch (1PL IRT) model to assess item difficulty, fit, discrimination and scale targeting. Second, Differential Item Functioning (DIF) analysis was conducted to examine fairness across grades. Third, Confirmatory Factor Analysis (CFA) (and where needed Exploratory Factor Analysis) was used to validate the dimensional structure of the DigiTest, supported by fit indices (e.g. RMSEA, CFI, TLI). A composite reliability score was also calculated for all dimensions theoretically differentiated in the DC framework.

Study II focused on identifying student profiles using hierarchical cluster analysis (Ward's method). A dendrogram guided the selection of clusters, and ANOVA with eta squared was used to determine differences between clusters and the relative importance of competence dimensions within each cluster.

Study III employed Structural Equation Modelling (SEM) to examine relationships between latent variables. Specifically, the analysis tested how attitudes predict operational skills and how individually developed skills (e.g. operational, programming, creation) predict more socially-oriented competencies (e.g. communication, legal behaviour). Model fit was evaluated using standard indices (RMSEA, CFI, TLI, WRMR, χ^2/df).

Study IV used non-parametric statistical analysis due to non-normal data distribution (Kolmogorov–Smirnov test). Descriptive statistics (means with confidence intervals) were calculated to characterise students' competence levels. Differences between dimensions and grades were analysed using Wilcoxon tests (within groups), Kruskal–Wallis tests (between groups) and Mann–Whitney U tests (pairwise comparisons). All analyses were conducted using SPSS.

3.5. Ethical considerations

All three studies were conducted in accordance with established ethical principles for educational research involving human participants. The research design and procedures were reviewed and approved by the Ethics Committee for Human Research at the University of Tartu (approval number 382/T-6, granted on 11 October 2023).

Participation in the study was voluntary for all participants, including schools, teachers and students. Prior to participation, informed consent was obtained from all teachers and students, as well as from students' legal guardians. Participants and their guardians were provided with clear information about the purpose of the study, procedures and contact details for further inquiries. Participants were informed of their right to withdraw at any time without any negative consequences, and they could request the deletion of their data from the database.

The study posed minimal risk to participants, as it involved standard educational assessment activities without any harmful procedures. No financial or material incentives were offered, avoiding any potential pressure to participate.

To ensure data protection and confidentiality, personal data was initially collected (e.g. personal identification codes) for linking datasets and longitudinal tracking but were subsequently pseudonymised. Each participant was assigned a unique code, and the key linking personal data to research data was accessible only to the data manager. Researchers conducting analyses worked exclusively with pseudonymised data. Personal data was stored separately from research data, and access was restricted to authorised personnel only. At the end of the DigiEfekt project, all data was anonymised.

Data was used solely for research purposes and reported only in aggregated form, ensuring that individual participants could not be identified. Participants also had the option to consent separately to linking their data with national educational databases, and refusal did not prevent participation in the study.

Finally, all stakeholders (schools, teachers, students and parents) had the right to receive generalised feedback about the study results, while no individual-level results were disclosed, thereby preventing any potential labelling or marginalisation of participants.

4. RESULTS

This section provides an overview of the main findings according to the research questions. First, this section provides results related to the Digitest development and applicability analysis phase, addressing test creation and evaluation, as well as its applicability. Second, it describes the results of the application phase of the Digitest, where levels of Estonian primary and lower secondary school students' learning-related digital skills and attitudes were discovered. All the findings are presented in more detail in **Articles I–IV**.

4.1. Development and applicability analysis phase of the Digitest

The main assignments for the development and applicability phase were to design a test for assessing primary and lower secondary school students' DCL and evaluate its quality. Additionally, the phase aimed to determine how the test could enable student clustering and how its various dimensions were related. In the following section, the development and validation process of the Digitest is explained and research questions 1 and 2 will be addressed.

4.1.1. Development and validation of the Digitest

The initial version of the Digitest items were developed for covering dimensions defined based on the synthesis of dimensions described by Pedaste et al. (2021) and Adov (2022) by the group of three educational technology experts. Further explanation of the test compilation can be found in **Article I**. The first test version had 89 items for assessing students' DCL related attitudes, skills and knowledge in 12 initial dimensions: performing operations with digital tools, communicating in the digital world, creating digital materials, programming digital content, assessment of coping in digital environments, comparative assessment of DC, legal behaviour in the digital world, protecting oneself and others in the digital world, attitudes towards behaviour, behavioural intention, perceived control and social aspects.

The first phase of the pilot study was conducted using a digital test administered through the Estonian national Examination Information System (EIS). The instrument combined attitude, performance-based and self-assessment components to capture different aspects of DCL. A total of 185 students participated. Both automated and human scoring procedures were used. Inter-rater reliability was evaluated using Cohen's unweighted kappa. Acceptable agreement thresholds were applied, and scoring criteria were refined where necessary. Based on the analysis, a small number of items were removed or revised to improve construct validity.

Item quality was examined using IRT analysis and confirmatory factor analysis, revealing strong overall test indicators were strong (item reliability = 0.91; person

reliability = 0.99; mean difficulty = 0.07). Differential item functioning (DIF) analysis across age groups showed that most items functioned similarly, although some age-related differences were identified and considered in item selection. For the attitude scale, items with satisfactory fit statistics and discrimination were retained for the second version. To ensure that each theoretical dimension was represented by at least three items, additional statements were selected based on inter-item correlations and factor loadings. One attitude item was reworded, and one new item was added.

For the skills and behaviour section, items were selected based on IRT fit, discrimination, DIF results, inter-item correlations and factor model fit. As a result, 19 items were retained unchanged, 6 were revised and 12 were removed. One new task was added to strengthen coverage of the targeted dimension. Predictive validity analysis showed that most test dimensions correlated at least 0.30 with students' self-assessed DC, except for the social aspects of attitudes (0.03) and programming (0.21), which were flagged for further refinement in subsequent development phases.

The second pilot (n = 426) re-ran the Digitest in the EIS environment using a shortened, revised instrument: 18 attitude statements (1–6 scale), 27 skill/behaviour items (task-specific scoring) and 13 self-assessment items. Scoring was mixed: computer-scored items, 13 fully human-rated items and 4 hybrid items (raters could override computer marks when answers were correct but presented in an unexpected format). Inter-rater work from phase 1 allowed a single rater to complete human/hybrid scoring in phase 2. Psychometric checks (WinSteps IRT and CFA) supported the instrument: mean difficulty ≈ -0.14 , item reliability = 0.87, person reliability = 0.99 and DIF analyses showed items were generally invariant across class/age groups. Some dimensions nevertheless showed low predictive correlations with self-assessment (notably social attitude, some attitude subscales, programming and protection), so these remain targeted for refinement.

Decisions from the phase-2 analyses led to targeted item changes and final selection rules: one human-rated open subtask was removed because responses reflected reading comprehension problems rather than the intended skill; several items with poor fit or low loadings were excluded from the final test; and the factor models (10 factors overall; 6 factors for skills; 4 for attitudes) produced good fit after these removals. Based on IRT, inter-item correlations and CFA, the scoring models for particular items were updated and the attitude content to improve coverage was adjusted.

Key changes between the second pilot study and the main study Digitest versions were minor: (1) assessment rubrics were updated; (2) two items for assessing social aspects were created in order to achieve a dimension that is measurable through four items; (3) two items assessing attitudes were removed from the test; (4) four items assessing skills and knowledge were removed from the test. Overall, all the dimensions in the main study were assessed with three items in order to conduct further analysis. **Article I** details the items and their theoretical foundations.

4.1.2. Usability of the Digitest for assessing students' digital competence for learning

An empirical study (Study 1) was conducted to answer the first research question and to find out what evidence supports the use of the Digitest for assessing students' learning-related digital skills, knowledge and attitudes.

The findings indicate that the Digitest is usable for assessing students' DCL across grades and dimensions. First, item difficulty functions appropriately across grade levels: no substantial differential item functioning was detected, meaning the test items do not systematically advantage or disadvantage specific age groups. While some items were relatively easier or harder for certain grades, these differences were not extreme, and overall targeting of students' ability levels was adequate. Importantly, overlap in performance between younger and older students further supports the instrument's suitability for assessing a broad competence range, although some items may require refinement for younger learners due to developmental factors such as reading comprehension.

Second, the construct validity of the Digitest is supported through its latent structure. The instrument captures DCL via nine sub-dimensions that cluster into higher-order factors reflecting attitudes and skills/behaviours. Although alternative higher-order models (one- or three-factor) are also plausible, the two-factor model showed the most stable parameter estimates, indicating that the test can meaningfully distinguish between key dimensions of competence.

Overall, the Digitest demonstrates sufficient psychometric quality for assessing students' digital skills, knowledge and attitudes. However, it also highlighting areas for further refinement, particularly in item design for younger students and in clarifying the higher-order structure of DCL. Detailed results of the quality indices of the 1PL IRT analysis, IRT DIF-analysis and CFA model fit indices can be found in **Article I**.

4.1.3. Applicability of the Digitest for designing digital learning processes

Two empirical studies (Study II and Study III) cover the scope of the second research question addressing the applicability of the Digitest. More specifically, determining how assessment results from the Digitest can be used to support the design of digital learning processes.

First, Digitest's applicability for student clustering was explored with hierarchical cluster analysis using the Ward method. According to the data, four meaningful student clusters concerning DCL could be established (see Figure 3).

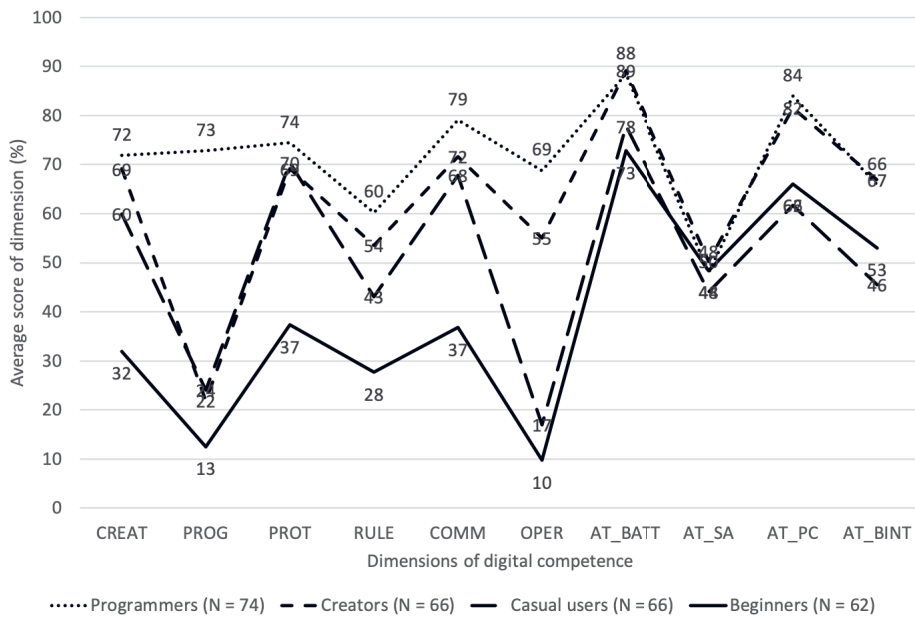


Figure 3. Student clusters based on their level of DCL (CREAT – creating digital materials, PROG – programming digital content, PROT – protecting oneself and others in the digital world, RULE – following the rules in the digital world, COMM – communicating in the digital world, OPER – performing operations with digital tools, AT_BATT – behavioural attitudes, AT_PC – perceived control, AT_SA – social aspects, AT_BINT – behavioural intention (see Article II)

The clusters are as follows: (1) Programmers – high performance across all dimensions; strongest in programming-related knowledge and skills; mostly positive attitudes. (2) Creators – strong in creating digital content; above-average operational and communication skills; positive attitudes; weaker than programmers in programming. (3) Casual users – average knowledge and communication/creation skills but low operational skills; moderate attitudes; limitations in basic technical execution. (4) Beginners – low performance across most skills and knowledge dimensions; only average attitudes; lack foundational operational and

programming skills. Detailed findings from the cluster analysis can be found in **Article II**.

Secondly, the SEM results strengthen evaluation of the applicability of the Digitest for designing digital learning processes by showing that the instrument does not only measure separate dimensions but also captures meaningful relationships between them.

Regarding the applicability and development of DCL, attitudes play a limited direct role in predicting DCL knowledge and skills development. Furthermore, the model reveals a developmental structure of DCL. Operational skills function as a foundational layer that predicts the development of more advanced, individually developed skills – specifically programming and digital content creation. These, in turn, predict competencies that require social contexts, such as communication, legal behaviour and protection in digital environments. The strongest relationship appears between content creation and protection, indicating that engagement in creating digital materials is closely linked to understanding issues of safety and ownership. **Article III** details the internal connections determined by the SEM analysis.

Overall, the Digitest enables identification of both hierarchical progression (from operational to higher-order skills) and functional connections between competence dimensions, making it applicable not only for assessment but also for informing the design and sequencing of digital learning processes.

In order to further validate the Digitest's applicability for student clustering and interconnectedness analysis, additional analyses were conducted with "Data 2" (data used for Articles I and IV; Articles II and III are based on "Data 1"). The analysis resulted in similar results, as students were divided into four similar clusters, as seen in **Article II**.

As reported in **Article III**, exploring the interconnectedness of the Digitest dimensions revealed that individually acquired skills – such as operational, programming and creative – predict those that require a social setting to develop, including legal behaviour, protecting oneself and others and communication. The crucial emphasis on having operational skills as a basis of other skills was also reconfirmed. However, contradictions regarding the role of attitudes in DCL development remain, requiring further investigation.

4.2. Application phase of the Digitest

Empirical study IV directly addressed the third research question – the level of Estonian primary and lower secondary school students' DCL – by gathering data during the Application phase. The results show that the students' DCL is uneven across various digital competence dimensions (see Figures 4 and 5).

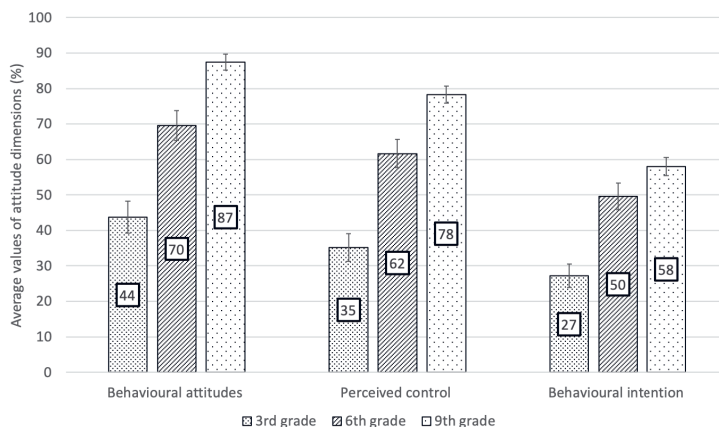


Figure 4. Mean scores of the attitude dimensions assessed with the Digitest, presented on a percentage scale with 95% confidence intervals (from Article IV)

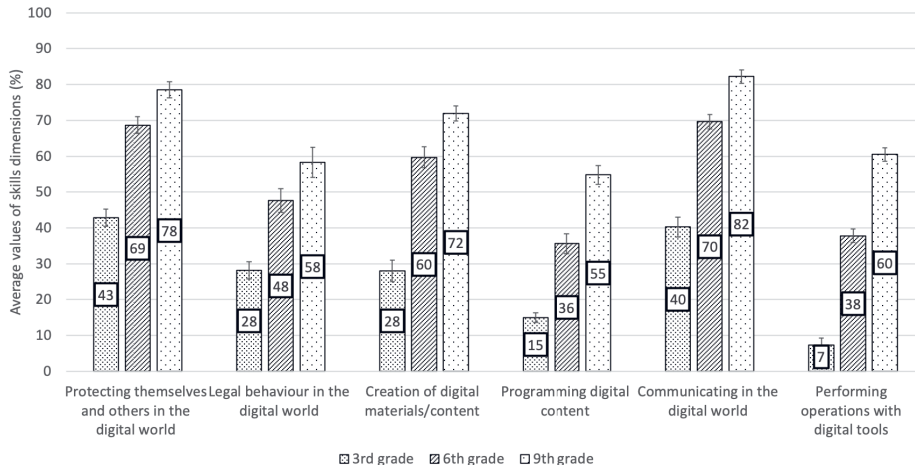


Figure 5. Mean scores of the digital skills dimensions assessed with the Digitest, presented on a percentage scale with 95% confidence intervals (from Article IV)

Overall, students perform best in communication and digital content creation, where especially older students demonstrate a solid understanding of collaboration tools and can identify relevant aspects of digital materials. However, younger students' responses are often more superficial and influenced by limited experience and reading comprehension.

Operational skills and programming are the weakest areas, particularly among younger students. Even basic technical tasks (e.g. file management, QR code creation, image editing) are challenging, and programming-related tasks pose difficulties even for older students, probably due to limited prior exposure.

In terms of safe and responsible behaviour, students show relatively good knowledge of protecting themselves and others (e.g. device security, health during screen use), but significantly weaker understanding of legal and ethical aspects (e.g. copyright, licensing, appropriate content use). Misconceptions are common, including acceptance of piracy for personal use and uncertainty about proper referencing.

Regarding attitudes, students are not uniformly positive. Behavioural intention to use digital tools for learning is the weakest attitudinal dimension. Students are divided between preferring digital and non-digital learning environments, and there are indications of students' experiencing cognitive overload when multiple digital tools are used. At the same time, fear of using digital technologies is generally low. Article IV details the findings on Estonian students' DCL.

5. DISCUSSION

This doctoral study was motivated by the need for a valid and practically applicable way to assess students' digital competence for learning. Within the study, the Digitest was developed and psychometrically validated, its applicability for educational practice was examined through clustering and structural analyses of DCL dimensions, and the instrument was applied in school settings to provide an overview of Estonian primary and lower secondary school students' digital knowledge, skills and learning-related attitudes. Taken together, this study not only addresses the long-standing gap in valid DCL assessment tools (Godaert et al., 2022; Siddiq et al., 2016), but also extends research by linking assessment, profiling and structural modelling of DC. Across the conducted studies, several key findings emerge regarding the measurement of DCL, the diversity of student competence profiles, the internal structure of DCL and the overall level of students' skills and attitudes.

First, the results confirm that DCL can be meaningfully assessed as a multi-dimensional construct using the Digitest. The findings from Study I demonstrate that the instrument is psychometrically sound and suitable for assessing students across a relatively wide age range. The test demonstrated appropriate distribution of item difficulty and minimal differential item functioning across grades, supporting fairness and comparability of measurement (cf. Siddiq et al., 2016). Furthermore, the identified structure – nine sub-dimensions grouped into broader attitudinal and skills-related components – supports the conceptualisation of DCL as consisting of both cognitive and motivational aspects, aligning with competence theory that integrates knowledge, skills and attitudes (Guitert et al., 2021; Ferrari, 2012; Weinert, 2001; Westera, 2001). However, some ambiguity remains regarding the higher-order structure, suggesting that DCL may be represented through one, two or three broader dimensions depending on the context. This reflects a broader issue in DC research, where multidimensionality is theoretically assumed but empirically unstable or highly correlated across dimensions (Ihme et al., 2017; Jin et al., 2020). This highlights both the complexity of the construct and the need for continued theoretical and empirical refinement.

Second, the findings from Study II reveal that students are not a homogeneous group according to their DCL but can instead be meaningfully grouped into distinct profiles. Four clusters (programmers, creators, casual users and beginners) were identified, each representing qualitatively different combinations of skills, knowledge and attitudes. This finding aligns with prior clustering studies in ICT use and competence (Scherer et al., 2017) but extends them by demonstrating that differences are not only quantitative (high–low) but structural (different competence configurations). Notably, a relatively large proportion of students demonstrated high competence, which may reflect changes in digital learning experiences, particularly in the context of the COVID-19 pandemic. This interpretation is consistent with evidence that pandemic-related remote learning accelerated both digital exposure and competence development (Gerard et al.,

2021; Lepp et al., 2021). At the same time, the presence of lower-performing clusters indicates that DC cannot be assumed and must be systematically developed.

Third, Study III provides insight into the relationships between different dimensions of DCL, highlighting a developmental structure. The results suggest that operational skills form a foundation for more advanced competences, such as programming and content creation, which in turn support competences requiring social interaction, including communication, legal behaviour and protection in digital environments. This hierarchical pattern is consistent with prior models of DC development, where foundational technical and informational skills enable higher-order competences (Iordache et al., 2017; Trigueiro et al., 2026). This finding refines rather than fully contradicts prior research, which has consistently shown that attitudes influence behaviour primarily through behavioural intention (Davis, 1989; Ajzen, 2012), rather than directly determining competence levels. Thus, the results are theoretically consistent with the Technology Acceptance Model and Theory of Planned Behaviour, where behavioural intention acts as a mediator between attitudes and action. Overall, this suggests that competence development is primarily driven by skill acquisition and practice, while attitudinal factors play a more indirect, enabling role.

Finally, the results from Study IV provide an overview of students' actual levels of DCL. The findings indicate that students perform relatively well in areas such as communication and digital content creation, while operational skills and especially programming remain weaker. This pattern is consistent with international findings showing stronger performance in communication-related competences and weaker performance in advanced or technical domains (Godaert et al., 2022). In addition, students demonstrate stronger knowledge in protecting themselves in digital environments than in understanding legal and ethical aspects, such as copyright and responsible content use. This imbalance reflects a well-documented gap in DC assessment and development, where safety awareness is more frequently addressed than legal and ethical understanding (Siddiq et al., 2016). Attitudes towards digital learning are mixed: while fear of using digital technologies is generally low, students do not consistently prefer digital learning environments, and some experience cognitive overload when multiple tools are used. This finding is in line with research showing that increased use of digital tools does not automatically lead to positive learning experiences, particularly when cognitive load is not managed (Tammets et al., 2021). A notable discrepancy is observed between students' perceived and actual competence, with a tendency to overestimate their skills, confirming earlier evidence on self-assessment bias in DC (Porat et al., 2018; Vonkova et al., 2021).

Taken together, these findings indicate that DCL is a complex construct with multiple interconnected dimensions that develop progressively over time. The level of students' DC varies significantly between students and across dimensions. While the Digitest provides a strong foundation for assessing DCL, the results also highlight the need for targeted support, differentiated instruction and further refinement of both theoretical models and assessment tools. Importantly,

the study demonstrates that assessment should not only measure competence levels, but also reveal structural differences and developmental pathways, which are essential for designing effective digital learning interventions.

5.1. Implications

The findings of this study have several important implications for educational practice, policy and future research, particularly in light of the growing importance of DCL in contemporary education. By providing empirical evidence on the structure, assessment and development of students' DCL, the study offers a basis for more informed decision-making and targeted interventions. The implications can be considered across three main perspectives: supporting teachers in designing and implementing effective digital learning processes, guiding policy-makers in developing coherent and evidence-based educational strategies, and identifying key directions for further research to refine both the theoretical framework and the assessment instrument.

5.1.1. Implications for practitioners

The results demonstrate that the Digitest provides a valuable, evidence-based tool for supporting the teaching and learning of DCL. Its main strength lies in enabling diagnostic and detailed assessment: teachers can identify students' strengths and weaknesses across skills, knowledge and attitudes, and use multidimensional results (sub-dimensions and latent variables) to give targeted, domain-specific feedback rather than relying on overall scores. However, its use with younger students requires caution, as some items may impose additional reading or cognitive demands.

A central implication is the need for differentiated and personalised instruction. The identified student profiles (beginners, casual users, creators, programmers) reflect qualitatively different competence patterns, not just levels. This means teaching should be adapted accordingly: beginners need foundational operational and programming skills; casual users require strengthening of basic operational skills and support for learning-related attitudes; creators benefit from more advanced technical and programming tasks; and programmers should be challenged with complex tasks to sustain development.

The findings also highlight the importance of structured progression in learning design. Instruction should follow a developmental sequence where operational skills form the foundation for programming and content creation, which in turn support more socially-oriented competencies (e.g. communication, legal behaviour, online safety). While improving attitudes alone is insufficient, skill development must remain the primary focus, with attitudes (especially behavioural intention) fostered alongside active and meaningful engagement in digital tasks.

From a pedagogical perspective, integrated and authentic task design is essential. Learning activities should combine creation, collaboration and responsible use of digital technologies to reflect the interconnected nature of DC and to support transfer across contexts.

Finally, several critical gaps need to be addressed in practice. Teachers should not assume that students possess basic operational skills, as these often remain underdeveloped. There is also a clear need to strengthen legal and ethical understanding, particularly regarding copyright and responsible content use. In addition, excessive use of multiple digital tools can create cognitive overload and hinder learning, suggesting the need for more deliberate and streamlined use of digital environments. Instruction should also account for younger learners' developmental limitations and explicitly support students in aligning their perceived competence with actual performance, as self-assessments tend to overestimate abilities.

Overall, the Digitest is most useful when it informs targeted, developmentally sequenced and differentiated instructional design, rather than being used solely as an assessment tool.

5.1.2. Implications for policymakers

A key contribution of this study for policymakers is the availability of a psychometrically validated instrument (Digitest) for monitoring students' DCL across educational levels. Such a tool enables evidence-informed decision making, allowing curriculum development to be guided by actual student performance. The multidimensional results highlight uneven competence development, which can inform more balanced curriculum priorities.

The fact that the same instrument functions across age groups also creates future opportunities for longitudinal monitoring, supporting a more coherent understanding of how DCL develops over time. However, before large-scale implementation, further refinement is needed, particularly regarding younger students in order to avoid issues where lower scores are due to poor reading comprehension and/or cognitive overload.

The findings also challenge linear, age-based assumptions in curriculum design. The presence of distinct student profiles across grades indicates that competence development is heterogeneous, requiring policies that support differentiated teaching rather than uniform progression. This includes providing teachers with appropriate resources, training and assessment tools to address diverse learner needs.

A consistent implication across results is the need to strengthen foundational competencies, especially operational and programming skills, at earlier stages of education. These foundational skills underpin more advanced and socially-oriented competencies, suggesting that curricula should follow a structured, hierarchical progression rather than fragmented exposure to digital tools.

At the same time, the study calls for a rebalancing of policy emphasis. While attitudes and motivation are often highlighted, the results indicate that skill

development pathways are more critical for competence growth. Similarly, there is a clear need to place greater focus on digital ethics and legal understanding, as students demonstrate significant misconceptions in these areas.

The findings also question the assumption of students as “digital natives” (Prensky, 2001). Although some students demonstrate high competence, substantial gaps remain, reinforcing the need for systematic support rather than reliance on informal learning. Post-pandemic developments suggest that increased exposure to digital learning may have improved competence but also introduced variability linked to teaching practices, underscoring the importance of teacher support and instructional quality.

Finally, the study highlights the limitation of relying on self-reported competence. Policymaking should therefore prioritise performance-based assessment approaches, such as the Digitest, to obtain a more accurate picture of students’ abilities.

In conclusion, effective policy should move towards a data-informed, age- and development-specific and differentiated approach to DC, grounded in validated assessment, strengthened foundational skills and integrated treatment of technical, cognitive and social dimensions of learning with digital technologies.

5.1.3. Implications for further research

The current doctoral study provides a validated and empirically grounded framework of DCL that can be used in both research and practice. The established framework serves as the basis for test development, conceptualizes DCL as a multidimensional construct consisting of nine specific dimensions that capture key aspects of learning with digital technologies. Importantly, these dimensions are not isolated but can be meaningfully organised into broader domains reflecting attitudes and skills (including knowledge and behaviour). This structure aligns with established theoretical understandings of competence and offers a comprehensive basis for analysing and supporting students’ DC development in educational contexts.

In addition, the Digitest itself can already be used as a practical assessment tool for measuring students’ DCL across these nine dimensions. Its design allows for the simultaneous assessment of multiple aspects of DCL, providing a nuanced profile of learners rather than a single aggregate score. This makes it particularly useful for identifying specific strengths and weaknesses, supporting differentiated instruction and informing targeted interventions. While further refinement is needed, especially for younger learners and for covering emerging competence areas (e.g. artificial intelligence), the current version of the Digitest already represents a functioning, research-based instrument that can support both diagnostic assessment and the systematic study of DCL.

In addition, findings suggest several directions for further research related to instrument refinement, theoretical clarification and deeper understanding of competence development.

First, there is a clear need for further development of the Digitest itself. This includes refining item design to improve suitability for younger students and reduce construct-irrelevant difficulty (e.g. reading-related cognitive load). Furthermore, competing models (one-, two-, three-factor) require additional empirical testing to determine the most meaningful representation of DC. Moreover, validation across different contexts and populations is necessary to ensure measurement invariance in order to make longitudinal DCL assessment possible. Longitudinal research is needed to examine how DC evolves over time, how students move between competence clusters and whether the proposed developmental pathways (from operational skills to higher-order and social competencies) hold causally.

Secondly, the results highlight the importance of understanding underlying mechanisms and relationships. Further research should investigate the drivers of cluster membership (e.g. teaching practices, access, frequency of use) and clarify causal relationships between attitudes, foundational skills and higher-level competencies. Although attitudes showed limited direct effects, their potential indirect role (e.g. through engagement) warrants deeper investigation. Model refinement is also needed, particularly for weaker or non-significant relationships.

Thirdly, there is a need to connect assessment with instructional practice. Research should explore how Digitest-informed instructional design impacts student learning, including the effectiveness of interventions tailored to different competence profiles. This aligns with design-based research approaches that test the practical application of identified competence structures.

An additional important direction for future research concerns the continuous development of the Digitest in response to rapid technological change. DC is not a static construct, and the increasing integration of artificial intelligence (AI) in learning environments requires the expansion of existing assessment frameworks. Future work should therefore explore how AI-related skills, knowledge and attitudes, such as understanding AI-supported tools, critical evaluation of AI outputs, ethical use and responsible interaction, can be incorporated into the Digitest. This implies not only adding new item types but also reconsidering the underlying competence model to ensure it remains relevant in evolving digital learning contexts. Without such ongoing adaptation, there is a risk that the instrument will lag behind actual educational practices and fail to capture emerging dimensions of DC.

Finally, several broader issues require attention. These include investigating the discrepancy between students' self-perceived and actual competence, examining the role of teachers and instructional practices in shaping both skills and attitudes and analysing how different digital learning environments (e.g. use of multiple tools) influence competence development.

Overall, future research should move beyond validation towards explanatory and intervention-focused studies, ensuring that assessment results are meaningfully connected to learning processes and outcomes.

6. CONCLUSIONS

This doctoral thesis addressed the development, validation and application of an assessment instrument for measuring students' DCL in primary and lower secondary education. The study was organised into two phases: (1) Development and applicability analysis, and (2) Application, both guided by specific research questions.

The first phase focused on creating and validating the Digitest as a multi-dimensional assessment instrument. In response to RQ1, the findings demonstrate that the Digitest is suitable for assessing students' DCL across multiple dimensions, including skills, knowledge and attitudes. The instrument showed acceptable psychometric properties, appropriate item difficulty across grade levels, and no major bias between age groups. Furthermore, the results support the conceptualisation of DCL as a structured, multidimensional construct, where distinct yet interrelated components can be meaningfully assessed.

In addressing RQ2, the study extends beyond measurement by examining how the assessment results from the Digitest can be used to support the design of digital learning processes. The findings indicate that the instrument provides actionable insights for educational practice in several ways. First, the multidimensional structure allows educators to identify specific strengths and weaknesses rather than relying on overall scores. Second, clustering analysis revealed qualitatively different student profiles, suggesting that learners cannot be adequately described by a single continuum of competence. Instead, differentiated instructional approaches are needed to support diverse competence configurations. Third, the analysis of internal relationships between competence dimensions demonstrated that DCL develops in a structured manner, where foundational skills (e.g. operational skills) support the development of more complex and socially-oriented competences. These findings provide a basis for sequencing learning activities and designing more effective digital learning environments.

The second phase focused on applying the Digitest to examine the levels of DCL among Estonian students. In response to RQ3, the results indicate that students' DCL is unevenly developed across dimensions. While certain competences, such as communication and content creation, appear relatively strong, others, particularly operational skills, programming and understanding the rules in digital world, remain less developed.

Moreover, differences between grade levels indicate developmental progression but also highlight that younger students may face challenges related to reading comprehension and task complexity, which should be considered in both assessment and instructional design.

Taken together, the results of this thesis contribute to both research and practice. From a theoretical perspective, the study provides empirical support for understanding DCL as a multidimensional and internally structured construct. From a methodological perspective, it offers a validated assessment instrument that combines performance-based tasks with attitudinal measures. From a practical

perspective, the findings demonstrate how assessment can inform differentiated instruction, support the design of digital learning processes, and provide insights into students' competence development.

Overall, the thesis highlights the importance of moving from general assumptions about students' digital readiness toward systematic, evidence-based assessment and targeted pedagogical interventions.

7. LIMITATIONS OF THE STUDY

Some limitations should be considered when interpreting the findings of this doctoral study.

First, the four studies are based on samples from Estonia, which may limit the generalisability of the results to other educational contexts. As DCL is influenced by national curricula, teaching practices and technological infrastructure, similar studies in other countries may yield different results.

Second, some limitations are related to the assessment instrument (the Digitest). Although the instrument is psychometrically validated, certain items may still require refinement. In particular, some tasks may not be fully contextualised within learning situations, potentially measuring general DC rather than learning-related competence.

Third, data quality issues emerged during test administration, especially among younger students. The possibility to skip questions led to missing data, particularly in more demanding tasks and in the attitude section located at the end of the test. These missing responses may reflect multiple factors, including limited skills, lower motivation, time constraints or reading difficulties. This suggests that test length, structure and administration conditions may influence the results.

Fourth, the assessment of attitudes relied on self-report measures, which may not fully capture students' actual dispositions or behaviours. Previous research and the current findings indicate that students tend to overestimate their competence, which raises concerns about the validity of self-reported data. Complementary methods (e.g. observations or alternative measurements) would strengthen the assessment of attitudinal aspects.

Fifth, some methodological limitations are related to sample size and selection in individual studies. For example, the clustering analysis was conducted on a relatively limited sample, and participation was voluntary, which may have resulted in overrepresentation of more motivated or digitally active schools. This may affect the identified cluster structure and its distribution.

Finally, although structural relationships between competence dimensions were identified, these findings do not confirm causal pathways. Longitudinal and experimental studies are needed to better understand how DCL develops over time and how different factors influence this process.

Overall, while the studies provide insights into DCL, the results should be interpreted with these limitations in mind, and further research is needed to strengthen and extend the findings.

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SUMMARY IN ESTONIAN

Digitesti loomine, valideerimine ning rakendamine

Digipädevus on tänapäeva ühiskonnas kujunenud üheks keskseks pädevuseks, mis mõjutab nii õppimist, tööelu kui ka ühiskonnas osalemist. Haridusvaldkonnas ei tähenda digipädevus üksnes tehniliste oskuste omandamist, vaid hõlmab endas ka teadmisi, hoiakuid ja võimet kasutada digivahendeid tähenduslikult õppimise toetamiseks (Guitert et al., 2021; Ilomäki et al., 2016). Sellest tulenevalt rõhutatakse üha enam digipädevuse arendamist juba põhikooli algusjärgus, et toetada õpilaste valmisolekut õppida digitaalselt rikastatud keskkondades (European Commission, 2019; Ma & Ismail, 2025). Samas ei kujune digipädevus iseenesest, vaid eeldab süsteemset ja sihipärast arendamist haridusprotsessis, mis omakorda eeldab usaldusväärseid viise selle hindamiseks ja arengu jälgimiseks.

Samas näitab varasem teaduskirjandus, et hoolimata digipädevuse olulisusest on selle hindamine endiselt probleemne. Paljud olemasolevad hindamisvahendid tuginevad enesehinnangule, mis ei pruugi kajastada õpilaste tegelikku digipädevust (Porat et al., 2018; Siddiq et al., 2016). Lisaks keskenduvad mitmed testid vaid üksikutele digipädevuse aspektidele ega paku terviklikku ülevaadet õpilaste oskustest, teadmistest ja hoiakutest (Godaert et al., 2022; Mattar et al., 2022). Samuti on vähe vahendeid, mis võimaldaksid hinnata nooremate õpilaste digipädevust, kuigi just selles vanuses pannakse alus edasisele arengule (Godaert et al., 2022; Siddiq et al., 2016). See loob olukorra, kus õpetajatel ja hariduspoliitika kujundajatel puudub piisav ülevaade õpilaste tegelikust pädevusest ning sellest, kuidas neid sihipäraselt arendada.

Veel üheks oluliseks probleemiks on digipädevuse käsitlemine ühe üldise oskusena, kuigi teoreetilised mudelid kirjeldavad seda mitmemõõtmelise konstruktiona, mis hõlmab omavahel seotud teadmisi, oskusi ja hoiakuid (Ferrari, 2013; Vuorikari et al., 2026). Empiirilised uuringud ei ole siiski üheselt kinnitanud digipädevuse mitmemõõtmelisust, kuna erinevad dimensioonid kipuvad olema tugevalt korreleerunud või avalduvad ühe üldfaktorina (Ihme et al., 2017; Jin et al., 2020). Selline vastuolu teooria ja empiiriliste tulemuste vahel raskendab nii hindamisvahendite arendamist kui ka saadud tulemuste tõlgendamist ja rakendamist õppeprotsessis.

Lisaks on vähe teadmisi selle kohta, kuidas erinevad digipädevuse komponendid omavahel seostuvad ning kuidas neid teadmisi saaks kasutada õppimise kavandamisel. Kuigi mitmed uuringud viitavad, et baasoskused, nagu operatsioonilised ja info-otsingu oskused, loovad aluse keerukamate pädevuste kujunemiseks (Iordache et al., 2017; Trigueiro et al., 2026), on nende seoste empiiriline uurimine endiselt piiratud. Samuti on piiratud arusaam sellest, millised on õpilaste tüüpilised digipädevuse profiilid ning kuidas need mõjutavad õppimist digivahenditega ja -keskkondades (Scherer et al., 2017; Karakoyun & Başaran, 2021). Selliste teadmiste puudumine piirab võimalusi kujundada tõendus põhiseid ja diferentseeritud õpistrateegiaid, mis arvestaksid õpilaste erinevate vajaduste ja arengutasemetega.

Kokkuvõttes osutab olemasolev kirjandus selgele vajadusele arendada terviklikke, mitmemõõtmelisi ja empiiriliselt valideeritud hindamisvahendeid, mis võimaldaksid hinnata õpilaste digipädevust õppimise kontekstis ning toetada selle sihipärasest arendamist hariduses.

Sellest lähtuvalt oli käesoleva doktoritöö eesmärk arendada ja valideerida hindamisvahend (Digitest) põhikooli õpilaste õppimiseks vajaliku digipädevuse hindamiseks ning välja selgitada selle rakendatavus õppeprotsessi kujundamiseks. Eesmärgi täitmiseks uurimisküsimustele vastamiseks viidi läbi neli omavahel seotud uuringut, mis jagunesid kaheks suuremaks etapiks: (1) arendamine ja rakendatavuse analüüs ning (2) rakendamine.

Arendamise ja rakendatavuse analüüsi etapis oli eesmärgiks välja töötada ja valideerida õppimiseks vajaliku digipädevuse hindamisvahend ning hinnata selle praktilist rakendatavust hariduses. Selles etapis sooviti vastata kahele uurimisküsimusele:

1. Millised on tõendid Digitesti sobivuse kohta põhikooliõpilaste õppimiseks vajaliku digipädevuse hindamisel?
2. Kuidas saab Digitesti tulemusi kasutada digitaalse õppeprotsessi kujundamise toetamiseks?

Rakendamise etapis keskenduti loodud instrumendi kasutamisele reaalses kooli-kontekstis, et saada ülevaade õpilaste digipädevuse tasemetest. Selles etapis sooviti vastata uurimisküsimusele:

3. Millised on Eesti põhikooliõpilaste digioskuste ja õppimisega seotud digihoiakute tasemed?

Uurimisküsimustele vastamiseks viidi läbi neli uuringut. Esimeseks uuringuks oli Digitesti valideerimisprotsess (uurimisküsimus 1; Artikkel I), mis hõlmas hindamisvahendi arendamist, testimist ning selle psühhomeetriliste omaduste analüüsi. Uuringus hinnati testülesannete kvaliteeti, raskusastet ning sobivust erinevatele vanuseastmetele, samuti selgitati välja digipädevuse dimensioonide struktuur. Tulemused näitasid, et test võimaldab hinnata mitut digipädevuse dimensiooni ning eristada õpilaste oskuste tasemeid erinevates vanuserühmades, kinnitades selle sobivust nii teaduslikuks kui ka praktiliseks kasutamiseks. Lisaks kinnitas analüüs, et testil on head psühhomeetrilised omadused, sh sobiv ülesannete raskusjaotus ja mõõtmise võrreldavus erinevates klassiastmetes, mis on oluline usaldusväärse hindamise tagamiseks ja potentsiaalselt ka õpilaste digipädevuse arengu jälgimiseks aastate lõikes. Tulemused on kooskõlas varasemate uuringutega, mis rõhutavad vajadust mitmemõõtmeliste ja praktilistele ülesannetele ülesehitatud hindamisvahendite järele (Godaert et al., 2022; Siddiq et al., 2016).

Teiseks uuringuks (uurimisküsimus 2; Artikkel II) oli õpilaste digipädevuse profiilide ehk klastrite analüüs, mille eesmärgiks oli hinnata Digitesti rakendatavust õppeprotsessi kujundamisel. Õpilasprofiilide abil selgitati välja, millised on õpilaste tüüpilised õppimiseks vajaliku digipädevusega seotud oskuste ja

hoiakute kombinatsioonid ning kuidas need üksteisest erinevad. Õpilaste klasteranalüüs tõi esile neli erinevat profiili (programmeerijad, loojad, juhukasutajad ja algajad), mis viitavad sellele, et õpilased ei erine ainult taseme, vaid ka digipädevuse struktuuri poolest. See tähendab, et sarnase üldtasemega õpilastel võivad olla erinevad tugevused ja nõrkused digipädevuse komponentides. See toetab vajadust diferentseeritud õpetamise järele ning on kooskõlas varasemate uuringutega, mis on tuvastanud sarnaseid õpilasprofiile digitehnoloogia kasutuses (Karakoyun & Başaran, 2021; Scherer et al., 2017).

Kolmandaks uuringuks (uurimisküsimus 2; Artikkel III) oli digipädevuse dimensioonidevaheliste seoste analüüs, mille eesmärgiks oli mõista, kuidas erinevad digipädevuse komponendid üksteist mõjutavad ning millises järjekorras tuleks digipädevuse arendamisel erinevatele komponentidele õppimisprotsessis keskenduda. Uuringus kasutati struktuurivõrrandite modelleerimist, et selgitada välja, millised õppimiseks vajamineva digipädevuse dimensioonid toimivad teiste dimensioonide kujunemise alusena. Uuringute tulemused näitasid, et digipädevuse komponendid on omavahel seotud. Eelkõige selgus, et tehnilised ehk operatsioonilised oskused on aluseks keerukamate oskuste kujunemisele, mis kinnitab varasemaid teoreetilisi käsitlusi (Iordache et al., 2017). Samuti ilmnes, et individuaalselt arendatavad oskused (nt operatsioonilised oskused, programmeerimine, sisuloomed) toetavad omakorda sotsiaalseid oskusi (nt suhtlemine ja digikäitumine), mis viitab digipädevuse arengulisele struktuurile. Hoiakute roll osutus seejuures piiratumaks, kuna otsest mõju oskuste arengule avaldas peamiselt vaid käitumiskavatsus, mis on kooskõlas tehnoloogia aktsepteerimise mudeli (TAM; Davis, 1989) ja planeeritud käitumise teooriaga (Ajzen, 2012).

Neljandas uuringus (uurimisküsimus 3; Artikkel IV) oli Digitesti rakendamine Eesti põhikooliõpilaste seas, et hinnata nende digioskuste ja digihoiakute taset. Uuring andis ülevaate õpilaste tugevustest ja nõrkustest õppimiseks vajamineva digipädevuse dimensioonides. Tulemused näitasid, et õpilaste oskused ja hoiakud varieeruvad märkimisväärselt nii õpilaste vahel kui ka digipädevuse erinevate dimensioonide lõikes, mis rõhutab vajadust süsteemse ja sihipärase digipädevuse arendamise järele koolides. Tugevamad olid suhtlemise ja sisuloomed oskused, samas kui tehnilised ja programmeerimisoskused olid nõrgemad. Sarnast mustrit on täheldatud ka rahvusvahelistes uuringutes, kus õpilased on edukamad igapäevaste digitegevustega seotud oskustes, kuid vähem arenenud keerukamates ja tehnilisemates valdkondades (Godaert et al., 2022).

Käesoleva doktoritöö panus teadusesse seisneb mitmetahulises lähenemises digipädevuse uurimisele, ühendades hindamisvahendi arendamise, valideerimise, empiirilise rakendamise ning digipädevuse sisemiste seoste ja õpilasprofiilide analüüsi. Varasemates uuringutes on rõhutatud digipädevuse olulisust, kuid samal ajal on esile toodud valideeritud hindamisvahendite nappus, eriti nooremate õpilaste kontekstis (Godaert et al., 2022; Siddiq et al., 2016). Käesolev töö aitab seda lünka täita, pakkudes empiiriliselt kontrollitud instrumenti, mis võimaldab hinnata digipädevust õppimise kontekstis põhikooli esimeses ja teises astmes. Lisaks laiendab töö senist teadmist, näidates, et digipädevus ei ole ainult tasemeline

nähtus, vaid ka struktuurne ja arenguline. Õpilaste jaotumine erinevatesse klastritesse ning digipädevuse dimensioonide omavahelised seosed viitavad sellele, et digipädevuse arendamine ei ole lineaarne protsess, vaid sõltub erinevate komponentide vastastikusest mõjust. See lähenemine aitab paremini mõista, kuidas digipädevus kujuneb ning millised tegurid seda mõjutavad.

Samuti kinnitab töö, et digipädevus õppimise kontekstis on kompleksne ja mitmemõõtmeline konstrukt, mis hõlmab nii teadmisi, oskusi kui ka hoiakuid ning mille areng toimub järk-järgult erinevate komponentide koostoimes (Guitert et al., 2021; Weinert, 2001; Westera, 2001). See rõhutab vajadust käsitleda digipädevust terviklikult nii teadusuuringutes kui ka hariduspraktikas.

Uuringu tulemuste põhjal saab esitada mitmeid soovitusi. Esiteks tuleks digipädevuse hindamisel kasutada mitmemõõtmelisi ja soorituspõhiseid vahendeid, mis võimaldavad hinnata nii oskusi, teadmisi kui ka hoiakuid. Sellised vahendid annavad täpsema ja realistlikuma ülevaate õpilaste tegelikust pädevusest võrreldes üksnes enesehinnangul põhinevate meetoditega (Siddiq et al., 2016).

Teiseks on oluline arvestada õpilaste erinevaid digipädevuse profile ning rakendada diferentseeritud õpetamist. Õpetamisel tuleks lähtuda õpilaste individuaalsetest tugevustest ja nõrkustest, pakkudes erinevatele profiilidele sobivaid õppetegevusi ja tuge.

Kolmandaks tuleks õppeprotsessi kujundamisel lähtuda digipädevuse komponentide omavahelistest seostest, alustades baasoskustest ja liikudes keerukamate oskuste suunas. Eelkõige tuleks pöörata tähelepanu operatsiooniliste oskuste arendamisele, kuna need loovad aluse teiste digipädevuse komponentide arenguks.

Neljandaks tuleks pöörata rohkem tähelepanu digipädevuse vähem arenenud valdkondadele, nagu programmeerimine ning digimaailma õiguslikud ja eetilised aspektid, mis on sageli hindamisvahendites tähelepanuta jäänud (Siddiq et al., 2016).

Lõpuks on vajalik jätkata uurimist digipädevuse arengu, hindamise ja rakendamise valdkonnas, eriti seoses uute tehnoloogiate, nagu tehisintellekti, kasutuselevõttuga hariduses. Tulevikus tehtavad uuringud peaksid keskenduma ka digipädevuse pikaajalisele arengule ning hindamisvahendite kohandamisele erinevates kultuurilistes ja hariduslikes kontekstides.

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