DIGITAL PUBLIC INFRASTRUCTURE FOR EDUCATION: NATIONAL DEVELOPMENT NEEDS AND CROSS-BORDER SOLUTIONS

Lappeenranta–Lahti University of Technology LUT

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Examiner(s): Associate Professor Jussi Kasurinen

ABSTRACT

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Digital Public Infrastructure for Education: National Development Needs and Cross-Border Solutions

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Keywords: *Digital Public Infrastructure (DPI); Education Technology; Finland; Estonia; Data Cooperation; Interoperability; Governance.*

This thesis examines the development and application of digital public infrastructure (DPI) in the field of education, focusing on how to improve DPI development so that it caters to the educational needs of nations and is implemented in an effective, accessible and equitable way. The study employs two complementary research methods: a systematic literature review (SLR) to synthesize existing knowledge on DPI in education and a case study to analyze cross-border DPI cooperation between Finland and Estonia. The SLR identifies the foundational requirements of DPI, such as transparent governance, interoperability, inclusivity, and sustainability, and explores how these characteristics influence education. The case study demonstrates how the two countries' cooperation through the Nordic Institute for Interoperability Solutions (NIIS) and the X-Road system embodies many of these principles by establishing a secure, federated data exchange framework. While this shared infrastructure effectively supports administrative and technical interoperability, its educational applications, such as digital credential exchange, student data mobility, and cross-border learning services, remain yet underdeveloped.

The findings indicate that DPI's potential to influence education depends on integrating these foundational infrastructures into educational policy and practice through targeted governance and legal alignment. The study concludes that international DPI collaboration offers a scalable model for equitable, future-ready education systems but requires further empirical research and technical implementation to realize its full pedagogical potential.

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Tämä opinnäytetyö tarkastelee digitaalisen julkisen infrastruktuurin (DPI) kehittämistä ja soveltamista koulutusalalla keskittyen siihen, miten DPI:n kehittämistä voidaan parantaa niin, että se vastaa kansakuntien koulutustarpeita ja toteutetaan tehokkaasti, saavutettavasti sekä tasapuolisesti. Tutkimuksessa käytetään kahta toisiaan täydentävää tutkimusmenetelmää: systemaattista kirjallisuuskatsausta (SLR) digitaalisen infrastruktuurin olemassa olevan tiedon syntetisoimiseksi, ja tapaustutkimusta, jossa analysoidaan Suomen ja Viron välistä DPI-yhteistyötä. SLR tunnistaa DPI:n perusvaatimukset, kuten läpinäkyvän hallinnon, yhteentoimivuuden, osallistavuuden ja kestävyyden, sekä tutkii, miten nämä ominaisuudet vaikuttavat koulutukseen. Tapaustutkimus osoittaa, kuinka Pohjoismaisen yhteentoimivuusratkaisujen instituutin (NIIS) hallinnoima X-Road-järjestelmä ilmentää monia näistä periaatteista luomalla turvallisen ja federoidun tiedonvaihtokehyksen. Vaikka tämä yhteinen infrastruktuuri tukee tehokkaasti hallinnollista ja teknistä yhteentoimivuutta, sen koulutussovellukset, kuten digitaalisten tutkintotodistusten vaihto, opiskelijoiden tietojen liikkuvuus ja kansainväliset oppimispalvelut, ovat yhä alikehittyneitä.

Tutkimuksen tulokset osoittavat, että digitaalisen infrastruktuurin tehokas vaikutus koulutukseen riippuu sen systeemien integroinnista hallinnon ja lainsäädännön koulutuskäytäntöihin ja -politiikkaan. Tutkimuksen johtopäätös on, että kansainvälinen koulutusinnovaatioiden yhteistyö tarjoaa skaalautuvan mallin kestäville ja teknologisesti kehittyneille koulutusjärjestelmille, mutta sen täyden pedagogisen potentiaalin hyödyntäminen edellyttää tarkempaa empiiristä tutkimusta ja teknistä toteutusta.

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SYMBOLS AND ABBREVIATIONS

Abbreviations

DPI	Digital Public Infrastructure
CDPI	Centre for Digital Public Infrastructure
UPI	Unified Payment System
SSO	Single Sign-on
JAD	Joint Application Design
ENISA	European Union Agency for Cyber Security
AI	Artificial Intelligence
ITU	International Telecommunication Union
NIIS	Nordic Institution for interoperability Solutions
EDUFI	Finnish National Agency for Education
UNDP	United Nations Development Program

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1 Introduction

This work is being done for my employer, Educraftor oy, which is an education consultancy company that emphasizes international cooperation in education. Educraftor is researching the role of Digital Public Infrastructure in education along with several other parties and offered the possibility to tackle one of their research questions. That research question ended up being “How are the digital ecosystem development needs different at a regional, global, national and international level?”, so initial work began with narrowing down the scope of the question (as this would’ve been far too large of a topic for a bachelor’s thesis otherwise) and deciding on what the specific objectives of this work should be.

1.1 Background

Education is an important part of advancement and innovation, as it has the potential to empower individuals and improve economic growth. The expansion of the internet enabled technologies to be supercharged with advanced information sharing, and Large Language Models along with big data have developed an era of extreme connectivity and system integration (Luckin & Holmes, 2016).

Despite these advances, digital education technologies remain largely localized and often copy the foundations of traditional education institutions rather than innovating new processes or forms for them. This issue has led to the fragmented education landscape that exists today, where coordination among educational stakeholders is sparse, learners’ data sits in individual data silos and contact with innovative methodologies is subject to chance (Organisation for Economic Co-operation and Development, 2023). All of this results in a suboptimal experience for learners, educators, administrators and policymakers alike.

Digital Public Infrastructure (DPI) presents a potential solution by integrating technology into a unified and scalable framework. DPI can enhance accessibility, equity, and quality in education, ensuring interoperability and fostering a learner-centred approach. By examining the role of DPI in education, this study aims to explore its development needs at

the national level and assess the potential benefits of cross-border collaboration, determining whether such collaboration can help to satisfy those needs.

1.2 Objectives

This study will investigate the development needs of DPI in education, from the perspective of Finland and its data cooperation with Estonia. The objectives of this study are to discover the challenges of developing digital infrastructure for education at a national level, and whether international cooperation can help to overcome these challenges. The research questions are determined as the following:

1. *What are the DPI development needs for education on a national level?*
2. *How has cooperation between Finland and Estonia helped to satisfy those needs?*

This study will involve the definition of DPI, showcase examples of how DPI manifests in the field of education in Finland, investigate the way DPI is developed, and whether that development could benefit from international cooperation. Existing material and research will be used to define DPI and determine what it has already been used for in Finnish education, as well as the outcomes of that use. Finland has been chosen as the target of this thesis because of my familiarity with it and its education systems, and therefore the data cooperation between Finland and Estonia has been chosen as an example of international digital ecosystem development.

This thesis will not examine the impact DPI has on education in detail, meaning empirically measuring the positive or negative effect it has on education, focusing instead on practical examples of DPI and the requirements that exist to develop it effectively. Additionally, this thesis will not examine all the possible merits of the data cooperation between Finland and Estonia but rather focus on whether this cooperation has specifically benefited the development of the digital ecosystem of education in Finland.

1.3 Structure

The structure of the thesis will involve 6 main chapters, along with any references and appendices:

1. **Introduction**: Presents the study's background, objectives, and research questions.
2. **Related Research**: Defines DPI and summarizes existing research on DPI in education. The concept of DPI development will be examined from multiple points of view, such as the end-user, developer, and public administration. Additionally, the background of the data cooperation between Finland and Estonia will be explored.
3. **Research Methods**: Describes the methodology used to analyze DPI's role in education, involving the explanation of why specific examples of digital infrastructure and the nation of Finland have been chosen for analysis.
4. **Results**: Presents findings from the research methodology. This will detail the identified development needs of DPI and describe the extent of the benefit that international cooperation has on DPI development with a case study of the data cooperation between Finland and Estonia.
5. **Discussion**: This section interprets results, attempts to answer the research questions, and discusses DPI's impact on education along with the benefits of cross-border collaboration. Also discusses the merits and limitations of this study.
6. **Conclusion**: Summarizes key findings and suggests future research direction.

2 Related Research

The purpose of this chapter is to elaborate on the concept of digital public infrastructure as it pertains to the context of this study. The first section of this chapter includes sources that help define DPI and its development, the second section includes related research on the impact DPI has on the education sector, and the third section includes sources specific to the perspective of DPI development in Finland and Estonia.

2.1 The Definition of Digital Public Infrastructure

According to Clark, Marin, Alper & Rabadan (2025), Digital Public Infrastructure refers to foundational digital systems such as digital identity, payments, and data-sharing systems. These systems are designed to be interoperable, reusable building blocks that serve the public and private sectors for benefit at a societal scale (Clark, et al., 2025). This definition closely aligns with how Jain and the Gates Foundation (2025) describe DPI: “connecting people, data, and money the same way roads connect people and goods,” where characteristics like openness, modularity, privacy-by-design, and strong governance are emphasized (Jain, 2025).

This framing positions DPI as a strategic layer within the national digital ecosystem, where it sits between physical devices and applications, delivering services to all. Considering DPI through this layered perspective helps to understand its role as a shared enabler, one that can significantly lower barriers to innovation, reduce redundancy or service duplication across sectors, and promote inclusive access to digital public services. For example, with one national sign-in service, organizations would no longer need to worry about creating their own verification and sign-in systems.

Clark et al. (2025) continue that DPI needs to function within a broader digital ecosystem, relying on existing hard infrastructure (like broadband and cloud) and non-technical enablers among its users such as governance and literacy to function. Treating DPI holistically, rather than isolating it as a specific technical stack, acknowledges that scaling and sustaining such infrastructure requires an ecosystem approach, and reinforces the idea that success depends not just on technology, but on legal frameworks, stakeholder engagement, and digital trust.

Therefore, DPI development should be handled by public entities such as the government, as they tend to be more successful in achieving and retaining such qualities in their projects (United Nations Development Programme, 2023).

Aro, Capps-Jenner, Fagerström & Renders (2025) explain that DPI differs from the traditional digitalization of systems, which tends to be siloed and sector-specific, by instead offering shared infrastructure that can be reused across all sectors. This enables the faster and more comprehensive rollout of digital services when compared to private solutions in the same digital ecosystem (Aro et al. 2025). Therefore, DPI can mitigate inefficiencies of reinvention while simultaneously empowering both public and private actors to innovate on top of a shared base. From a developer's perspective, this makes DPI a catalyst for competitive and collaborative ecosystems, enabling better quality services and inclusivity, rather than letting fragmentation hinder progress.

However, the definition of DPI is not a very technical one, and it is debatable what programs, software, and services should or shouldn't be included in it. There are many factors that can influence categorization, such as ownership, affected stakeholders, and intended end-users. For the purposes of this study, DPI is considered as digital infrastructure that is:

1. Publicly owned
2. Intended for all & accessed equitably
3. Being actively maintained or developed

Some examples of this might include Estonia's eID digital identity system (Eesti.ee, 2025) and India's UPI unified payment system (National Payments Corporation of India, 2025).

2.2 The Impact of DPI on Education

DPI is increasingly being framed by organizations as essential for transforming education through interoperable, scalable, and learner-centric systems which enable processes such as identity verification, data exchange, and pedagogical quality assurance (Aro, et al., 2025). Developing DPI for education can help transfer some processes of learning from a fragmented, institution-bound education model to a connected digital learning ecosystem. However, the benefits of developing DPI for education are different for developed vs.

developing nations, as pre-existing infrastructure plays a large role in how digital ecosystems can be utilized. Larsson, Liew & Frankenhauser (2023) note that DPI in education could especially help nurture access, inclusion, and equity in education for children in impoverished areas, for example by improving the coverage of social registration and government-to-person payment systems.

Digital learning platforms accessed via DPI can offer meaningful improvements in educational access and quality, e.g. by compensating for teacher shortages and delivering interactive content in remote regions. Zaw & Hlaing (2024) emphasize that DPI provides a systemic approach to addressing the current educational landscape's inefficiencies in remote, developing countries where traditional education infrastructure is weak or non-existent. In these cases, one of DPI's most significant contributions is democratizing access to education by removing barriers related to location, infrastructure, and socio-economic constraints. However, challenges persist, such as limited internet connectivity, lack of digital devices, and under supported educators adapting to online teaching. (Zaw & Hlaing, 2024)

For a more concrete example of DPI improving education, one of its previously defined uses is enabling digital identity solutions such as Single Sign-On (SSO) gateways, which streamline authentication for students and educators (Centre for Digital Public Infrastructure, 2024). Such gateways reduce redundancy in user management and allow access to multiple learning platforms and educational tools while improving security and privacy. The implementation of data exchange layers further enhances interoperability between systems by allowing the secure transfer of learner data across platforms, reducing administrative burdens on a national level and improving efficiency.

Another potential element of DPI is the integration of AI-powered applications to personalize learning experiences. Luckin & Holmes (2016) describe how AI-driven systems can analyze a student's progress, identify strengths and weaknesses, and tailor educational content accordingly. This shift toward adaptive learning has been shown to improve engagement and outcomes, particularly for students who struggle with traditional teaching methods (Luckin & Holmes, 2016). The use of AI is not an inherent part of DPI development, and public entities should take care in using technology that may fail to reach the same commitments of trust, accessibility, and ethics that a publicly owned digital ecosystem should have. Similarly to DPI, the development of AI should rely on the same principles of non-technical enablers such as governance and literacy.

The United Nations Development Programme report (2023) underscores that DPI enables faster, more inclusive uptake of services, better transparency, and ecosystem-wide innovation. Though the UNDP report primarily quantifies DPI's impact in finance, justice, and climate sectors, its broader implications as related to accelerating service adoption, promoting inclusion, and fostering governance innovation, seem to suggest similar transformative potential in education. This is corroborated by a prior review conducted by Haleem, Javaid, Qadri & Suman (2022), where it is stated that:

> "traditional classroom instructions fall short of providing an immediate learning environment, […] In contrast, digital learning tools and technology fill this void."

The review emphasizes that the development of such digital learning tools requires an effort greater than the sum of a few small companies, which is where large, public infrastructure such as DPI comes into play.

Based on the information provided by UNDP (2023), Larsson et al. (2023), and Zaw & Hliang (2024), Table 1 has been constructed to summarize the effects that DPI has had on education in developing nations versus developed nations.

Developing nations	Developed Nations
1. Expanded access to education in remote or underserved areas via digital learning platforms. High priority in sparsely populated nations.	1. Further enhances efficiency and interoperability of education systems (e.g., unified learner IDs, portable credentials).
2. Improved engagement and comprehension when DPI-backed platforms include interactive tools, though hindered by device and connectivity gaps.	2. Encourages innovation by lowering barriers for private educational technology providers to integrate with public education systems.
3. Reduced inequality when DPI is paired with affordable internet, device provision, and teacher training	3. Strengthens data governance and learner privacy through consent-based frameworks, building trust in digital education tools.
4. Supports scalable educational technology ecosystems rather than fragmented pilots, provided infrastructure and policies align.	4. Improves personalization and lifelong learning pathways through integrated data exchange and credential systems.
5. Can establish secure digital ID and certification systems to verify learning outcomes and support workforce transition.	

Table 1: Effect of DPI on education in nations

This table is meant to provide a short overlook at how the development of DPI for education in Finland and Estonia (proponents of the case study in this thesis) compares to its development elsewhere in the world.

2.3 DPI Development in Finland and Estonia

According to Clark et al. (2025), DPI facilitates the exchange of learning materials, credentials, and best practices. Therefore, it is not unreasonable to assume that the development of DPI can be extended to the international level to significantly improve cross-border collaboration in education between countries. In September 2022, Finland and Estonia signed a treaty facilitating electronic exchange of population register data (Digital and Population Data Services Agency, 2018). This enables automatic updating of personal data when individuals move between the two countries and it is all managed via their respective data-exchange systems. The digital cooperation between Finland and Estonia has enabled shared access to population data and the digital infrastructure borne from it could be further applied to enhance both nations' educational capabilities while reducing duplication of efforts. The arrangement has reduced administrative burden for both citizens and authorities and has the capacity to tangibly enhance citizens' experiences, instead of remaining as a footnote on the DVV's website that few citizens would come across.

Hardy (2024) explains how the interoperability between Finnish and Estonian data services is underpinned by a "trust federation", allowing service consumers and providers across the two countries to communicate securely and seamlessly as though part of a single ecosystem. The interoperability could facilitate more than just cross-border population data sharing, by introducing services such as e-signing, medical data sharing, and mutual recognition of digital signatures (Petrone, 2022). This so-called "trust federation" exemplifies DPI diplomacy at its best, where infrastructure competencies foster cooperation and mutual trust. Such diplomacy confers a strategic advantage: cross-border service delivery improves while simultaneously bolstering public trust, thus positioning the region as a forerunner in integrated digital governance. International DPI cooperation is therefore not only useful for productivity reasons, but to also exert influence in foreign politics.

This abstract trust federation gave birth to The Nordic Institute for Interoperability Solutions (NIIS), which was founded by Finland and Estonia in 2013, and jointly oversees the

development, maintenance, and governance of cross-border digital ecosystems (Nordic Institute for Interoperability Solutions, 2025). The institution handles technical documentation, licensing, development, auditing, vendor training, and international partnerships, funded jointly by its member states. Silm, Jauhiainen, Raun & Tiru (2020) comment that one of the tangible benefits of NIIS' establishment was creating temporary population mobilities between Estonia and Finland, which could be tracked with mobile phone data. The establishment, mission, and funding of NIIS reference its role as an enabler of cross-border mobility and e-governance, as well as relay its compliance under the Digital Public Goods Standard (Silm, et al., 2020). Hardy (2024) notes that many of the challenges of Nordic interoperability seem closer to being solved when the NIIS achieved the milestone of taking over core cross-border development between Finland and Estonia in 2018.

One of the core components of the cross-border development that has been referenced thus far is the X-Roads system, which is a free and open-source data exchange solution (Nordic Institute for Interoperability Solutions, 2025). Table 2 provides an overview of this system noting its features and relevance to international DPI development.

Aspect	Description	Relevance to Cross-Border DPI
System Type	Open-source, secure data exchange layer connecting public and private organizations.	Forms the basis for interoperable e-government services in Estonia, Finland, and other adopters.
Governance	Jointly developed and maintained by NIIS.	Ensures sustainability, shared investment, and coordinated updates across countries.
Architecture	Decentralized — data stays with the original provider; X-Road only mediates secure transfers.	Enhances privacy, security, and trust while enabling real-time data access between nations.
Security Features	Strong authentication, encryption, logging, and monitoring of all transactions.	Builds trust between states by guaranteeing integrity and auditability of cross-border data flows.
Interoperability	Uses standard APIs and protocols; supports multiple languages and service types.	Allows services from different jurisdictions to "speak" to each other without custom integrations.

Cross-Border Connection (2018)	Estonia's X-Road linked with Finland's Suomi.fi Data Exchange Layer on 7 Feb 2018.	Enabled automatic data exchange (e.g., population registers), reducing duplicate procedures.
Scalability	Adopted beyond Estonia and Finland (e.g., Iceland, Faroe Islands, Kyrgyzstan) with NIIS support.	Demonstrates a replicable DPI model for regional digital cooperation.
Openness & Licensing	Open-source under the MIT license with global community contributions.	Encourages transparency, innovation, and potential adoption by other governments.

Table 2: Overview of the X-Roads system

This table will be primarily referenced in the case study section of this thesis, as it is a critical component of the data cooperation that Finland and Estonia partake in.

3 Research Methods

This thesis will primarily be a case study on the digital public infrastructure development for education in Finland and Estonia but will employ a systematic literature review (SLR) as a complementary research method to help investigate the overall nature of DPI development. These research methods were selected to address the exploratory nature of DPI research and to provide both a broad theoretical foundation and a concrete, context-specific example of how DPI development impacts education at the national level.

Okoli & Schabram (2010) state that a systematic literature review is a structured method for identifying, evaluating, and synthesizing existing research on a specific topic. Unlike traditional narrative reviews, an SLR applies a replicable protocol to minimize bias and ensure comprehensive coverage of available literature (Okoli & Schabram, 2010). This approach is particularly suited to emerging fields such as DPI, where studies are still sparse across disciplines and lack consolidated frameworks, i.e. most of the research is not the kind of rigorous, peer-reviewed work that can be found in other fields. By following systematic procedures, the review establishes a theoretical baseline that informs subsequent empirical inquiry, which in this case is the case study.

The SLR for this study is non-empirical and qualitative in focus. Relevant academic databases such as Google Scholar and Web of Science (WoS) are searched, supplemented by organizational sources used in ongoing DPI-related projects managed by my employer. Search keywords included “digital public infrastructure,” “education technology,” “interoperability,” and “digital ecosystem development”. However, the first keyword did not match many results in Google Scholar and the Web of Science database, so it was replaced with the latter three. In total, 15-30 relevant studies were found.

The review process for these sources followed the three main stages described by Okoli & Schabram (2010):

> “Planning – defining research questions and inclusion criteria.
>
> Conducting – executing database searches, screening abstracts, and applying eligibility filters.
>
> Reporting – synthesizing results in relation to research objectives.”

The eligibility of a source was based on whether the abstract wholly or partially related to the following three topics, which are meant to address the first research question of this study "*What are the DPI development needs for education at a national level?":*

- Providing requirements or characteristics for the foundation of DPI in education.
- Exploring the impact that various development methods have on developing DPI.
- Mapping the ideal characteristics and development methods of DPI with the educational needs of nations.

If the abstract related to one of these topics, the source was noted and examined to determine the extent to which it provided answers to the research objectives of this study. These results have been synthesized in the "SLR Results" chapter.

The case study method, as articulated by Yin (2009), is a rigorous empirical approach for investigating contemporary phenomena within real-life contexts, especially when boundaries between phenomenon and context are not clearly defined. Yin highlights that case studies are ideal when researchers seek to answer "how" and "why" questions, draw on multiple evidence sources, and require in-depth contextual insights. Given the limited availability of large-scale comparative DPI data, a case study enables the examination of Finland's DPI environment and its cooperation with Estonia, providing empiric real-world evidence to complement the systematic literature review, and hopes to answer the "how" of international cooperation facilitating DPI development.

The embedded case study focuses on Finland and its cross-border DPI collaboration with Estonia under the Nordic Institute for Interoperability Solutions (NIIS) and X-Road framework. These countries were selected because of proximity and researcher familiarity, as well as the NIIS being one of the forerunners in advanced digital ecosystems. Data sources for the case study include policy documents and official reports from educational ministries and technology agencies, framework analyses of digital education and interoperability initiatives in both countries, and cross-border DPI cooperation records, such as NIIS documentation and agreements on population register exchange.

In line with Yin's methodology, this case study uses multiple sources of evidence to ensure validity and reliability. The case study addresses both research questions "*What are the DPI*

development needs for education at a national level?" and "*How has cooperation between Finland and Estonia helped to satisfy those needs*?" by providing:

- Concrete examples of educational DPI systems operating in Finland.
- Evidence of international cooperation facilitating DPI development.
- Evaluation of shared strategies to determine their effectiveness in meeting national education infrastructure needs.

By combining the systematic literature review with the case study approach, this study hopes to holistically realize the challenges of DPI development for education at a national level, both in general and specifically in Finland, and pair it with an empirical analysis on how international cooperation helps overcome those challenges. The SLR delivers a comprehensive, unbiased theoretical framework, while the case study grounds that framework in a specific empirical context, following Yin's (2009) principle of analytic generalization.

4 SLR Results

This chapter explores the results of the SLR in three sections. The first section explores the requirements of digital infrastructure for education, i.e. the definition of its objectives, how it should be managed, governed and funded, in what form should it exist, and where should it exist. The second section explains the impact that various development methods have on the development of DPI, along with noting how such development affects accessibility, equity, and quality of education. The third section maps the ideal foundation and development methods of DPI from the first two sections with the educational needs of nations, which are primarily based on their economic and geopolitical objectives.

4.1 Creating a Foundation for DPI in Education

The definition of Digital Public Infrastructure was explored in chapter 2.1 but will be reiterated here in a more educational context. DPI comprises foundational, reusable digital building blocks, such as digital identity, secure data-sharing layers, single sign-on systems, and certification frameworks, that are designed to support education systems with accessibility, equity, and quality at scale. As Clark et al. (2025) frames it, DPI must align with principles like interoperability, modularity, openness, strong governance, and privacy by design. Likewise, Aro et al. (2025) emphasize DPI's role in enabling education systems to transcend fragmented, localized structures, thereby supporting inclusive, learner-centred ecosystems. To create a system that matches these definitions, the foundation of DPI for education must include certain technical and architectural characteristics, along with clear requirements for its governance and management.

Regarding architectural characteristics, the first and most important aspect is an open and modular architecture design. The components of the digital system should be reusable across multiple domains (public and private, educational and beyond), which lower implementation costs and avoid duplication (Clark, et al., 2025). The second core aspect of the architecture is the implementation of data exchange layers. Secure, standardized infrastructure allows seamless movement of educational data across systems (e.g., learner profiles, credentials, assessments) and should follow already established building-block paradigms such as the

ones set by GovStack or ITU (GovStack, 2025 & Saha, 2019). The X-Roads system used by NIIS is a good example of this, as its open-source and comprehensive documentation provides clear instructions on data exchange and interfacing (Table 2: Overview of the X-Roads system). Saha (2019) also notes on digital platform architecture, that "with the use of standard and open interfaces, the digital platform is available to all the key actors in the value delivery ecosystem to build and use components," emphasizing the importance of openness and reusability.

Technical requirements for DPI derive primarily from the architectural requirements, and are more flexible in their implementation, thus the requirements for them are not as strict. However, according to Clark et al. (2025) there are still some key characteristics that DPI should include. Certification, quality assurance and legal/security modules should be included as components of the system, and are meant to ensure that educational content, platforms and data flows meet legal, technical, and pedagogical standards set by organisations such as the NIIS or the European Union Agency for Cybersecurity (Hardy, 2024) & (ENISA, 2025). Less abstract technical components that should be included are mentioned by CDPI (2024) and include technologies such as Digital identity and SSO, which are key enablers for user convenience and system integration across platforms.

While technical and architectural requirements determine the uses and benefits of DPI, it is equally important to build public infrastructure with the correct governance and management. A robust governance framework ensures public oversight and neutral stewardship, and it should convene diverse stakeholders while maintaining neutrality to foster innovation (Aro, et al., 2025). The governance framework should also implement open standards and regulatory clarity by having the governing bodies define interoperable standards, data protection rules, and service quality criteria across sectors (Organisation for Economic Co-operation and Development, 2023). Lastly, the framework should enable institutional coordination through agile central bodies, multi-sector platforms like GovStack, or public-private partnerships to align policy, technical development, and implementation (Saha, 2019).

Another process to found well-managed and governed infrastructure is by ensuring the objectives and mission of that infrastructure is clear. One way to achieve this is with selecting the correct course of funding for the system, and like physical public infrastructure, DPI demands long-term investment. According to the European Commission (2025), funding for

digital infrastructure should support capacity-building and maintenance, ensuring that the infrastructure remains updated, secure, and responsive to evolving needs in the technology sector. In Finnfund's 2024 annual report, it is mentioned that funding for digital infrastructure should prioritize reusable sources over one-time grants and leverage economies of scale for monetary generation. Public-private cooperation should be enabled, where governments may invest in standards and core services while private actors contribute complementary innovations (Finnfund, 2024), i.e. public institutions should remain the primary governors of the system, but not necessarily the sole funders. Setting the mission of the digital infrastructure would therefore mostly come from those same public institutions. For example, Finland supports a digital infrastructure strategy (Ministry of Transport and Communications, 2018) that emphasizes the mission of the infrastructure:

> "The digital infrastructure must enable living, working and entrepreneurship across Finland. The needs of people, businesses and industry have been taken into consideration in the aims and measures of the strategy."

Although the strategy primarily focuses on physical telecommunications infrastructure such as optical fibre networks and is set to end in 2025, the same policies and principles applied to the development process of that infrastructure should continue to apply for digital ecosystems.

Lastly, the proper foundation of DPI for education should include clear standards on "where" in public infrastructure the ecosystem should be integrated. The Centre for Digital Public Infrastructure (2025) notes that to be effective, the digital ecosystem should integrate hard infrastructure, soft infrastructure, and digital service layers. Hard infrastructure involves systems such as broadband and data centers, soft infrastructure involves regulatory frameworks and data governance (such as the NIIS), and digital service layers that sit closest to end-users and take the form of learning apps or administrative systems for e.g. government employees (Aro, et al., 2025). DPI is therefore placed at multiple levels of a nation's public infrastructure, and enables it to serve as a flexible, scalable backbone across educational contexts and systems.

4.2 Development Methods for DPI

This section examines how different development methods, i.e. the approaches, processes, and design choices used to build, implement, and govern digital public infrastructure affect its efficacy. Development methods in this context relate to technical architecture, governance and funding models for development, design principles, deployment strategies, and ecosystem engagement.

Because DPI has been defined as a framework that promotes accessibility and equity, a good development design principle to start with is inclusive, human-centred design. Giacomin (2014) explains that human-centred design, in a technological context, has a high likelihood of improving usability and access for traditionally underserved users. Martinez, Taylor & Grown (2025) identify six critical steps for designing DPI to advance equality, highlighting design practices that explicitly consider rural communities, low-income households, people with disabilities, and multilingual populations. Examples include offline-capable, multilingual DPI interfaces used in Kenya and Ethiopia, similar to those used in India that were mentioned in chapter 2.1. In education, inclusive DPI design enables broader participation by students who otherwise face connectivity or literacy barriers. By embedding accessibility at the design stage, DPI reduces digital divides rather than reinforcing them (Larsson, et al., 2023). Whether an institution chooses to implement multiple design principles or not, the inclusion of human-centred design as one of them should be a high-priority.

Other design principles may be borne from the characteristics of the foundation of the DPI, referring to the management and governance of the digital infrastructure and was elaborated on in chapter 4.1. Martinez et al. (2025) emphasize that publicly accountable governance models lead to scalable and equitable DPI systems and continue that educational DPI should be managed as public infrastructure, not as isolated software platforms, ensuring control over data, funding, and infrastructure at the national level. This is likewise underscored by UNDP (2023) because the value of open-source DPI frameworks stems from the fact that they invite transparency and foster domestic innovation (United Nations Development Programme, 2023). This is all to conclude that well-founded DPI, that follows the technical, architectural, management and governance requirements expected of it, is likely to already include the desired design principles without needing much further input.

Further building off a well-founded DPI are development methods that engage governments, civil society, academia, and private innovators to create more adaptive and sustainable education platforms. The UNDP (2023) and ITU (2025) both highlight the importance of embedding DPI within a larger ecosystem, where policy frameworks, institutional capacity, and technical expertise develop in parallel. Davidson (1999) explains that end-users of the digital infrastructure, i.e. civil society, can participate in the development of it by utilizing joint application design (JAD) principles, where user participation is used to expedite development and improve the quality of its specifications. Similar principles can be used to involve private innovators and governments, which would all fall under the umbrella of the term end-user, whether they are using the system from a learner's or administrator's perspective. In education, this collaborative approach to development ensures that DPI platforms meet local pedagogical needs and reflect diverse perspectives. By co-creating infrastructure with multiple stakeholders, governments can develop DPI that is socially legitimate, better funded, and easier to maintain.

The final thing to consider with DPI development methods is reliability and continuity. When DPI is deployed using phased, resilience-oriented strategies, it can safeguard continuity and quality of education during crises or rapid change. The World Bank's ID4D and G2Px initiatives show that resilient DPI, such as digital ID, payment, and data-exchange layers, can maintain essential services and provide targeted support in emergencies (The World Bank, 2025). Similarly, Larsson et al. (2023) point to DPI-enabled platforms like DIKSHA and UPI in India, which kept education accessible during the COVID-19 pandemic. Specifically considering DPI development meant for education, resilience-focused deployment ensures that learning systems can function during disasters, network outages, or sudden enrolment shifts.

4.3 DPI Development Needs of Nations for Education

This section synthesizes insights from chapters 4.1 and 4.2 to illustrate how specific national educational priorities, which are shaped by economic and geopolitical objectives, can be met through specific DPI development strategies. The section maps theoretical DPI foundations and development methods to national education needs.

The first consideration for a nation's education priorities is for those derived from economic objectives, and one such objective may be achieving economic competitiveness. Nations seeking to enhance economic competitiveness via education and workforce readiness can deploy DPI, particularly certification, credentialing, and learning platforms, to streamline skills verification, lifelong learning, and employability (Larsson, et al., 2023). UNDP (2023) emphasizes that holistic education powered by DPI enables verification of educational credentials, promotes lifelong learning, supports workforce upskilling, and fosters economic growth through entrepreneurship and civic engagement, and Li (2024) argues that economic competitiveness via education is primarily obtained with upskilling. Therefore, countries prioritizing economic growth could integrate credential verification (e.g. digital microcredentials) into interoperable DPI systems that lower barriers to employment and improve social mobility, which best utilizes the results of population upskilling attained via education. Nations with large informal economies or skills mismatches can especially benefit by building transparent, scalable learning-to-work pathways. Inclusive, credential-based DPI becomes a foundational asset for economic competitiveness achieved via education.

Regarding other economic objectives, DPI can be structured to target equity by enabling inclusive access to educational services, reaching underserved communities through scalable, accessible digital infrastructure. UNDP's DPI framework centres equity and inclusion by emphasizing safeguards, inclusive design, and mechanisms ensuring that all benefit from digital systems. Zaw & Hlaing (2024) mention that for countries grappling with stark geographic or income disparities, DPI that includes offline capabilities, local language options, and accessible user interfaces ensures that educational platforms reach students beyond urban centers. Designing DPI as a public good can significantly reduce educational inequities.

Another consideration for a nation's education priorities is for those derived from geopolitical goals. Cross-border DPI cooperation supports geopolitical goals such as regional integration, transnational talent mobility, and mutual recognition of educational credentials (Hardy, 2024). The OECD (2023) mentions the importance of enhanced cross-border cooperation in DPI to ensure resilience and effectiveness across varying economic contexts. Countries aiming to integrate regionally, for example, through shared labour markets or educational exchanges, can leverage interoperable DPI systems (e.g., digital

identity and data-sharing layers) to facilitate secure, seamless transfer and recognition of academic credentials. Therefore, coordination of DPI across borders serves both digital resilience and geopolitical integration, reducing friction for student mobility and professional qualification recognition, and could serve as an effective application for mobility-based goals that e.g. the European Union supports (ENISA, 2025).

The development of DPI serves strategic national goals by creating resilient, adaptive infrastructure that can sustain educational delivery, improve upskilling, and maintain international relations amid technological change. The CDPI campaigns for DPI to be used as shared, interoperable systems that support service delivery at societal scale, so the inherent nature of DPI is of that where it supports the social and geopolitical goals of its member nations. WEF highlights DPI's role in acceleration of structural digital transformation, including for education and children's services (Larsson, et al., 2023). Countries investing in long-term resilience, nationally or regionally, benefit from DPI architectures designed for scalability and adaptability; for example, modules that support AI-enhanced tutoring or alternate-delivery models during disruptions (Haleem, et al., 2022). Embedding DPI within forward-looking digital strategies enables nations to proactively modernize their education systems and respond to global demands. Table 3 maps national needs (objectives) to components of DPI development and their educational benefits.

National Objective	DPI Strategy & Components	Educational Benefit
Economic development & workforce skills	Credentialing systems, microlearning, interoperable data exchange	Enhances employability, supports upskilling, increases economic inclusion
Regional integration & mobility	Cross-border digital ID, data-sharing, credential recognition	Streamlines student/professional mobility, mutual recognition of qualifications
Equity & rural access	Inclusive, offline, multilingual DPI design	Extends quality education to remote or marginalized communities
Resilience & future-readiness	Adaptive, scalable DPI embedded in national digital strategies	Supports education continuity and innovation amidst crises and technological change

Table 3: National needs mapped to DPI development components.

This table is partially meant to be used as a summary of chapter 4 and therefore provides a quick reference of the SLR results for the following case study of DPI systems in Finland. The national needs, DPI components and educational benefits described here are at a general level and can be compared to those discovered in the case study.

5 Case Study Results

This chapter investigates the data cooperation between Finland and Estonia in three sections. The first section provides concrete examples of educational DPI systems operating in Finland and notes on their development context, primarily using public statements by the nations and government reports as material. The second section examines evidence of international cooperation facilitating DPI development in the case of Finland and Estonia, using the results of the SLR and related research as reference. The third section evaluates the shared DPI development strategies to determine whether it is helping them meet national education needs, comparing them to those explored in the SLR.

5.1 Existing Educational DPI Systems in Finland

This section outlines key digital public infrastructure platforms and strategic initiatives underpinning educational systems in Finland. The section references earlier literature review findings on the governance, architecture, inclusivity, and ecosystem alignment of DPI systems and elaborates how these components materialize in real-world Finnish contexts.

Finland has articulated a clear national vision to become a global leader in sustainable digitalization of education by 2027. The strategy emphasizes equal learning opportunities, cross-generational collaboration, and ethical, needs-based digital tool design to support accessibility and equality in education (Ministry of Education and Culture, 2023). Aligned with EU's Digital Decade goals, Finland's National Strategic Roadmap defines clear targets for competencies, digital infrastructure, public service delivery, cybersecurity, and the data economy, and places education at the core of digital transformation (Finnish Government, 2024). These strategic frameworks set by Finland ensure DPI systems for education are well-integrated within broader governance, capacity, and policymaking ecosystems.

Finland's commitment to educational equity is rooted in its digital infrastructure investments. The system present in Finland ensures universal internet connectivity and device access, supported by ongoing professional development to empower educators with effective digital teaching methods. The Finnish National Core Curriculum (2016) explicitly embeds digital and media literacy as core competencies in education, so complementing it

with a comprehensive ecosystem of cooperation between educational institutions and DPI governance bodies would serve it well.

While the national strategy and curriculum establish the context for the existence of DPI systems in Finland, the Finnish National Agency for Education (EDUFI) oversees them in practice. Examples of digital platforms that EDUFI handles are Studyinfo.fi, a shared portal for vocational, upper secondary, and higher education applications, and Vipunen.fi, a statistical portal offering detailed education data (Finnish National Agency for Education, 2025). These platforms fall under our definition of DPI and include pedagogical tools, digital content, and systems designed around device access, teacher competencies, and digital tool alignment.

The various documents provided by the Finnish government and its education institutions, along with the current DPI systems that the institutions employ seem to indicate that current Finnish digital DPI emphasizes inclusive access, teacher capability development, and robustly governed national learning service ecosystems. These have helped sustain Finland's strengths in education technology integration. The OECD's comparative studies highlight Finland’s robust education technology ecosystem and governance and emphasize that it has good capacity for further development DPI in schools (Organisation for Economic Co-operation and Development, 2023).

5.2 The Facilitation of DPI Development with International Cooperation

This section examines how cooperation between Finland and Estonia has supported DPI development in education and more broadly. It traces institutional arrangements, technical integration (especially via X-Road), and draws heavily from the prior research conducted in chapter 2.3 as well as the development methods of DPI from chapter 4.2. To reiterate, the roots of cross-border DPI cooperation between Finland and Estonia dates to a 2013 Memorandum of Understanding signed by the two countries' prime ministers, which formalized collaboration on developing the X-Road data exchange environment. The cooperation matured through subsequent agreements between Estonian and Finnish agencies (e.g. Estonia’s RIA and Finland’s Population Register Centre) that laid out coordination mechanisms and a roadmap for jointly managing the X-Road core (Nordic Institute for Interoperability Solutions, 2025). This X-Road environment will be the primary focus of this

section, as it is a prime example of DPI following a key development requirement stated in the SLR: having governance that is neutral, inclusive, and sustainable rather than ad hoc or vendor-driven.

Hardy (2024) notes that when Estonia and Finland connected their national data exchange layers in 2018, they federated their X-Road instances (Estonia's X-Road and Finland's Suomi.fi Data Exchange Layer). Interoperability is enabled through the trust federation model, where each side retains control over its own systems, but mutually accepts credentials, signatures, and access under shared protocols and security measures. The trust federation allows service providers and consumers across the two countries to communicate as if part of a unified ecosystem, which is a key requirement of cross-border DPI. The architecture also aligns with other DPI design principles identified in the SLR: decentralization, privacy preservation, modular connectivity, and mutual trust mechanisms. However, to confirm the alignment of the X-Road system with those principles, it is important to examine the publicly available documentation and source code of the system (X-Road, 2025). A summary of the overall X-road system can be found in Table 2: Overview of the X-Roads system, but here we will go into the more technical details of it.

According to the X-Road documentation site, the architecture is explicitly designed to be decentralized: data exchange happens directly between organizations' security servers without central intermediaries, and each organization retains ownership over its data. The documentation also describes a layered protocol stack (REST or SOAP over secure transport) that encapsulates security, message routing, and metadata services in modular components. Regarding security architecture, X-Road supports strong authentication, encryption, digital signatures, time stamping, and logging of transactions. The source code (available via GitHub, per X-Road developer resources) is openly licensed (MIT), which increases transparency and invites community scrutiny, consistent with open standards and auditability. Documentation on the message transport protocol shows that communication between security servers occurs via mutual TLS and secure encapsulated messaging, meaning each transaction is confidential. The documentation also includes use cases like federation, metadata distribution, configuration proxy, and trust service management, which reveal how X-Road supports cross-border federation by distributing configuration and access rights across instances. Lastly, features such as environmental and operational monitoring (tracking service usage and server health) are built into the system to maintain

robustness without sacrificing decentralization. The public documentation and open code of X-Road broadly confirm that its design is consistent with the DPI principles identified (decentralization, modular and secure connectivity, privacy, trust). However, the documentation is more focused on infrastructure and message exchange than on domain-specific applications, which does not provide much insight on how to build an educational service layer (credential exchange, student data mobility, learning content interoperability) on top of this foundation.

Regarding this educational service layer, Clark et al. (2025) suggest DPI facilitates exchange of learning materials and credentials, implying that the Finnish-Estonian data infrastructure could extend beyond administrative registers into educational systems, and Finland and Estonia have indeed explored cross-border e-services that rely on X-Road's connectivity in education (Nordic Institute for Interoperability Solutions, 2025). The e-services should be able to provide recognition of credentials, student mobility services, and shared educational content exchange, but such services are currently nascent rather than fully deployed. Therefore, the X-Road system cannot be considered a full-proof example of successful international DPI development cooperation, but rather as a proof-of-concept. To better evaluate the cooperation, the strengths and challenges of it when viewed through the lens of educational DPI needs are illustrated in Table 4:

Strengths / Successes	Gaps / Limitations
Creation of NIIS provides stable, joint governance and neutral management of shared DPI components. Ensures sustainability and balanced oversight.	Some decision-making remains nationally siloed; differing administrative structures can slow joint implementation.
X-Road federation enables secure, real-time data exchange while maintaining data sovereignty. Proven reliability since 2018.	Full interoperability in education (e.g., credential exchange, student data mobility) still under development.
Shared population registers eliminate duplicate data entry and reduce bureaucratic friction for citizens and institutions.	Benefits remain largely administrative rather than pedagogical; limited end-user visibility.

Mutual recognition of digital identities and signatures builds institutional trust and sets precedent for other domains.	Legal differences in data protection, education law, and consent management complicate cross-border expansion.
Model adopted by Iceland, Faroe Islands, and Kyrgyzstan—showing replicability of the Finnish-Estonian governance model.	Expansion beyond Europe may face contextual and infrastructural mismatches.
Cooperation improves service reliability and exemplifies "DPI diplomacy," enhancing both nations' reputations as digital leaders.	Low public visibility: citizens may not perceive tangible benefits unless educational services are layered on.

Table 4: Strengths and limitations of DPI development cooperation

The table shows that Finland–Estonia DPI cooperation has succeeded in establishing strong technical and governance foundations, but the educational applications of that infrastructure remain yet unrealized.

5.3 The Satisfaction of Educational Needs with Shared DPI Development

The final section of this case study evaluates how the shared digital public infrastructure between Finland and Estonia meets the educational needs identified in Table 3. Building on the results from the systematic literature review and the findings of sections 5.1 and 5.2, this section assesses the extent to which the shared DPI, particularly the X-Road system and the governance model under the Nordic Institute for Interoperability Solutions (NIIS), fulfills national objectives such as economic development, regional mobility, equity, and educational resilience.

Finland and Estonia's cooperation on shared DPI infrastructure is notable for how effectively it meets many of the criteria for a well-governed, sustainable, and interoperable digital ecosystem. Table 5 below summarizes the alignment between these national educational objectives and the features of the shared DPI and is a continuation of Table 3 from chapter 4.3. A new column has been added that attempts to evaluate the degree of satisfaction that a national objective attains from the identified DPI component.

National Objective	DPI Features and Components	Degree of Satisfaction
Economic development & workforce skills	Shared data exchange through X-Road enables potential credential recognition and data portability for workforce training. NIIS governance promotes interoperable, scalable systems aligned with future employment and skills policy.	**Partial** – Strong foundations for workforce-aligned digital credentialing exist, but the educational application layer remains underdeveloped.
Regional integration & mobility	Mutual recognition of digital identities and signatures through a trust federation supports cross-border mobility and service access.	**Strong** – Citizens can already benefit from automatic data updating across borders, facilitating movement and educational continuity.
Equity & rural access	Open-source design, inclusive governance, and distributed architecture ensure service accessibility and transparency.	**Moderate** – Infrastructure enhances general digital access, but explicit equity measures in education are limited.
Resilience & future-readiness	Decentralized, secure architecture and joint management through NIIS ensure continuity and adaptability.	**Good** – System resilience is demonstrated in other public sectors but not yet fully applied to educational continuity or crisis response.

Table 5: The satisfaction of national needs with Finnish-Estonian DPI cooperation

Overall, the Finnish-Estonian model demonstrates strong progress toward systemic readiness and governance maturity, but its direct educational benefits are still emerging.

The NIIS has proven important in maintaining a balanced, neutral, and sustainable model of shared governance. By institutionalizing collaboration beyond political terms, NIIS safeguards the long-term stability of the X-Road core infrastructure. This stability aligns with the SLR findings that DPI success depends on sustained, transparent governance, and the administrative benefits of this cooperation already extend to citizens in tangible ways. When individuals relocate between the two countries, population registry data is automatically updated through the federated exchange. While the shared DPI between Finland and Estonia performs well in governance and interoperability, it has yet to achieve the same maturity in direct educational applications. Based on the objectives of DPI that the UNDP (2023) and Aro et al. (2025) explain, some gaps that remain are:

- **Lack of an Educational Service Layer:**
    - Although X-Road and NIIS provide the foundations, there is no fully implemented cross-border educational data ecosystem yet. Systems that could allow credential exchange, student data portability, or shared digital learning resources are still in early conceptual or pilot stages.
- **Legal and Regulatory Constraints:**
    - Differences in national data protection regimes (Petrone, 2022) and consent management frameworks continue to limit the exchange of sensitive educational information. Harmonization of educational data governance and privacy rules would be a prerequisite for cross-border learning data mobility.
- **Limited Awareness and Sector Engagement:**
    - The educational community, including teachers and administrators, remains largely unaware of the possibilities of shared DPI (European Comission, 2025). The infrastructure functions mostly at the governmental and technical levels, while front-end educational services are still underdeveloped.
- **Uneven Digital Priorities:**
    - While both nations are highly digitized, the pace of DPI implementation differs across sectors. Education has so far been slower to adopt X-Road-based services compared to areas like health or e-governance, partly due to stricter confidentiality norms and limited cross-sector collaboration (ENISA, 2025).

Overall, the shared DPI initiatives between Finland and Estonia satisfy many of the national educational needs at a systemic and infrastructural level. They succeed in fostering trust, interoperability, and governance resilience, which are important preconditions for the educational use of DPI. However, these successes remain mostly latent, as the educational potential of the infrastructure has yet to be realized through concrete applications.

6 Discussion

This chapter discusses the findings of this study within the broader context of digital public infrastructure (DPI) development and its implications for education. It evaluates how the results contribute to existing knowledge, how they address the research questions, and what limitations affect their generalizability. The chapter also considers the potential research risks associated with case study and literature review methodologies, emphasizing the contextual nature of the results.

6.1 Interpretation of Results

The results of the SLR and the case study of the Finnish-Estonian cooperation model indicate that the development of DPI for education should be approached as both a technical and institutional process and require governance structures that ensure inclusivity and interoperability. The systematic literature review demonstrated that DPI designed for education should enable equitable participation, data portability, and systemic coordination across sectors. These findings align with recent international research emphasizing DPI as a foundation for sustainable human development (Clark et al., 2025; Aro et al., 2025; UNDP, 2023). The case study of Finland and Estonia further confirmed that governance and interoperability mechanisms are essential preconditions for effective DPI. The cooperation between the two countries, particularly through the Nordic Institute for Interoperability Solutions (NIIS) and the X-Road system, demonstrates how shared digital ecosystems can create resilient and scalable infrastructures. However, the findings also revealed that while administrative and technical integration between Finland and Estonia is advanced, the educational applications of these systems remain underdeveloped. The shared DPI facilitates secure cross-border data exchange and citizen mobility, but it has yet to be leveraged for educational services such as credential recognition and learning resource interoperability.

When compared with broader DPI research, the findings of this thesis mostly corroborate existing knowledge. Yin (2009) and Okoli & Schabram (2010) explain that case study and systematic review methods allow for the exploration of socio-technical systems that evolve differently across contexts. This research follows that premise, showing how the institutional

and infrastructural maturity of DPI depends on national policy coherence and cross-sector alignment. Global studies on DPI, such as those on India's UPI (National Payments Corporation of India, 2025) and Estonia's Digital Signing (Eesti.ee, 2025) have demonstrated the transformative potential of shared digital systems (UNDP, 2023; World Bank, 2025). Yet, many of these existing systems have focused primarily on identification and public service delivery. By focusing specifically on educational implementation of digital public infrastructure, this study hopes to add a new perspective to the existing literature: DPI must not only connect data systems but also support the learning process itself through interoperability in credentialing, assessment, and content delivery.

From a broader perspective, these therefore findings reinforce the need for educational systems to be actively integrated into national and cross-border digital strategies. As more nations invest in DPI to support digital transformation, educational ministries and institutions must ensure that the infrastructures being developed are designed to support learning continuity and credential portability. The study also implies that DPI diplomacy, international collaboration around shared digital systems, can play a strategic role in enhancing administrative efficiency. Future research could focus on empirical measurement of DPI's educational impact, examining how shared infrastructures affect student outcomes, teacher practices, and institutional collaboration. Cross-country comparisons could also reveal how contextual factors, such as legal frameworks, funding models, and cultural expectations, shape DPI's educational efficacy.

6.2 Addressing the Research Questions

The study aimed to answer two primary research questions:

1. *What are the DPI development needs for education at a national level?*
2. *How has cooperation between Finland and Estonia helped to satisfy those needs?*

Regarding the first question, initial work was done to determine what DPI development is and in what ways it manifests, along with determining what the education needs of nations generally are. The related research and work done in the literature review demonstrate that the foundation of DPI development for education requires digital access, structured

governance, interoperability standards, sustainable funding, and institutional collaboration across ministries. The SLR established that national-level DPI for education must combine technical robustness with inclusive and ethical design to ensure accessibility, trust, and adaptability. These results were mapped to education needs that were collected from secondary sources for generalization, and the result of that work culminates in Table 3.

Regarding the second question, a case study on the data cooperation between Finland and Estonia was performed. After exploring existing DPI systems for education in Finland and determining the extent of cooperation that Finland and Estonia perform based on their core X-Road system, an attempt was made to determine how well features of that cooperation satisfy national education needs (Table 5). The results showed that international cooperation can satisfy many foundational DPI needs, such as governance, interoperability, and trust, but does not automatically translate into educational impact. The cross-border integration achieved through X-Road and NIIS provides a powerful infrastructure for future educational cooperation, yet tangible applications for credentialing, student data management, or learning content exchange remain limited. Thus, cooperation has effectively built the means for educational DPI but not yet the ends that directly serve educational users.

6.3 Limitations and Research Risks

There are some limitations that influence the interpretation and generalizability of this study. First, the analysis did not include extensive technical exploration or empirical validation of DPI systems. While the research examined technical documentation and governance frameworks, it did not perform quantitative analyses or measure system performance through data or usage statistics. Although the objectives of this study stated that the impact of DPI on education wouldn't be empirically measured, this absence of numerical or empirical validation is still a loss to the capacity of substantiating the findings through technical evidence or user data.

Second, the case study did not specifically investigate how existing DPI systems in Finland or Estonia have been impacted by the X-Roads cooperation. The analysis instead treated the Finnish and Estonian systems as complementary examples within a shared governance framework, rather than tracing direct causal or developmental effects between them.

Consequently, the study cannot definitively conclude how cross-border interoperability has altered or enhanced Finland's existing national DPI systems in education or administration.

Third, while the study identified national educational needs and mapped them against DPI development components, these needs were derived from the academic and institutional literature rather than being taken directly from official government programs or policy documents of Finland or Estonia. As a result, the alignment between the study's analytical framework and national strategic priorities may be partial rather than exact.

More broadly, as Yin (2009) notes, case study research inherently reflects the specific characteristics of its environment and cannot account for all contextual variables such as institutional culture, governance capacity, or policy maturity. Therefore, while Finland and Estonia provide valuable insights into cross-border digital cooperation, the findings may not be directly transferable to other regions with differing socio-political or technological contexts. The systematic literature review also carries methodological risks typical of secondary research, including potential publication bias, selective emphasis, and language limitations. As Okoli & Schabram (2010) emphasize, the interpretive synthesis of prior studies can introduce subjective weighting of evidence. This is present in this study as well due to the selection of sources that were searched with keywords contained in my employer's previous research.

7 Conclusions

This study examined the development need of digital public infrastructure (DPI) for education, with a specific focus on the cooperative DPI environment between Finland and Estonia. It explored how DPI systems can enable equitable, efficient, and interoperable education services and how international collaboration can support these developments. The analysis combined a systematic literature review with a case study approach to generate a holistic understanding of DPI's role in national and cross-border educational ecosystems.

The research was undertaken to address the growing global emphasis on digital transformation in education and to respond to the relative scarcity of studies connecting DPI frameworks with concrete educational outcomes. By investigating Finland and Estonia, two nations on the cutting edge of international data cooperation, the study aimed to identify replicable governance models and cooperation mechanisms that could guide other countries in building sustainable educational infrastructures.

The results demonstrated that DPI development for education requires a balance of technical interoperability, transparent governance, and inclusive policy design. The Finnish–Estonian cooperation through NIIS and X-Road provided a strong institutional and technical foundation for shared digital ecosystems, but educational applications such as credential exchange and student data mobility remain at a formative stage. The findings also confirmed that governance stability and trust mechanisms are as critical to DPI success as technological performance.

These results suggest that while Finland and Estonia's shared DPI satisfies many foundational requirements, such as resilience, interoperability, and transparency, it only partially fulfills the educational needs identified at the national level. The research questions were therefore answered by demonstrating that DPI enables but does not automatically deliver educational transformation; this requires explicit integration of educational policy, legal harmonization, and service-layer development.

In the future, the findings of this study could inform both policy design and further empirical research. Policymakers may use the Finnish–Estonian model as a reference for building regional DPI governance frameworks, particularly in the education sector. Future work

should include technical and quantitative analyses of DPI performance, explore the educational service layer in practice, and evaluate how shared infrastructures influence learning outcomes, equity, and institutional collaboration across borders.

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