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Smart digital learning resources are evolving into an adaptive ecosystem

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KEY MESSAGES

- The field of digital learning resources is undergoing its fourth generational shift. This marks a deeper transformation than before, as the field moves towards a self-regulating digital ecosystem.
- Commercial and open learning resources, two previously separate ecosystems, are increasingly converging.
- Estonia's Lifelong Learning Strategy 2020,¹ the Digital Turn Programme² and the shift to distance learning during the Covid-19 pandemic have accelerated the development of a self-regulating digital learning ecosystem, which has now reached a crossroads and requires forward-looking decisions.
- Adaptive digital learning resources and learning analytics, currently being tested only within research circles, offer the means to realise the flexible learning objectives set out in Estonia's Education Development Plan 2035.³

INTRODUCTION

When Estonia launched the Tiigrihüpe (Tiger Leap) programme⁴ in 1996, its initiators were wise enough to secure not only hardware and internet connections for schools but also subject-specific

educational software. At the time, such software was distributed on CD-ROMs and websites and consisted of computer programmes offering learning materials divided into lessons or



reference resources, mainly in the form of text and images, and less often as interactive multimedia. In 2008, the Koolielu (School Life) portal was created through a collaboration between the Tiger Leap Foundation and Tallinn University's Educational Technology Centre. It provided teachers with a platform for sharing their own presentations, notes, worksheets, tests and similar materials. However, the first generation of commercial digital textbooks emerged without a national framework or government support, and the small size of Estonia's textbook market severely limited publishers' capacity for digital innovation.

An early success story in the field of digital learning resources for non-formal education was Teooria.ee (2008), an online platform for practising traffic theory used in driving schools, as well as web-based tools supporting the informal learning of Estonian, such as ETV's Mudila and Keeleklikk. This article examines the current state and future prospects of the field in Estonia, placing it in the broader context of European and global trends.

THE EVOLUTION OF DIGITAL LEARNING RESOURCES TOWARDS A SELF-REGULATING ECOSYSTEM

Education technology experts in Estonia use the terms 'e-learning' (*e-õpe*) and 'digital learning' (*digiõpe*) interchangeably to refer to teaching and learning supported by digital tools – hardware, software and digital learning materials. Digital learning therefore does not refer solely to online distance learning but often takes place in classrooms with the help of digital tools. Web-based learning environments used in digital learning can be grouped into:

- group communication platforms, such as Microsoft Teams or Google Classroom;
- institutional learning management systems (LMSs), the most widely used in Estonian universities being Moodle;
- personal learning portfolios, such as a learner's personal WordPress blog.

All three types of learning environments share a common feature: teachers and pupils must populate them with digital content – learning

materials, tasks and solutions – while the web platform helps structure, manage, submit and provide feedback on this content. More specific types of digital learning resources include digital textbooks (the most widely used platforms in Estonian schools are Opiq and Maurus), educational mobile applications (e.g. Math99 for gamified maths learning), subject-specific digital services (e.g. GeoGebra), services supporting particular learning methods (e.g. the debate platform Kialo or the concept mapping tool CMapTools), and assessment services (e.g. the Estonian Examination Information System, EIS). People less familiar with educational technology often confuse learning environments with study information systems. In Estonian schools, the most common of these are eKool and Stuudium, and in vocational education, Tahvel. These systems serve administrative rather than instructional functions, managing pupils and class groups.

Repositories have been created for storing and sharing digital learning materials online. These allow keyword searches by text, author or filters, provide recommendation systems for popular or similar materials, and enable browsing by curriculum or target group. The main national open-access repository for digital learning resources is the e-Schoolbag (e-Koolikott), maintained by the Ministry of Education and Research. It contains over 40,000 interactive learning materials and enables teachers to create or adapt interactive resources in HTML5 format. Materials created with H5P can be used directly in e-Schoolbag (without logging in) or exported to learning environments such as Moodle or Canvas, which can generate rich datasets for detailed learning analytics.

The development of the digital learning resources and related services currently used in the Estonian education system was strongly driven by the Lifelong Learning Strategy 2014–2020, which included the Digital Turn Programme. As a result, by the start of the Covid-19 pandemic, the curricula for both lower and upper secondary schools were already largely covered by both open-access materials published in e-Schoolbag and commercial digital textbooks on the Opiq platform. Although Estonia's current Education Development Plan 2021–2035⁵ no longer refers explicitly to digital learning resources, one of

its central goals – flexible learning pathways – presupposes the availability of smart digital learning tools.

Together, these services are often described as forming a digital learning ecosystem. The metaphor draws on biological ecosystems to describe how modern digital services are distributed, adaptive, self-organising and interconnected. One of the key challenges of this approach is that learners' personal data, behavioural patterns, user accounts and performance records are stored across numerous service providers, some of which operate under different legal frameworks and may pass data on to third parties. For this reason, the next generation of digital learning resources must be developed with clear technical and legal requirements for service providers to ensure secure integration with central registers and study information systems while keeping learners anonymous to the service providers. Such an anonymity-preserving service integration interface is supported by the Learning Tools Interoperability (LTI) standard developed by the global edtech consortium 1EdTech. With the rapid spread of AI-based services in education, risks to learners' privacy and the intellectual property of authors are growing even more serious. It is therefore crucial for Estonia to establish strict requirements for digital learning ecosystem services used in general education in the near future.

In summary, the development of digital learning resources and related services in Estonia over the past 30 years – and looking ahead – can be divided into four generations:

1. Integrated educational software (1996–2003): distributed on CD-ROMs and websites
2. File-based static digital learning materials (2003–2016): presentations, text files and web pages
3. Web 2.0 transformation (2016–2024): interactive materials hosted by external service providers (e.g. Kahoot, Desmos and LearningApps)
4. Adaptive, AI-supported digital learning resources (from 2024): designed to support

flexible learning pathways, personalised learning and learning analytics, distributed within a decentralised service ecosystem.

The following sections examine the current state of digital learning resources in two ecosystems – open/free and commercial – which have evolved separately due to differing legal and business frameworks. We then outline possible future scenarios for Estonia's digital learning ecosystem based on trends in science and technology.

THE CONVERGENCE OF OPEN AND COMMERCIAL EDUCATIONAL RESOURCES

From a copyright perspective, digital learning resources can be divided into open educational resources (OER) and commercial educational resources. In the case of the latter, all rights – including the right to copy, distribute and modify the work – remain solely with the owner, even if the material is freely accessible online. Open educational resources, by contrast, are freely available and adaptable learning materials that can be used, modified and shared without restrictive licensing. According to UNESCO, which leads the global OER movement, open educational resources are 'learning materials that may be freely used and distributed, often under open content licences such as Creative Commons.'⁶ The main motivations for creating and sharing OER are to improve access to education, enhance the quality of learning materials, promote the democratisation of education and encourage educational innovation.⁷

Traditional copyright gives the author full control over their work, but it also significantly restricts access, free use and adaptation of digital learning resources.⁸ As in many other countries, in Estonia the main producers of copyright-protected digital learning materials are textbook publishers. In recent years, however, they have been joined by educational technology startups such as Foxcademy, Math99 and Praktikal. The largest commercial digital learning platform in Estonia is Opiq, developed by Star Cloud OÜ, which hosts more than 500 digital textbooks for general education schools published by various companies. The advantage of open content licences such as



Creative Commons⁹ is that they balance the rights of authors and users.¹⁰ Their weakness, however, is that teachers who adapt resources often overlook the fact that they have included images or texts protected by copyright in materials carrying a CC BY-SA licence.¹¹ Another unresolved issue is how to license learning materials that include content generated with the help of artificial intelligence.

Estonia's largest open-access digital learning platform, e-Schoolbag, was created in 2016 at the request of the Ministry of Education and Research. To facilitate reuse, all interactive learning materials on the platform carry the CC BY-SA licence. In general, however, Estonian schools prefer commercial learning materials – especially digital textbooks – that comply with the national curriculum and whose quality is ensured through professional reviewing. The procurement of educational materials and digital learning resources for schools is funded by the Ministry of Education and Research, yet the level of state support has remained unchanged for a decade at 57 euros per pupil per academic year. During that time, the state budget has grown by 126% and the average salary of general education teachers by 115%; the average textbook price has doubled. Applied research projects commissioned by the Ministry, such as DigiEfekt led by the University of Tartu (see Article 5.4), have provided research-based solutions but have had little direct impact on the development of commercial digital learning resources by publishers and edtech startups. The Ministry is planning to introduce an entirely new approach to funding the procurement of digital learning resources – one based on teacher vouchers – to create a marketplace for selling both teacher-created and company-produced materials directly to the target audience. The situation described above has already widened educational disparities between wealthier and poorer municipalities. The former have long been accustomed to using their own budgets to purchase high-quality digital learning licences for their schools. Unless measures are taken in the coming years to increase textbook funding and develop a functioning market for digital learning resources, unequal access to learning materials will increasingly deepen educational inequality.

DIGITAL LEARNING RESOURCES AT A CROSSROADS AFTER COVID-19

After the pandemic ended and the responsibility for paying Opiq licence fees shifted to schools, the platform's user numbers fell threefold. Interviews with teachers and school leaders¹² suggest that lack of funding was not the only reason behind this sharp decline. Both teachers and pupils seemed to experience 'digital fatigue' – a desire to return to ordinary school life. While countries such as France, Sweden and Denmark had already banned smart devices in schools, Estonia's Ministry of Education and Research has so far maintained its support for schools' right to make autonomous decisions. An alternative approach, following the examples of Portugal and Austria, would be to provide every pupil with a laptop or tablet through state support to ensure equal access to quality education, even in the smallest schools and least affluent municipalities.

Acquiring and using high-quality digital learning resources remains a challenge. In addition to affordable digital textbook licences and the continued development of open educational materials, this also requires access to digital devices and internet connectivity in every classroom. These are areas where the Estonian school system still has considerable room for improvement. Experts who have long worked in the field now share an understanding expressed by President Toomas Hendrik Ilves in his 2014 Independence Day address: 'What brought us here will not take us further.'¹³ If the state decides to give educational technology companies the opportunity and responsibility to build the next-generation digital learning ecosystem on a market-driven basis, it should at the same time ensure equal access to learning resources for all educational institutions, teachers and learners. However, a market-based approach combined with greater state support would address only the needs of formal education, leaving non-formal education – such as art, music and sports schools, technology and nature clubs, and adult education – in a disadvantaged position. In these fields, learning content is highly diverse, and there is virtually no financially sustainable market.

The field of digital learning resources is now entering a phase of sociotechnical transition, where innovators are testing alternative technical, pedagogical and economic models for the next generation of digital learning ecosystems. For example, in Austria, the startup Teachino.io is gaining popularity in schools by replacing static repositories with large language models that generate adaptive learning pathways and automatically produce materials tailored to each pupil's level and learning habits. In this sense, the adaptivity of future digital learning resources may take on a new meaning. AI could not only select the most suitable learning activities and materials from existing ones but also generate them in personalised form, based on the learner's goals and detailed learning analytics. It should be noted, however, that current experiments with automatically generated adaptive digital materials have not yet been recognised by researchers or teachers as being on a par with those created by subject experts.

Based on the developments outlined above, three possible scenarios can be envisioned for the next decade in the evolution of digital learning resources:

- **Stagnation.** If Estonia's current solutions and funding levels persist, the field of digital learning resources will stagnate, inequality between schools and municipalities will increase, and innovation will fade. New digital tools will be developed mainly within informal education that many parents will be unable to afford, such as gamified learning environments.
- **A two-tier system.** Limited and mostly media-driven innovations – such as AI-based platforms – will bring rapid progress only for a small community of motivated innovators and schools, while the mainstream education system remains digitally under-resourced, textbook-based and focused on traditional exam preparation.
- **Flexible smart learning for all.** A social, cultural, economic and technological generational shift in the digital learning resource ecosystem, driven by collaboration between universities, the public sector, and private enterprises to

create a new, accessible pool of digital learning resources for all schools. The foundations for such a system would include converting the national curriculum into a machine-readable format and developing adaptive digital learning resources and AI-supported tools to enable flexible, learner-centred and self-directed learning pathways.

The following section presents the findings of the EduFlex applied research project, commissioned by the Ministry of Education and Research and carried out by Tallinn University between 2021 and 2024; its results point towards the third scenario.

A VISION OF THE FUTURE: FLEXIBLE LEARNING PATHWAYS AND ADAPTIVE DIGITAL RESOURCES

Among its goals for 2035, Estonia's current Education Development Plan seeks to create more flexible learning structures and content and to reduce barriers between different types of formal and non-formal education. The plan and related documents repeatedly refer to flexible learning pathways, though without defining the concept in detail. The EduFlex project's primary goal was to establish a scientifically grounded conceptual framework for understanding, describing and studying flexible learning pathways and learner-centred education.¹⁴ In addition, the project sought to test this framework in practice by implementing various types of flexible learning, along with supporting learning resources, environments and methodologies, in real school settings.

We began by clarifying key terms – for example, distinguishing between instructional trajectories designed through instructional design for many learners and a personal learning path, which refers to the record left on a digital platform by a learner's interactions with digital learning materials, peers and teachers. We also distinguished four levels of learning trajectories:

- macro-level trajectories offering learners flexible choices between types of schools, study areas, and general or vocational education;

- meso-level trajectories describing options available to learners within a specific school level – choices between elective subjects, courses, ability groups and modes of study;
- micro-level trajectories representing differentiated approaches for achieving one or two specific learning outcomes;
- nano-level trajectories that no one is likely to have the resources to document fully, but where a teacher or AI-based agent can, during a single lesson, recognise individual learning needs and support them through varied activities, resources, guidance or other methods.

At all levels, a degree of flexibility can be built into trajectories, even when all learners are ultimately expected to achieve the same learning outcomes. Earlier generations of adaptive learning platforms – from programmed learning in the 1960s to adaptive hypermedia in the 1990s – understood adaptivity mainly as sequencing tasks and materials according to individual learner performance, without giving the learner any control. The EduFlex project, by contrast, aimed to support co-regulated learning, where the learner (in collaboration with the teacher where necessary) decides on the next type of activity – for example, individual, pair or group work – as well as the task’s difficulty level, number of repetitions and modes of support, such as hints or examples. A recommendation algorithm analyses the learner’s digital path and suggests appropriate options, but the final decision must involve human judgement. Such flexible learning requires, in addition to subject knowledge, the systematic development of self-regulation and learning skills in every learner and every learning trajectory.

Designing and analysing micro- and nano-level flexible learning pathways first requires breaking down the learning outcomes defined in the national curriculum into smaller knowledge and skill units and linking each outcome to digital learning objects available across different platforms. Before EduFlex began, a working group on flexible learning pathway infrastructure led by data scientist Peep Küngas had already started this work at the Ministry of Education

and Research. By 2021, the group had developed a machine-readable format for describing learning outcomes in the national curriculum, with examples published on the Semantic MediaWiki platform. Building on this approach, EduFlex created flexible learning trajectories for Year 9 algebra based on a machine-readable domain model, complemented with interactive exercises developed in the H5P content authoring tool, which is used in e-Schoolbag. These trajectories were tested with nearly 200 pupils in real classroom settings, their individual learning paths were collected and analysed using learning analytics tools,¹⁵ and experiments were conducted with AI-assisted generation of adaptive tasks at specified levels of complexity.¹⁶ The cautious conclusion was that, for now, the automatic generation of adaptive activities and tasks by text-based AI tools is feasible only with the involvement of a human expert.

Turning this vision into the foundation of a new digital learning regime will require solving numerous technical, pedagogical, economic and legal challenges. For example, Estonia’s Personal Data Protection Act and the GDPR currently do not permit the large-scale collection of learners’ performance data envisioned here. There are also serious obstacles to integrating open and commercial learning materials within flexible learning pathways (unless the state first purchases licences for all commercial materials for all learners). Nevertheless, within the global community of educational technology innovators, new technical standards and market models are emerging that could pave the way for a next-generation digital learning ecosystem – one that allows cross-use of learning content from multiple providers alongside open educational resources.

REFLECTION

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Thirty years since the launch of Estonia's Tiger Leap programme, we now have a broad range of learning environments, digital textbooks, educational apps, digital learning materials, learning-support services, digital study information systems and repositories. Collectively, these are often referred to as the digital learning ecosystem. But can we really call it that? When these tools are managed by different owners, hosted on different platforms, used by some teachers and pupils but not others – when everyone builds their own system or none at all – is it still an ecosystem? In teachers' professional standards, the educational ecosystem is defined as a network of institutions, educators, learners and other individuals and organisations within a region, the relationships between them, and the resources available to its members. In the digital world, resources exist and are created, managed and used by people, but these actors often do not form a coherent network. The different applications, services and content rarely interact with one another. In this sense, we are still some way from a genuine ecosystem.

The main obstacle to building a digital learning ecosystem lies in the use of data within an increasingly restrictive legal environment. Can we influence the international policies that, as a member of the European Union, we are obliged to follow? People are becoming more aware and more sensitive, and laws often protect us preemptively against almost any use of data. Yet without data, no meaningful connections can be made between the components of the network; without those connections, we cannot know what works well and what does not in the digital domain. As a result, the world of digital solutions risks becoming a confusing patchwork of isolated elements in which neither teachers nor pupils have confidence.

To turn this confusion into a functioning ecosystem, three things are needed.

- 1. Clear rules that support development and smart solutions.** The use of digital learning resources can only become truly smart if researchers, developers, teachers and learners are able to collect and use data systematically about the use and effectiveness of all digital tools, services and content. Such data makes it possible to determine which learning outcomes are achieved through which approaches. Regulations should not hinder the processing of data needed for innovation – on the contrary, they should facilitate it. Data can and should be anonymised, but it must remain connected. This is essential for a new Tiger Leap: Estonia can be a true innovator only if its rules enable smart, data-informed decisions while protecting people's rights.
- 2. Fair compensation for contributors to the ecosystem.** We already have a vast array of components to integrate into a digital learning ecosystem – some open-access, others commercial. For the ecosystem to function organically, there must be a system that ensures fair remuneration for those who create applications, services or content. Beyond financial incentives, social impact is also crucial – the opportunity to shape how learners perceive and understand the world.
- 3. Personal digital devices and internet access for every learner to reduce educational inequality.** A digital learning ecosystem can function only if most learning takes place within it and leaves a digital record. Many countries are moving in the opposite direction, introducing national restrictions on pupils' use of digital devices. Estonia, however, has the opportunity to lead by example – to show the world how to expand pupils' digital autonomy while supporting collaborative learning, self-regulation skills and the assessment of not only academic achievement but also of learners' mental, physical, social and emotional well-being.

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