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Deliverable Report

Extending Design Thinking with Emerging Digital Technologies

Grant Agreement Number 101060231

HORIZON-CL2-2021-TRANSFORMATIONS-01-05

(Integration of emerging new technologies into education and training)

Deliverable D2.1
Report on the theoretical review

Due date of deliverable: 28 February 2023

Actual submission date: [add]

Exten(DT)^2 identifier	Deliverable D2.1 Report on the theoretical review
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Work Package /Task no.	WP2 / Task 2.1
Work Package lead	NTNU
Document status (select)	Draft Version 1 (created 8 Jan) Draft Version 2 (created 31 Jan) Draft Version 3 (created 10 Feb, after Katrien Strubbe´s feedback) Draft Version 4 (created 16 Feb, after Manolis Mavrikis and Filothei Chalvatza´s feedback)

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Abbreviations

AI	Artificial Intelligence
AR	Augmented Reality
CK	Content Knowledge
DF	Digital Fabrication
DT	Design Thinking
EDM	Educational Data Mining
ET	Emerging Technologies
EU	European Union
IoT	the Internet of Things
LA	Learning Analytics
ML	Machine Learning
PK	Pedagogical Knowledge
STEAM	Science, Technology, Engineering, the Arts, and Mathematics
STEM	Science, Technology, Engineering, and Mathematics
TK	Technology Knowledge
TPACK	Technological Pedagogical Content Knowledge
TPD	Teacher Professional Development
TPK	Technological Pedagogical Knowledge
VR	Virtual Reality

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Summary

Exten. (D.T.)² Overview: scope and objectives

The overarching goal of the Exten. (D.T)² project (text below as written in the proposal) is to use emerging technologies such as Artificial Intelligence (AI), Augmented Reality (AR), 3D printing, and Virtual Robotics to enhance pedagogical values, sustainable digitisation and potential for wide deployment of Design Thinking (DT). In Exten. (D.T.)², we argue that enhancing DT with Emerging Technologies (ET) could make DT a more feasible, accessible and inclusive approach for all students and teachers. In addition, the integration of ET in DT could preserve and expand DT at the scale of the dynamic, multifaceted and immersive aspects of this approach. The main target groups of this project are teachers and students at the level of K-12 education.

To reach the goals of this project, as shown in Figure 1, we will uniquely integrate ET, including AI in the form of Learning Analytics (LA), AR, 3D printing/scanning and virtual robotics, with these expressive media aiming to leverage the digital implementation, monitoring and evaluation of DT projects in the context of K-12, but also to increase our understanding of how they can support students 21st-century skills development. This will, in turn, increase the scope, educational potential and applicability of DT in mainstream schooling.

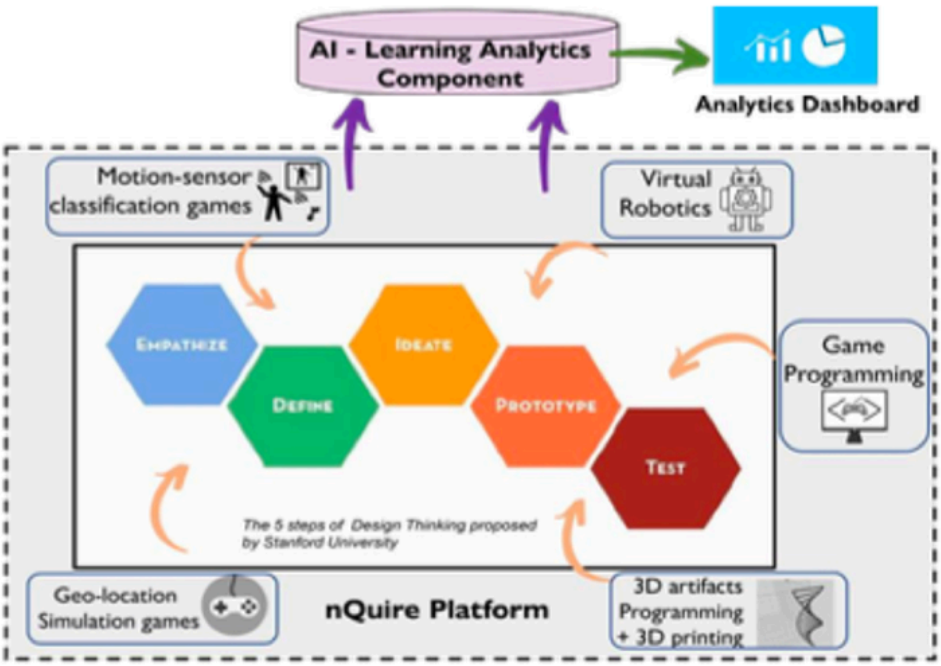

Figure 1. The Exten. (D.T.)² approach to a sustainable digitalisation of education (Source: the Exten. (D.T.)² project proposal)

The specific objectives of Exten.(D.T.)^2 are to:

- Design, develop, implement and scale up a transformative pedagogical intervention for supporting the implementation, monitoring and evaluation of DT projects, digitally extended with emerging technologies.
- Bring together different stakeholders in rethinking the nature of emerging technologies for design thinking activities by co-creating Exten. (D.T.)^2 resources and technologies for inclusive learning.
- Support Teacher Professional Development (TPD) concerning the necessary competencies for the meaningful exploitation of the project's technologies in DT activities.
- Create a network of schools and out-of-school organisations connected through nQuire that will collaborate on DT projects during and beyond the project timeframe. It will empower students to define problems that influence their lives and provide them with 21st-century skills to solve them.
- Develop a Framework for stakeholders and policymakers, including guidelines on setting up, monitoring, and evaluating DT projects supported by the project's emerging technologies.

Objectives of the deliverable

The deliverable.2.1. (namely, a theoretical review) is the first of three deliverables of WP2, which will be built on the best available research and rooted in the challenges of supporting the digital transformation of the education ecosystem.

This deliverable aimed to identify Best Practices, Challenges and Requirements to enhance Design Thinking with Emerging Technologies in a valuable way for students, teachers and other educational stakeholders' digital literacy. In addition, this deliverable will be used as a base for creating and developing the framework (D2.2.) of WP2.

The deliverable 2.1. reports on the outcomes of Task 2.1. This task comprehensively reviews current best practices, approaches and perspectives for integrating the project's technologies (Learning Analytics-Feedback, AR-motion sensors, 3D printing and V- Robots) in STEAM and Design Education regarding both online and blended learning contexts.

1. Introduction

1.1. Interrelation of the deliverable with other WPs

The deliverable identifies best practices, challenges and requirements for enhancing design thinking with emerging technologies (relevant to the project), which could be inspiring and insightful for other WPs (as described in Figure 2 below), e.g., Co-design of Educational Resources and Material (WP3), Shaping Technologies (WP4), School Interventions (WP5), Professional Development (WP6), and Evaluation (WP7). Based on the literature, this deliverable aims to shed light on what is known on relevant topics and deliver this information as a baseline for critical thoughts for the work of the WPs and the project.

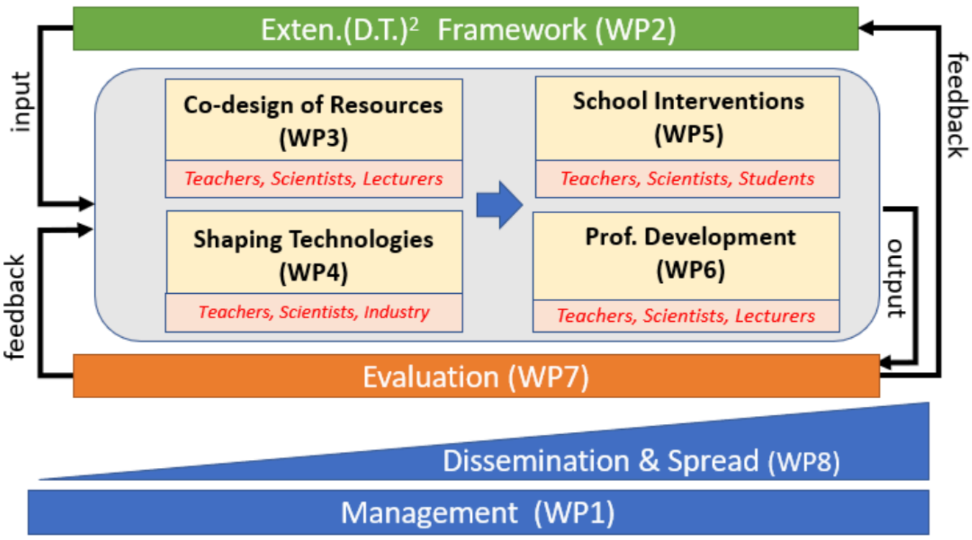

Figure 2. Pert diagram showing the project's WPs and their interrelation (Source: the Exten.(D.T.)² project proposal)

1.2. Structure of the deliverable

This deliverable presents the process executed to identify practices, challenges, and requirements in enhancing DT with ET in a valuable way for students, teachers and educational stakeholders' digital literacy. The present report constitutes the following four parts:

- Introduction: This section shows the relation of the deliverable with other WPs.
- Theoretical foundations: This section gives outline of DT and ET in K-12 education, and digital transformation of education.
- Methodology: This section describes the methodology used for the deliverable.
- Results: This section is consisted of the following four subsections.
    - Overview: This section briefly presents an overview of the pedagogical concepts used with DT in current research (subsection 4.1.1.), the content of activities and skills that existing DT interventions aimed to cultivate (subsection 4.1.2.), the materials and resources where particularly focused on

the digital tools used in DT (subsection 4.1.3.), teacher's role in DT (subsection 4.1.4.), the formality of DT interventions (subsection 4.1.5.). duration of DT intervention (subsection 4.1.6.) and assessments used in DT (subsection 4.1.6.).

  - Best Practices: This section outlines the best practices for enhancing DT with ET for students (subsection 4.2.1.), teachers (subsection 4.2.2.), and educational stakeholders (subsection 4.2.3.). This section also highlights the current trends of DT and related practices (subsection 4.2.4.) and frameworks on digital competencies (subsection 4.2.5.) identified in the literature. Last, this section reviews the best practices for applying ET in educational contexts (subsection 4.2.6.).
  - Challenges: This section reports the challenges in enhancing DT with ET for students (subsection 4.3.1.) and teachers (subsection 4.3.2.). In addition, this section presents the challenges of adopting DT to the school curriculum (subsection 4.3.3.) and the challenges of providing suitable tools and extending ET to DT (subsection 4.3.4.) identified in the literature.
  - Requirements: To overcome the challenges identified in the literature and reinforce the best practices, this section accordingly conceptualises the requirements for students (subsection 4.4.1.), teachers (subsection 4.4.2.), educational stakeholders (subsection 4.4.3.), technology development (subsection 4.4.4.), and for creating inclusive DT projects and ethical implementation of technologies (subsection 4.4.5.).
- Discussion: This section conceptualises and maps the follow-ups of Exten. (D.T.)^2 based on what was found in the relevant literature. This links the future actions of the project and sets the ground for the work described in the proposal to address the existing challenges and requirements inspired by the best practices examples.
- Conclusion: This section summarises the key findings of the deliverable and concludes the work.
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2. Theoretical foundations

2.1. Design thinking in K-12 education

With a focus on human-centred and user-oriented design, the Design Thinking (DT) (Brown, 2008) provides a dynamic process with clear steps for creating novel, workable, and sustainable product solutions collaboratively. Previous research has viewed DT as valuable for preparing young generations with critical 21st-century skills in a rapidly changing new era. For example, DT is regarded as crucial for education in the 21st century and a highly recognised resource (Matthews & Wrigley, 2017). DT also enables students to use a user-oriented strategy for tackling wicked problems (complex, real-life, disputed, socio-scientific concerns), such as creating innovative solutions to sustainability problems that still need to be tested (Buhl et al., 2019). In addition, DT has the values to complement monodisciplinary thinking by offering an effective technique for collaborative creative work across disciplines (Lindberg et al., 2010).

DT process consists of various stages uniquely linked and frequently iterative, such as empathising with the users, ideation and brainstorming, prototyping, testing and refinement, sustainability planning, and delivery of the final product or service. A few widely used DT models exist, such as the Stanford d.school Design Thinking Process (Figure 3) and the Double Diamond Process (Figure 4).

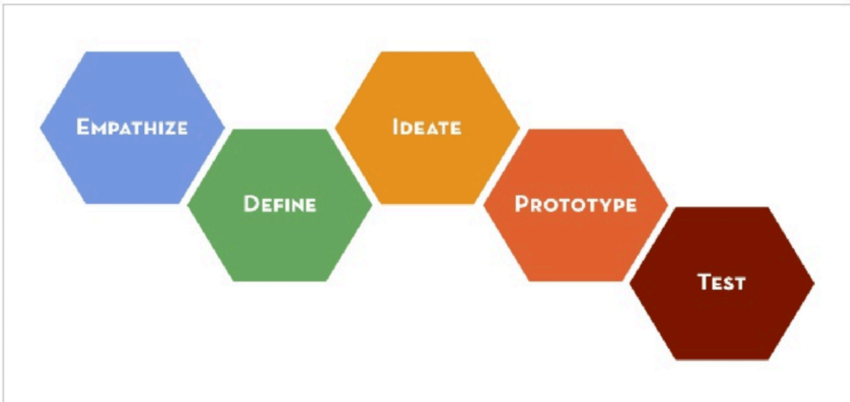

Figure 3. Sandford d.school Design Thinking Process[1]

[1] https://dschool.stanford.edu/

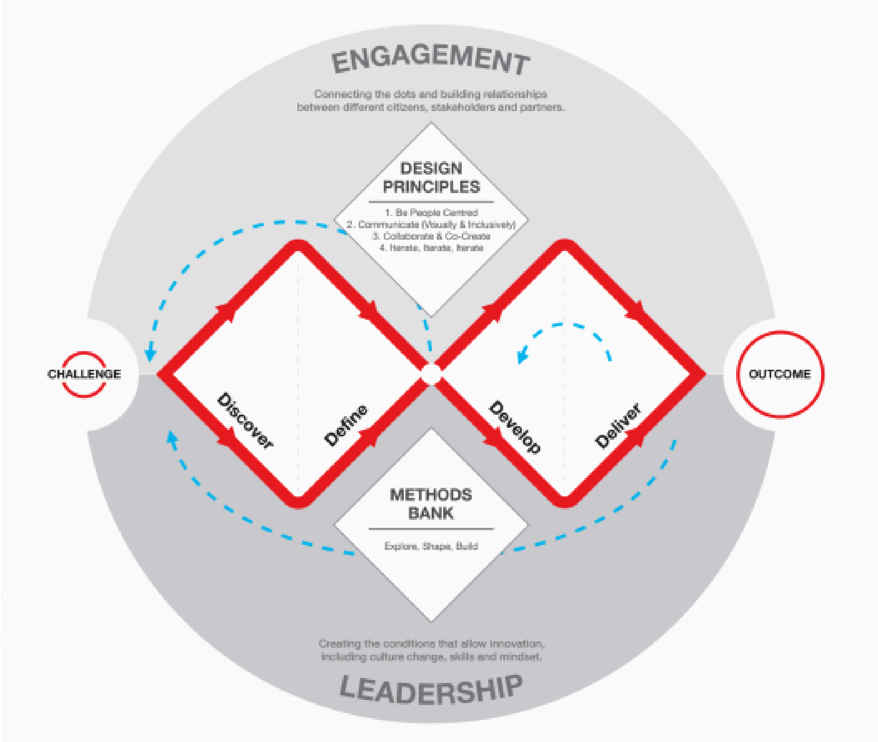

Figure 4. Double Diamond (Design Process Model) popularised by the British Design Council[2]

It is widely accepted that DT is vital as a bridge in STEAM education and other multidisciplinary subjects. There are various applications of DT in K-12 education. According to a recent review by (Panke, 2019), most DT programs in K-12 focus on STEM and STEAM education. For example, some programs engage students in the engineering DT process to solve engineering problems (Mentzer et al., 2014, 2015), and some teach students physics concepts (Simeon et al., 2022) and programming (Gross & Gross, 2016) through the DT processes. DT was also embedded in subjects such as design (Christensen et al., 2019), geography (Carroll et al., 2010), technology (Gennari, Melonio, et al., 2022; Lin et al., 2020), and also in multidisciplinary curricula (Cutumisu et al., 2020; Leinonen et al., 2020).

2.2. Emerging technologies in K-12 education

Technology's role as a constructivist and exploratory medium has recently received fresh attention, given considerably more pertinence as individual and social computational or digital literacy (Angeli & Giannakos, 2020; Grover & Pea, 2017; Wing, 2008). Rotolo et al. explain emerging technologies (ET) as "*technology radically novel in using a different basic principle to fulfil a given function than what was previously used to achieve a similar purpose, thereby changing the status duo*" (Rotolo et al., 2015). Many new and innovative technologies are being developed and are not yet widely available or fully mature for educational purposes. For example, augmented reality (AR), learning analytics (LA), artificial

2 https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/

intelligence (AI), machine learning (ML), the internet of things (IoT), virtual reality (VR), 3D printing, and robotics are growing in educational contexts.

With regards to educational data mining (EDM) or LA, their promising use has been envisioned by Berland et al. (2014) that can be used in constructionist pedagogical approaches and open the door for more people adopting the student-centred approaches as it might increase the viability of assessment on a broad scale, permit the development of smarter technology for real-time feedback, speed up and improve the feedback process to students and give researchers a deeper understanding of the learning processes (Berland et al., 2014).

To boost the potential of ET in DT, a previously promising but sparsely used pedagogical innovation, the Exten. (D.T.)^2 project aims to address this challenge by uniquely integrating pedagogically valuable digital solutions, such as coding, modelling, and game design, with LA, AR for embodied learning, and 3D printing for rapid prototyping.

2.3. Digital transformation of education

In a world where digital technologies are advancing at great speed and constantly reshaping the world around us, citizens should receive the appropriate education that will equip them with attitudes, competencies and skills to show responsible citizenship on a personal and professional level. Digital transformation has changed our society with a significant impact on our everyday lives and made clear the need for education and training systems and institutions to have greater levels of digital capacity. In addition, the current tendency toward online and blended learning has been further driven by the COVID-19 pandemic. According to the “Commission staff working document”, digital technologies in teaching and learning revealed fresh, creative approaches for educators and students to plan their teaching and learning and engage in more flexible online interactions. Parallel to this, the adoption of digital technologies for education revealed issues and disparities between those who have access to them and those who do not (including people from disadvantaged backgrounds); issues related to the digital capacities of education and training institutions; issues related to teacher preparation; and issues related to general levels of digital skills and competences (Commission staff working document SWD 209 final, 2020). In this sense, the advantages but also the dangers of digitalisation are shown.

In response to all the above, an updated European Union (EU) policy initiative called the Digital Education Action Plan (2021–2027) lays out a shared vision for high-quality, inclusive, and accessible digital education across Europe. It intends to support Member States' efforts to modernise their educational and training systems[3]. This initiative involves a wide range of actions and priorities, among others, priority 1, “Fostering the development of a high-performing digital education ecosystem”, and priority 2 “, Enhancing digital skills and competencies for the digital transformation”.

While the use of digital technologies in teaching and learning, when properly planned and designed, presents several advantages, their use also presents difficulties since learners must be digitally literate and educators must master the digital environment to develop high-quality and engaging learning experiences (Commission staff working document SWD 209 final, 2020). The adoption of digital technologies and enabling society to profit from the digital transformation while avoiding the problems that may result from digital exclusion or inappropriate use of technology are crucial roles that education and training systems must play (Commission staff working document SWD 209 final, 2020).

Exten. (D.T.)², aims to contribute to the digital transformation in education using emerging technologies in DT. As an illustration, Exten. (D.T.)² addresses the challenge of the appropriately delivered teaching and learning processes via the involvement of digital solutions such as coding, modelling, and game design with LA-enabled systems. Besides, this effort also aims to involve all relevant actors (e.g. teachers, students, and educational researchers) in co-designing the ET and appropriate professional materials, frameworks and guidelines for their use in practice.

[3] https://education.ec.europa.eu/focus-topics/digital-education/action-plan

3. Methodology used to find relevant literature for deliverable´s purpose

The deliverable is based on results from a literature review on digital technologies in DT education (and STEAM-related contexts). In this process, the following approach was taken:

- During the initial steps, we tried different search strings to familiarise ourselves with the topics, as shown in Figure 5. Also, we investigated keywords used by similar reviews and revisited and changed the search stings.

Design Thinking
- Design thinking education
- Design thinking learning
- Design thinking pedagogy
- Design thinking program
- Design thinking curriculum
- Design thinking course
- Maker education
- Learning by doing
- Game-based learning
- Design-based learning
- Constructionism

Emerging Technology
- Digital technolog*
- Learning technolog*
- Educational technolog*
- Educational robot*
- Educational gam*
- Learning analy*
- Virtual reality
- Augmented reality
- Mixed reality
- Virtual robot*
- Motion sensor
- 3D printing
- Digital Fabrication
- Digital literacy
- Digital media
- Digital design
- Computational empowerment

K-12
- Pupil
- Children
- Adolescent
- K-12 student
- Primary school
- Middle school
- Secondary school
- High school
- Secondary education
- Teacher
- Educator

Figure 5. Search strings used for the initial exploration

- The search strings that were selected for screening were: ("Design Thinking" AND ("digital" OR "analytics")) to ensure the inclusiveness of related topics and meanwhile stick to the concept of DT.
- Searches were performed in relevant search engines and databases, including SCOPUS, Web Of Science, ERIC, IEEE, ACM digital library, and Google Scholar. Special attention has been given to relevant journals such as the International Journal of Child Computer Interaction, the International Journal of Computer-Supported Collaborative Learning, the British Journal of Educational Technology, the International Journal of Science Education, and the Journal of Science Education and Technology. Also, relevant conferences were screened, including FabLearn, CHIplay, CHI, CSCL, LAK, CSEDU, EC-TEL, IDC etc.
- We conducted random Google Scholar searches and quality checks on the major references, to our best knowledge, that appeared in the records we used in our search string. Besides, we used the snowball strategy that relied on cited sources and additional context knowledge of the field based on the first screening of the papers.
- To cover all the topics relevant to this deliverable, additional searches on the engines above, databases and venues also happened "on demand" to find relevant literature supporting aspects missing from the collected records.
- The types of literature used included books, scientific research papers, EU project deliverables, and EU governmental reports and documents.

- The date range was prioritised to publications in the past ten years, and studies worldwide published in English were included for screening. As a result, the total number of initial records was 5.040.
- Studies were assessed for relevance in the following three aspects. (1) It should be in an education/learning context (especially in design education and STEAM). (2) It should involve K-12 students or teachers/educators. Moreover, (3) At least part of the paper should address or report either a technology (e.g., digital and analytics tool) for DT, curriculum/program of DT, or TPD for DT.
- In total, 148 documents were included in the final literature review and are reported in all the sections of this deliverable.
- The final collected documents were flagged with relevant codes depending on their category for the data extraction. The codes included mainly: DT, STEAM, pedagogy, technology, teachers, students, professional development, best practices, challenges, needs, requirements, criticism, competencies, skills, school, formal, and informal education. Based on these, the documents were collected and further analysed based on the sections of the overview, best practices, challenges, requirements and their respective sub-sections (e.g., for students, for teachers, for educational stakeholders, DT and ET).

4. Results: a state-of-the-art

4.1. Overview

In this section, we briefly outline the state-of-art referring to most of the critical components identified in the framework of the spider web model for curriculum development proposed by Van den Akker et al. (2010), as shown in Figure 6. In the following sections, we present (1) the pedagogical concepts related to DT (inspired by the components of rationale and learning activities in the spider web model), (2) content and skill (inspired by the components of content and aims and objectives in the spider web model), (3) material and resources (with a particular focus on the digital tools and technologies), (4) teacher role, (5) group size, (6) formality (reflecting on the component of Location), (7) intervention duration (inspired by the component of Time), and (8) assessment.

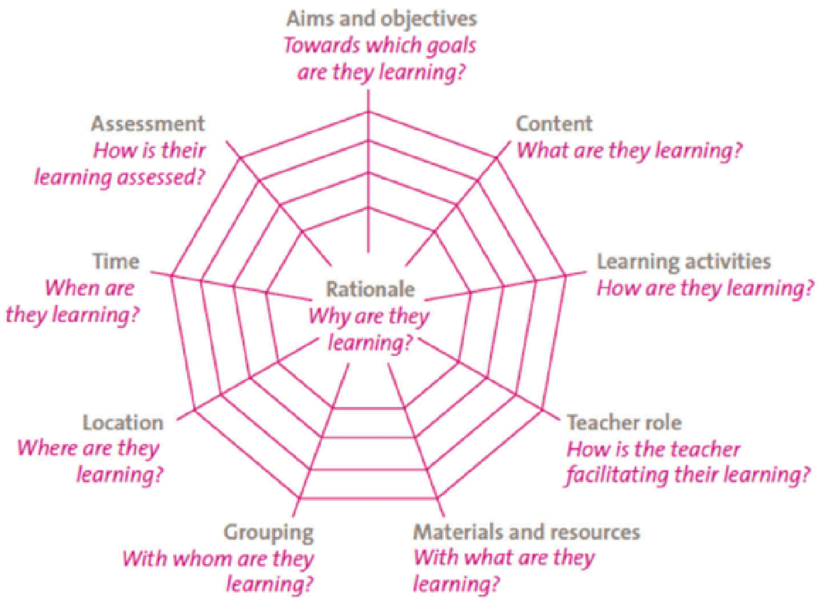

Figure 6. The Spider Web Model for Curriculum Development proposed by (Van den Akker et al., 2010)

4.1.1. Pedagogical concepts related to DT

We found some educational concepts have been interchangeably or blended with DT (e.g., maker education, constructionism, design-based learning, etc.). In the following paragraphs, we list a few cases as an illustration.

Maker Education and DT share many similarities, such as ideating, making, and aiming to nurture 21st-century skills. A review (Veldhuis et al., 2021) claimed that many practices had used both approaches of DT and maker education in the school setting or informal settings such as after-school activities. For example, case studies that used these two pedagogical concepts, e.g., in the context of Fab Lab Oulu (Laru et al., 2019; Pitkänen et al., 2020), Danish Fab Lab (Andersen & Pitkänen, 2019) maker Spaces in Sweden (Eriksson et al., 2018;

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Kjällander et al., 2018), and maker spaces in the US (Campos et al., 2019; O'Brien et al., 2016), online distributed making in Canada (Murai et al., 2021), interdisciplinary modules for making in Germany (Spieler et al., 2022).

It is a well-accepted view that Maker Education and making inherits the underlying tenets of Constructionism, which conceptualises learning and knowledge building as a process constructed from making artefacts (Papert & Harel, 1991). Furthermore, we found that some studies (Donaldson & Barany, 2019; O'Brien et al., 2016) particularly referred to constructionism as their theoretical rationale in their programs emphasising DT and maker education.

Similar to learning by doing, Design-Based Learning or, in other words, learning by designing (Kolodner et al., 2003) is another pedagogical concept that was introduced to instruct and enable students to go through DT and learning processes (Huang & Wang, 2022; Ke, 2014; Scheltenaar et al., 2015; F. Zhang et al., 2019; F. Zhang, Markopoulos, Bekker, et al., 2022). As an illustration, in some literature, DT is referred to Design-Based Learning which is a paradigm that "applies DT in a problem-based or project-based learning context" (F. Zhang et al., 2020) and is perceived as a "model for enhancing creativity, endurance, engagement and innovation" (Dolak et al., 2013). Using DT in the classroom enables students to create their ways of knowing and doing by going back and forth through a series of design phases (e.g., insights, investigation, ideation, and implementation); consequently, students gain experience and understanding of the ideas and information offered in the design project (F. Zhang, Markopoulos, Bekker, et al., 2022).

Design is often used to promote student engagement but is rarely studied as a disciplinary phenomenon. According to Oleson et al. (2021), it still needs to be clarified how to characterise the kinds of design that may accompany computing topics even though design and computing tend to intersect in educational contexts. For example, in the study of Oleson et al. (2021) identified two types of design within existing computing education curricula: non-disciplinary problem-space design, which deals with defining software requirements, and disciplinary program-space design, which deals with choosing how best to meet those requirements (Oleson et al., 2021).

4.1.2. Content of Activities and Skills

DT has mainly been used so far for scaffolding, supporting, teaching and enhancing the subject-based content knowledge and associated skills. As described in the literature, many of these are related to each other, e.g.,

- STEM subjects (Forbes et al., 2020; Nail & El-Deghaidy, 2021)
- STEAM subject-based knowledge (Henriksen et al., 2019; Kijima et al., 2021)
- engineering design and mathematical understanding (Chiu et al., 2013)
- mathematics learning (Ke, 2014)

- creativity (Grammenos, 2016; Rao et al., 2022)
- problem-solving (Carroll et al., 2010)
- critical thinking (Rao et al., 2022)
- spatial thinking skills (Bhaduri et al., 2019, 2021)
- computational thinking skills (Eriksson et al., 2019; Grizioti & Kynigos, 2021)
- digital fabrication techniques like 3D printing and laser cutting (Leinonen et al., 2020; Smith et al., 2015)
- computational empowerment (Dindler et al., 2020)
- programming (Chytas et al., 2018; Weibert et al., 2014)

4.1.3. Materials and Resources

Low-tech materials were often used to conceptualise ideas during the early design phases. For example, in one study (Malinverni et al., 2020), students need to build a "wearable robotic costume" using the Makey-Makey. They used different craft materials to connect with Makey- Makey**,** such as cardboard, coloured papers, tapes, EVA foam, modelling clay, aluminium foil, etc.

According to the investigation by (Malinverni et al., 2020), transitioning from low-tech materials to digital materials created richness in explorations and possible formalisation. The richness of props available in the software enabled the possibility of shaping and reshaping their idea, experimenting with different solutions, putting and removing stuff, and changing shapes and dimensions. Even if some students started from an already defined idea, they allowed themselves to ‘’get lost’’ in the materials and playfully improvise with them, following a non-goal-oriented learning and creative process. Some other students were not interested in using the software for experimenting but in obtaining the best possible formalisation of their low-tech prototype. In this case, their initial idea was not drastically modified but improved and optimised. At the same time, while the initial low-tech prototype was not satisfying them, the transition to 3D modelling allowed them to find their path to the satisfaction of being proficient as shown in the study of Malinverni and colleagues.

Overall, various technologies and digital tools have been used in DT interventions. However, we found that technologies are not fully covering all stages and scenarios of DT in education; for instance, no specific technology was found to support the stage of empathising with the users, and no dedicated tool was found to support capturing students´ learning progress in real-time or support distributed collaboration during DT education. Furthermore, despite growing interest in developing virtual robotics and AR-motion sensors, to our knowledge, they have not yet been implemented in DT in the context of K-12 education. Besides, technologies were primarily developed for students as the primary users, while how to engage and prepare teachers for that is very limited.

Below we listed some tools used for specific contexts and situations:

DT activities authoring (for educators)

- TEACH21 (Bekker et al., 2019; Taconis et al., 2018)
- GROOW[4]

Scaffolding DT process (for students)

- DigiSNap (Gennari, Matera, et al., 2022)

Prototyping/construction

- Lilypad[5]
- Arduino[6]
- Mblock[7]
- Tinkercad[8]
- Makey Makey[9]
- Littlebits[10]
- Scratch[11]
- Makers Empire 3D App (Hatzigianni et al., 2021)
- MaLT2 for creating and animating 3D dynamic figural models (Grizioti & Kynigos, 2021)
- FabCode (Agrawal et al., 2014)

Game authoring/modding (for students)

- SILO consists of a web-based game authoring tool and an app on the phone for playing the games (Wake et al., 2018)

Information sharing during the DT process

- Fireflies and DBL task cards for communicating emotions and tasks (F. Zhang, Markopoulos, An, et al., 2022)

Reflection (for students)

- ReflectionScope: a camera-based digital tool (Z. Zhang et al., 2020)

Assessment tool

- DeL tool to assess students' stances towards inquiry as a general measurement of design literacy (Christensen et al., 2016)
- EmoForm to retrospectively assess students' emotions and self-perceived learning (F. Zhang et al., 2019)
- Posterlet: game-based assessment that collects evidence regarding two DT strategies (Cutumisu et al., 2019)

Web-based learning environment

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[4] https://tast.tools/groow/
[5] https://the-lilypad.com/store/home.php
[6] https://www.arduino.cc/
[7] https://mblock.makeblock.com/en-us/
[8] https://www.tinkercad.com/
[9] https://makeymakey.com/
[10] https://classroom.littlebits.com/explore/search
[11] https://scratch.mit.edu/

- WISEngineering, a new web-based learning environment (Chiu et al., 2013)

4.1.4. Teacher's role

Teachers play a different role in DT than one expects in traditional learning contexts. For example, teachers often acted as a facilitator organising the learning activities, providing instruction on the DT process and learning tasks, and providing feedback and evaluation to students (Smith et al., 2016; Veldhuis et al., 2021). These dynamic roles and responsibilities teachers experienced in DT also created challenges for them to manage and switch balance frequently depending on the context (Hjorth et al., 2016).

4.1.5. Group size

Even though not every study in this literature review specifies the grouping of their DT activities, we found that most DT projects involved a small group of two to six students working collaboratively, e.g., (Aflatoony et al., 2018; Carroll et al., 2010; F. Zhang, Markopoulos, Bekker, et al., 2022), while only a few reported the case of individual learning. Given the opportunistic nature of the design process (Guindon, 1990), students are supposed to move back and forth between collaborative and individual tasks (F. Zhang, Markopoulos, Bekker, et al., 2022). Research has also shown that DT can potentially improve students' 21st-century skills, such as collaboration (Kolodner et al., 2003). Therefore, it is unsurprising that students can practise their collaboration skills while working in a small team. Besides, the complex design process may require teamwork to solve the wicked problem collaboratively using students' prior knowledge and experience.

4.1.6. Formality

Most reported studies occurred in a formal setting as a part of school education. However, some took place, e.g., after-school programs (Simeon et al., 2022; Won et al., 2015), innovative summer camps (Rao et al., 2022), or design workshops (Zhou et al., 2017, 2021). This suggests an encouraging trend of adopting DT in formal, non-formal and informal educational settings.

4.1.7. Intervention duration

We found that DT interventions span from a day to a year-long academic period, depending on the program's ambition or the case study context. For example, a 3-day workshop described in the study of Kijma et al. (2021) examined how DT can cultivate female students' interest in STEAM. Slightly differently, Sabuncuogh (2020) presented a one-year (over 36 weeks) curriculum for teaching middle school students AI, in which DT has been used in one module for skill and knowledge building (Sabuncuoglu, 2020).

4.1.8. Assessment

During the process of DT and learning, students need to identify problems, make plans, keep track and reflect on their progress, evaluate the constraints of design solutions, and test and make improvements. For example, some traditional assessments were found, such as summative evaluation of students' learning using questionnaires and surveys (in some cases with open-ended questions) to evaluate**,** e.g., students' skills or knowledge gains (Marks & Chase, 2019; Simeon et al., 2022), and self-efficacy (Vongkulluksn et al., 2018). Some other assessment approaches, e.g., collecting students' portfolios (Chan & Holbert, 2019), experience sampling forms (F. Zhang et al., 2019), interviews and classroom observations, were used to evaluate students' learning experiences during the DT process. Overall, what seems missing is the real-time analysis and assessment of students' learning processes in DT.

4.2. Best practices

This deliverable aimed to identify best practices to enhance DT with ET in a valuable way for students, teachers and educational stakeholders' digital literacy. Concerning best practices, we followed the definition of the term "best practice" described in (Papanastasiou, 2021; Walsh et al., 2022), which refers to specific, evidence-based procedures that are most likely to result in enhanced performance or better conditions. Below we present the best practices from the literature for each topic, i.e., regarding students (subsection 4.2.1), teachers (subsection 4.2.2), educational stakeholders (subsection 4.2.3), DT (subsection 4.2.4), frameworks on digital competencies (subsection 4.2.5), and ET (subsection 4.2.6).

4.2.1. For Students

(1) Provide students with modalities and playfulness in technologies and tools used in learning. For example, the results of a survey study by (Sabuncuoglu, 2020) regarding teaching children AI suggested that combining physical (e.g., worksheet activities) and digital exploration (digital interactive content) was found to be highly appreciated by students. Besides, students also enjoyed the playful way of learning with many trials and errors and the rewards that kept them active in the learning process.

(2) Provide equal opportunities for learning among different gender groups. We need to ensure that activities are appealing and relevant to many, both boys and girls (or other), to promote equal possibilities for all children to comprehend and learn about digital literacy and DT. For example, one study by (Eriksson et al., 2018) demonstrated that girls are sometimes more likely to attend if boys are not invited.

(3) Create reflection sessions. One study by (Milara et al., 2020) suggested that the emphasis on reflection is beneficial for students. Such activities allow students to participate, find new, creative ways of learning, and get excited about learning.

(4) Promote students' learning and self-efficacy. An intervention (Schlegel et al., 2019) revealed that making increased students' self-efficacy and STEM possible selves refers to future-oriented motivational aspects reflecting their self-concepts and identities that a person believes they could possess one day; cf. (Markus & Nurius, 1987). This suggests a promising impact of maker and DT programs on students' adaptation to STEM subjects. Another study by (Tsai & Wang, 2021) evaluated the relationship between students' DT disposition and computer programming self-efficacy. The results indicated that students' self-directed programming learning experience was beneficial for their DT disposition. Besides, students' disposition to ideate, prototype and define significantly predicted the overall computer programming self-efficacy. This suggests that enhancing young students' design thinking dispositions in identifying problems, brainstorming ideas and presenting models of solutions may improve their computer programming self-efficacy.

4.2.2. For Teachers

(1) Developing teachers' mindsets entailing openness, curiosity, responsiveness, and willingness to use technology and materials in daily professional practices for teaching DT is the key to becoming a DT educator. Such an open, curious and responsive mindset will encourage teachers to view creation as a learning process rather than a completed output (Landwehr Sydow et al., 2021).

(2) **Use DT as a framework to educate teachers and reframe their engagement with curriculum planning**. TPD should be hands-on and theoretically grounded (Stevenson et al., 2019). Kelly et al. (2019) described a model of TPD for teachers based in Australia in response to their new DigiTech curriculum, in which DT has been used as the core guiding framework for teachers (as designers of learning technologies) to be equipped with DT-related skills and mindsets. The results in this study (Kelly et al., 2019) suggest that the process of DT (e.g. brainstorming, mapping, rapid prototyping and peer evaluation) is a viable path for teachers to work through in redesigning or rethinking curriculum. Teacher education might consider DT as a framework for teachers to blend the analytic with the creative in how they think about curriculum (Henriksen et al., 2019).

(3) Use technological pedagogical content knowledge (TPACK) as a framework to equip teachers with related knowledge for the digital transformation of DT. This framework was proposed by Mishra and Koehler (2006) to conceptualise teachers' knowledge construction through the connections among multiple aspects of knowledge. As shown in Figure 7, to connect their technology knowledge (TK) with their pedagogical knowledge (PK), for instance, teachers can create technological pedagogical knowledge (TPK), which can then be combined with content knowledge (CK) to create TPACK. Additionally, Koh et al. (2015) have argued that teachers should construct their TPACK using design thinking as a strategy to address the complex factors in technology-integrated lesson design and the 21st-century learning (Koh et al., 2015).

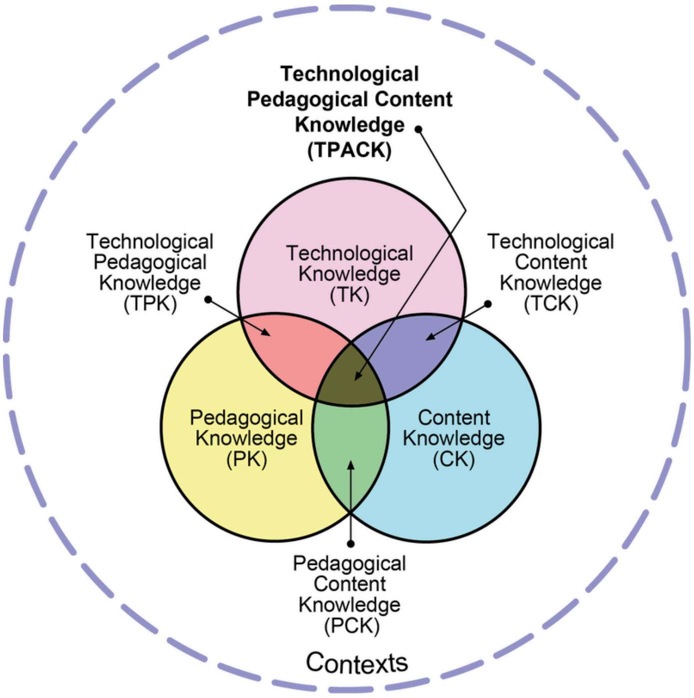

Figure 7. the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006)

(4) **TPD using FabLab@SCHOOLdk design process model**. The varying TPD activities are framed by this model of Hjorth et al. (2016), as shown in Figure 8. It can provide a good structure for teachers´ learning processes and managing problem-solving processes in education. Further, the teachers can use this model in designing and implementing DT interventions in their own teaching practice.

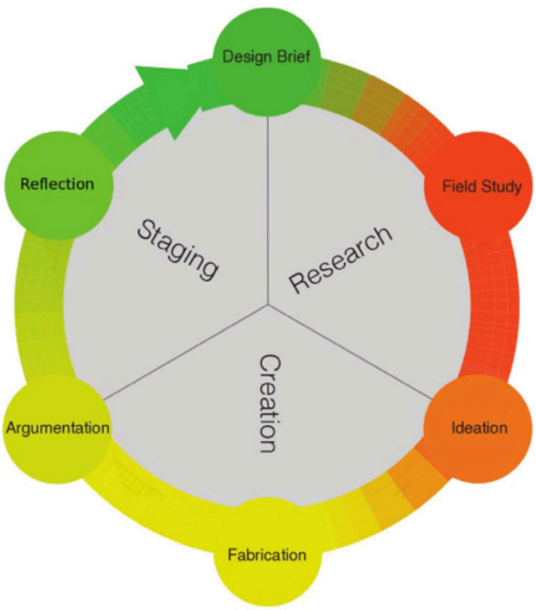

Figure 8. FabLab@SCHOOLdk design process model (Hjorth et al., 2016).

(5) Structured TPD with step-by-step training. Structured TPD with supplementary online professional development and an extended application phase is considered critical support for TPD (Stevenson et al., 2019). During TPD, teachers should be familiarised with ill-structured assignments (Pitkänen et al., 2020). Importantly, adequate and enough training should be reserved for TPD to establish the resources and responsibilities that each school and practitioners need to consider (Milara et al., 2020).

4.2.3. For Educational Stakeholders and their role

(1) **Build a stakeholder community.** Professional development should be socially oriented and establish collaboration between teachers and other educational stakeholders (Pitkänen et al., 2020). Our review pointed out the importance of having a community of educational stakeholders. For example, a study by Andersen and Pitkänen (2019) identified five essential stakeholders who support and develop a field of practice:

- Pioneers — key actors in developing new teaching practices
- Principals — enabling and supporting teachers in adopting new methods and competencies and initiating new learning activities in schools
- FabLab leaders — providing the Pioneers with TPD within technology and pedagogy
- Project leaders — supporting the work of FabLab leaders and making it meaningful in and around the educational organisations
- The FabLab@SCHOOLdk organisation — facilitating and developing internal and external collaboration.

Another study by Milara et al. (2020) presented the concept of the Community of Practice as their best practice. The stakeholders in this community include:

- In-service teachers from the six comprehensive schools who initially joined the community. The principals of each school chose the teachers among their staff. Instead of selecting only technology-skilled teachers or with ICT background, they were recommended to choose teachers from different backgrounds to avoid silos. In addition, it was preferred to include teachers who needed to be more technology-skilled but were excited about learning new things and willing to inspire their colleagues.
- Principals from the six participating schools decided on general education strategies and allocate educational resources. Principals need to understand their teachers' opportunities and challenges and need to assign adequate resources, and show their support.
- Officials from the local education administration. This includes teachers not working full time as docents but taking some administrative or organisational tasks.

- University researchers and teachers in the fields of Learning and Education Technology, Human-Computer Interaction and Computer Engineering.
- Fab Lab instructor. Experts in the field of DF, with some pedagogical background.

(2) **Support collaboration and transferability.** A shared understanding and a common starting point of TDP for each school to work is essential (Milara et al., 2020). In a study by Veldhuis et al. (2022), teachers emphasised the importance of collaboration with other educational stakeholders in curriculum development. The co-creation of design projects among various stakeholders could democratise the creation of educational materials (Veldhuis et al., 2022).

4.2.4. Current trends of DT and related practices

This section compiles the components and elements of DT presented by current related practices. For example,

(1) **A framework for teaching Design-Based Learning** (i.e. a compatible pedagogical concept to DT, see subsection 4.1.1.) **with digital toolkits** proposed the following five key elements based on insights gained from literature research and two case studies (Scheltenaar et al., 2015).

- *Roles*. It is crucial that teachers adjust to a mindset where students are more self-directed than they are just blindly following a process. Teachers should also become comfortable with or confident in the fact that they cannot always foresee the results of design activities.
- *Design brief.* It should provide the opportunity to engage in a design process and should define a clear goal for the use of the toolkit.
- *Design-based learning.* It is an educational approach that incorporates a design process to stimulate learning.
- *Toolkit.* The toolkit's usability plays an important role in this framework. The toolkit should be sufficiently inclusive to allow use by students with a variety of learning preferences while also providing the opportunity to dig deep into the toolkit's components and features (Resnick, 2007).
- *Learning goals.* Another crucial fact is that the approach must enable the evaluation of whether learning objectives were met. The design approach and briefing must both help with this.

(2) Bosch identified **critical elements regarding DT in the maker-based curriculum** as below (Bosch, 2022)

- *Empathy.* It is a crucial component of DT and one of the project's primary building blocks, serving as both a significant learning objective and a way of being for teachers.

- *Participation.* It was crucial to interact and work with individuals outside of one's own age group. It was also crucial to find purpose and develop their own agency while developing and creating something for other people.
- *Learning goals.* The learning goals should facilitate students to think and act in new ways, make mistakes, learn from failures, practice collaborative work related to new digital technology, and document the learning process.
- *Assessment criteria.* This should be designed based on the main learning goals and the structure of the curriculum.
- *Design brief.* It is open-ended, offering students the freedom to take the design in their own direction but constrained to support the process.
- *Clear assignments and pedagogical material.* This is started by showing the Double Diamond design model (see Figure 3 in section 2.1.) to students, pointing out the current stage of the process and the next steps to move on in the process. Daily assignments offer a clear description of the motivation behind them.
- *Experimental and hands-on exploration-oriented activities.* The digital tools are used in a creative way rather than following step-by-step instructions, which creates an engaging and motivating way to design something meaningful for others.
- *Collaboration and mutual learning.* The teacher forms the student groups considering it better to copy authentic co-design processes in which diverse students come together. Students pre-defined their roles, considering it is engaging for them to be responsible for their own tasks.
- *Reflection.* It should be part of the process. At the end of each session, students add details of the progress and photos to their e-portfolios.
- *Teachers' varying roles and their mindsets and modes of teaching.* Teachers should have multiple roles, such as teachers, facilitators, authorities, supporters, and peers.

(3) According to the combination of inquiry-based learning with DT, the H2020 eCraft2Learn Project outlined **a five-stage pedagogical approach** (as shown in Figure 9) for bringing digital fabrication to the educational context (Suero Montero et al., 2020) includes:

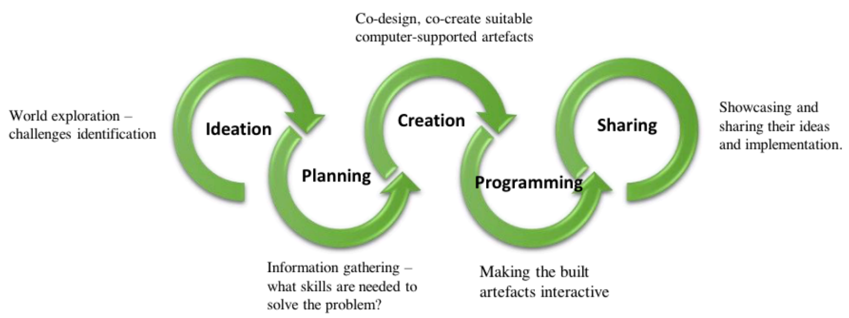

Figure 9. Five-stage pedagogical approach (Suero Montero et al., 2020)

- *Ideation through world exploration*. Students can explore the world by taking pictures, exploring online or physically outside the classroom to find out the challenge one is facing.
- *Planning*. After the challenge has been identified, the students gather information to develop a project plan. They can receive feedback on their project plan from the teacher and the group members. They may do this parallel with the stages of ideation and creation.
- *Creation*. In this phase, the students use digital fabrication technologies to co-design and co-create their artefact solutions that are computer-supported. This stage also includes crucial components like the simulation and visualisation of the designs.
- *Programming*. Students decide on appropriate scripts (high-level programming languages) for their designs to work. Two additional components of this stage are integrated SW/HW simulation and software debugging.
- *Sharing.* Students share and showcase their projects in the classroom and through the open (online) community to receive feedback worldwide.

4.2.5. Frameworks on Digital Competencies

(1) **The DiKoLAN Framework.** To design and implement digitally aided science education, DiKoLAN specifies the digital competencies that are pertinent. These include methodological skills and knowledge connected to digitalisation, both of which are crucial for a variety of goals in educational practice. In addition, as shown in Figure 10, DiKoLAN makes a distinction between three more subject-specific competency areas (e.g., data acquisition and data processing) and four broader, less subject-specific competency areas (e.g., documentation and presentation).

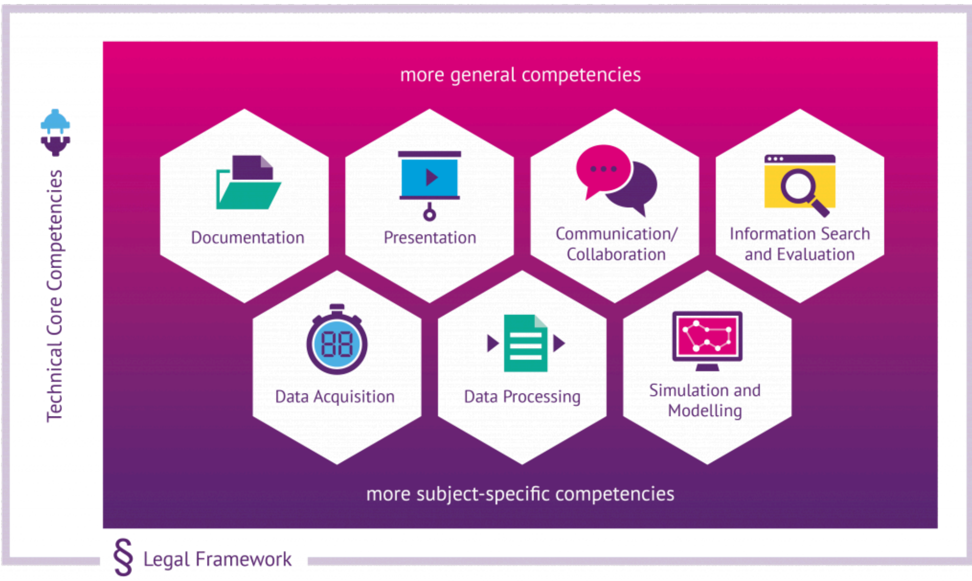

Figure 10. DiKoLAN – Digital Competencies for Teaching in Science Education (Kotzebue et al., 2021)

(2) **The UNESCO ICT Competency Framework for Teachers.** The ICT competencies advance as a teacher moves up the stages from Knowledge Acquisition to Knowledge Creation. As shown in Figure 11, the six components of each level are ICT in Education Policy, Curriculum and Assessment; Pedagogy; Application of Digital Skills; Organization and Administration; and Teacher Professional Learning. These components represent the regular responsibilities of a practising teacher. To enable teachers' ongoing improvement, each level builds on the abilities and understanding attained in the one before it.

Figure 11. The UNESCO ICT Competency Framework for Teachers (*UNESCO ICT Competency Framework for Teachers - UNESCO Digital Library*, 2018)

(3) **European Framework for the Digital Competence of Educators: DigCompEdu.** Teachers serve as examples for the younger generation. It is crucial that they have the digital skills necessary for all citizens to be able to engage fully in a digital society. These competencies are outlined in the European Digital Competence Framework for Educators (DigCompEdu) (Joint Research Centre (European Commission) et al., 2017), as shown in Figure 12. In addition to being utilised as the foundation for teacher training and professional development inside and outside Europe, DigCompEdu has gained widespread acceptance as a tool for assessing and certifying digital competence. Teachers must possess these competencies to participate personally and professionally as citizens of society. They must be able to demonstrate their digital proficiency to learners and impart their creative and critical use of digital technology if they are to serve as role models.

Figure 12. European Framework for the Digital Competence of Educators: DigCompEdu (Joint Research Centre (European Commission) et al., 2017)

(4) **The Digital Competence Framework for all citizens with new examples of knowledge, skills and attitudes.** As shown in Figure 13, the core competencies for the lifelong learning (Vuorikari et al., 2022) list critical competencies for citizens to live fulfilling lives, be employable, engage in active citizenship, and be included in society. Each key competency is related to and complements the others. In other words, developing competencies in one domain will be aided by developing competencies in another.

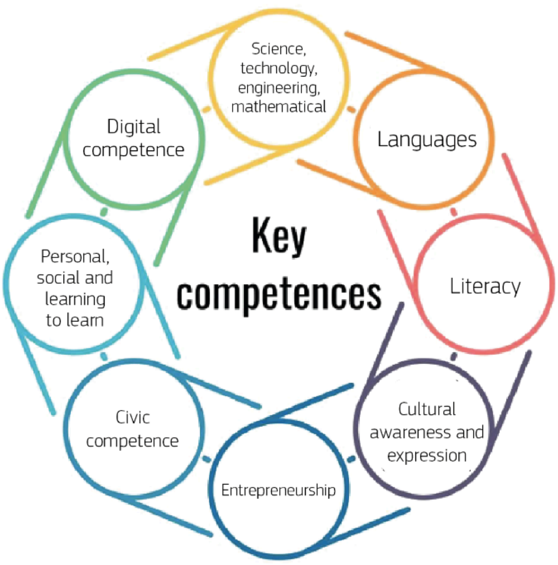

Figure 13. Digital competence is part of the Key Competence Framework for Lifelong Learning and is interlinked with other competencies (Vuorikari et al., 2022).

4.2.6. Emerging Technologies

(1) **3D printing.** Presenting objects in 3D space through 3D printing technology can help students comprehend and learn topics (Li et al., 2020). By digitalising the production process, 3D printing technology overcomes spatial restrictions and is based on digital model files. Through the direct and quick production of tangible items, 3D printing can bring concepts to life and expand our capacity for thought and imagination (Lewis, 2019). The ability to exhibit objects realistically, especially those not readily available in classrooms, is a fundamental benefit of 3D printing as a rapid prototyping tool for DT (Alexandra, 2020). For instance, 3D printing can provide mathematical models and 3D visuals to students in maths classrooms. Students can learn through experience using 3D-printed reproductions of historical and cultural artefacts in their history lessons. The most compelling use of 3D printing in education is providing chances for instruction in real-world situations (Huang & Wang, 2022). 3D printing in education encourages student learning and has applications in design thinking, learning, and motivation.

(2) **Learning Analytics (LA) for teachers and students.** LA, with the usage of the appropriate system, gives the possibility for personalised learning and feedback that is presented as a compelling justification for the adoption of LA because it can lower delivery costs while also improving learning experiences, accelerating the development of competency, and fostering greater collaboration among learners (Greller & Drachsler, 2012). Therefore, it is possible to have the following:

- Appropriate systems that, with the use of LA, can provide personalised feedback at scale (with personalised messages) (Pardo et al., 2019).
- Authorable educational interactive tasks for exploratory learning activities that an "author" (e.g. teacher, instructor, researcher, designer, etc.) can:
    - o dynamically configure the data a learning object will log throughout a user session. This can include data obtained through user-widget interaction as well as data derived from events that cause the widget to produce data on its own (Karkalas et al., 2017)
    - o define guidelines for providing students with real-time feedback (based on log data that is dynamically created as the learner interacts with the activity
    - o have less cognitive load and lower entry hurdle to generate or alter feedback (Karkalas et al., 2017)
    - o It appears to lower the entry hurdle for potentially interested designers who wish to generate or alter the feedback (Karkalas et al., 2017)

LA dashboards often consist of visual elements with charts, graphs, indicators and alert mechanisms (Podgorelec & Kuhar, 2011). In general, dashboards have multiple benefits and uses in educational contexts. According to Schwendimann et al. (2017, p 37), a definition of a learning dashboard is a single display that aggregates different indicators about learner(s), learning process(es) and learning context(s) into one or multiple visualisations. In their systematic literature review, the purpose of the learning dashboards was summarised in three main groups (1) self-monitoring, (2) monitoring others (3) administrative monitoring (Schwendimann et al., 2017).

Even though the LA dashboards have not yet been widely used specifically in design thinking, leveraging aspects from their use in similar contexts, they have the promise to:

- Offer students insight into their learning, enabling them to self-evaluate (Greller & Drachsler, 2012).
- Improve students´ decision-making processes and academic achievement (Howell et al., 2018).
- Assist teachers in providing administrators and students with more helpful feedback on their learning processes (Dawson et al., 2014).
- Enhance student and teacher performance, enhance learning effectiveness, and identify and intervene with students at risk of academic failure (Herodotou et al., 2019).
- Support the retrospective data analysis and their real-time monitoring (Gutierrez-Santos et al., 2016; Karkalas et al., 2016).
- Facilitate the adoption of constructionist approaches by providing real-time classroom analytics (Mavrikis, Geraniou, et al., 2019).

(3) AI in education has shown great advancements and potential for teachers and students.

- Previous research (Holmes & Tuomi, 2022; Salas-Pilco et al., 2022) showed that AI had created some opportunities for teachers, such as
- Automated grading and virtual assistants such as chatbots that helps to lessen teachers' workload,
- Classroom orchestration and predictive analytics to identify students who are at risk of failing a course,
- Classroom monitoring and adaptive learning that pinpoints areas to provide more focused learning experiences.

For students, the applications of AI in education also showed much potential (Holmes & Tuomi, 2022) such as:

- Intelligent tutoring systems,
- AI-assisted apps,
- AI-assisted simulations,
- AI to support learners with disabilities,
- Automatic essay writing,

- Chatbots,
- Automatic formative assessment,
- Learning network orchestrators,
- Dialogue-based tutoring systems,
- Exploratory learning environments,

AI-assisted lifelong learning assistants. Although AI is limited in design thinking education so far, AI-assisted stimulations such as AI-enhanced augmented reality have enabled students to explore and manipulate three-dimensional models of organic molecules to enhance their understanding of STEM subjects (Behmke et al., 2018).

(4) **Augmented reality (AR) and motion sensors.** AR is an experience in which the user interacts with the real-world environment while additional computer-generated information, such as text, images, 3D models, music, and video, is superimposed in real-time. Hence, the user perceives the surrounding environment as enhanced with stimulants that trigger or substitute senses (in case of disabilities). Focusing on optical enhancement, AR applications rely on user interaction and aim at providing the user with useful information through head-mounted displays, handheld displays and spatial displays.

AR technologies help learners engage in authentic exploration in the real world, and virtual objects such as texts, videos, and pictures are supplementary elements for learners to conduct investigations in the real world. AR holds much potential to function as a powerful educational tool in the remote education (Wu et al., 2013). Specifically, one recent review by (Mohammadhossein et al., 2022) provides an overview of the benefits of using AR in learning, e.g.,

- Attention: More awareness and alertness towards the learning objective
- Cognitive load: Reduced cognitive load
- Confidence: Increased learner confidence in terms of the learning experience
- Critical thinking: Using AR helps to identify critical issues
- Engagement: Increased learner engagement
- Imagination and creativity: Using AR allows for new ways of approaching and solving problems
- Independent learning: Increased learner ability to learn independently
- Concentration: The increased focus of the learner
- Joy and interest: Increased joy and interest when learning
- Learning activity and outdoor experience: Increased opportunities for new learning activities
- Memory retention: Improved capabilities related to remembering learning content
- Motivation: Increased motivation to learn

- Participation (co-operation): Increased participation
- Perceived learning attitude: Improved attitude towards the learning experience and the learning content
- Practical skills: Using AR allows one to train practical skills in new ways
- Satisfaction: Increased learner satisfaction in terms of the learning experience
- Self-efficiency and self-regulation: Improved learned
- Spontaneous learning: Increased opportunities to learn spontaneously
- Team collaboration: Improved ways of working together as a team
- Team interaction: Improved team interaction
- Understanding of abstract concepts: The improved visualisation makes it easier to grasp complex facts

(5) **Educational (Virtual) Robotics.** Since the early 1990s, educational robotics programs have regained interest and appeal as engaging and inspiring learning environments that encourage many students to follow STEM career choices (Melchior et al., 2005). While the concept of robots has been introduced as a design challenge in some DT projects, we have yet to find the application of virtual robotics in existing DT interventions. However, there are many promises of using educational robotics or virtual educational agents for education in general.

- Virtual robotics echoes the constructionist philosophy that it enables learners complete freedom to familiarise themselves with the curriculum by interacting with the software.
- Virtual robotics tend to be highly customisable and interactive and have overcome many limitations associated with physical robotics. With virtual robotics, the learners interact solely with the software, reducing the scope of possible errors and increasing precision.
- Virtual robots are cheaper and more precise than physical robots, and more importantly, they enhance the flexibility of robots and their components (no physical limitations). It eliminates many economic issues in acquiring and maintaining physical robots while simultaneously increasing equipment availability.
- In addition, the behaviour and appearance of virtual robots can easily be manipulated without worrying about the feasibility of the equipment (Zhong et al., 2020).

(6) General aspects of the use of technologies

- Progression in digital fabrication and technology comprehension
  Young students are introduced to various technologies and tools as part of several courses and activities designed to pique their interest in technology in general. Examples include creating 3D models and prints, writing robot code,

using laser cutters, etc. But many of these events emphasise the equipment or the specific technology itself. It is vital to start with anything easy, which can help students move from more straightforward knowledge to more detailed knowledge. Students must be given a chance to show that they can apply their knowledge of digital manufacturing in creative ways (Eriksson et al., 2018).

- Connect the use of technologies for DT and skills acquisition
  The digital-enriched environment provides opportunities for fostering DT skills. One study (Hatzigianni et al., 2021) revealed that engagement with digitally-supported maker spaces provides opportunities for developing young students' DT skills.
  DT projects facilitated through computer-based environments help students learn mathematical concepts and principles. Besides, such an environment, e.g. WISEngineering, can be particularly beneficial for students who are at risk in a socioeconomically diverse and low-performing district (Chiu et al., 2013). Computer-aided drawing and 3D printing are powerful tools that help students understand concepts, showcase their creativity, motivate them to learn, and enhance their DT skills (Huang & Wang, 2022).

4.3. Challenges

This deliverable aimed to identify challenges to enhancing DT with ET in a valuable way for students, teachers, and educational stakeholders' digital literacy. Concerning challenges, the focus is on aspects that have been identified and require attention including relevant literature that has shown to provide criticism to DT. Below we present the challenges from the literature for each topic, i.e., regarding students (subsection 4.3.1), teachers (subsection 4.3.2), educational stakeholders and DT (subsection 4.3.3), and ET (subsection 4.3.4).

4.3.1. For Students

(1) **Frustrations and uncertainty.** When learning DT for the first time, students will experience uncertainty and frustration as they attempt to comprehend and grasp it using each person's perspective on the project (Glen et al., 2015; Panke, 2019). Students with a low tolerance for ambiguity may need help embracing the DT process. This has been regarded as one criticism of DT.

(2) **Lack of knowledge of using new tools and dynamic engagement with digital materials.** According to the study by Weibert et al. (2014), this was observed with new tools like 3D modelling, soldering irons, Lilypad and FTDI. Students needed help with using physical artefacts, both in handling delicate components and using the tools of making. Some were also concerned that they would break something (Weibert et al., 2014). When choosing software, teachers should consider the

students' experiences, technological proficiency, and talents. Giving students various opportunities to engage in software and tools can keep them interested in learning activities for several weeks and give them chances to improve their skills. This helps reduce the frustration that students (who have fewer experiences in DT and technologies) may have (Bhaduri et al., 2019). Another general issue is enabling students to engage more actively with digital materials in their work. Students frequently used a single technology as a foundation for their work. But it was challenging to go from fascination to sound design work because of the dependence on a predetermined technology. Because of the capabilities of the technology, this frequently led to random thoughts being condensed into physical, and later digital, shapes. The absence of dynamic engagement with various digital and analogue materials constrained students' ideas. They frequently hit a wall or switch to new ideas halfway through their work (Smith et al., 2015).

(3) **Lack of creative ideas.** Because of the lack of creative ideas, students will be more likely to take things for granted and be less motivated to accomplish their teacher's assignments. This was also reported as a challenge in the project described by Weibert et al. (2014) about students' limited ability to find inspiration for figure designs, a need for individualisation, self-imposed quality standards and a desire to share creations.

(4) **Teamwork, collaboration, negotiation, and conflicts.** Some DT projects required the students to collaborate, but they needed help communicating and compromising their ideas. Most activities were implicit and ad hoc; students needed more terminology for their tasks beyond repeating the teacher's instructions. It was evident how challenging it was for the students to analyse and externalise their ideas through the group design environment and how their decisions and subsequent actions were made (Smith et al., 2015).

Due to the possible disagreements and lack of cooperation within their teams, students may have interpersonal challenges when working on design thinking projects in the classroom (Lynch et al., 2021; Panke, 2019). Additionally, the iterative process of DT is likely to cause some interpersonal conflict. The authors pointed out that instructors should offer constant support during all DT stages to resolve this tension resulting from ambiguity because a sense of security may inspire creativity.

(5) **Creative overconfidence.** Although some courses aimed at nurturing creative confidence, they were ineffective in enhancing students' creative self-efficacy. Furthermore, the lack of critical feedback regarding the skills participants demonstrates, especially in short workshop settings focused on productive outcomes and learning experience, results in a relatively slow development of skill-based learning, especially for those with no prior expertise (Taheri et al., 2016).

(6) **Conceptualise and navigate the messy process.** Teachers in DT education often give a quick overview of the assignments, which are frequently very basic or arbitrary. As a result, students need help conceptualising the learning and design processes. This

challenge served as a springboard for students to develop concepts based on their imaginations or preferences. In this sense, it may function as the student's initial source of engagement drive. However, most students needed help choosing a focused direction (Smith et al., 2015). Some students were competent at inventing arbitrary ideas but needed more resources to analyse and navigate their difficulty beyond their immediate imagination. Simple solutions and conclusions frequently result from the activities' constrained scope and organisational structure (Smith et al., 2015).

(7) **Difficulties in visualising, making and conceptualising design outcomes.** A study by Weibert et al. (2014) demonstrated that students needed help visualising, making circuit layouts, creating objects from fabric, and relating programming code to physical, real-world events. Similarly, during the remote workshops described in Roumelioti et al. (2022), some students needed help visualising the designed artefacts. All of them could describe their ideas in terms of components, as ideated in the DigiSNaP toolkit. However, when they moved to the programming stages, it was unclear that they were programming the ‘‘brain’’ of the smart thing. Moreover, it was unclear if their physical prototype might require additional sensors and actuators to attach.

4.3.2. For Teachers

(1) **Lack of common language to talk about TPD for DT in education.** Although teachers are passionate about transforming their lessons and introducing DT to their colleagues, it is challenging for them to express what they are doing and talk about their professional development (Landwehr Sydow et al., 2021).

(2) **Lack of experience relating to the complex design process.** The methodology of DT interventions emphasised the capacity to produce reflection and knowledge through an exploratory and iterative process. This opposed the more methodical approach of creating products that were practical, beautiful, or realistic and that the teachers' perceptions and experiences represented (Hjorth et al., 2016). Teachers needed to gain experience dealing with real-world situations and organising more intricate digital fabrication procedures in the classroom. As a result, they needed help comprehending a complicated design process (Smith et al., 2016). The lack of training and experience in the complex processes of DT will also contribute to the issue of educators thinking more creatively and innovative in the learning (Razali et al., 2022).

(3) **Lack of knowledge to connect assessment to learning objectives.** Teachers who participated in a workshop study (Veldhuis et al., 2022) mentioned that they needed help connecting assessment activities with the learning objectives they had established for their students. In addition, given the non-linear paradigm nature of DT, assessment often takes on informal forms. As a result, teachers might not possess sufficient knowledge to evaluate the learning outcomes of students´ designerly qualities.

(4) **Complexity in managing the technologies and design materials.** Teachers working on integrating DT into the school curricula needed help controlling digital technologies and design resources (Smith et al., 2016). They were concerned that they lacked the skills to handle digital technologies. They needed help managing and storing analogy design materials and being aware of the various benefits and affordances of externalisations such as e.g. sketches, mock-ups, and other externalisations (Hjorth et al., 2016). As a result, teachers should have created special design materials for framing and providing feedback on the students' processes. They also needed to gain expertise or experience switching between analogies and digital mediums when developing and making ideas (Hjorth et al., 2016). In addition, some DT materials used in online learning may have technical problems in the form of poor sound quality, causing students to be unable to clearly hear the teacher's voice when delivering the lesson (Razali et al., 2022; Tseng et al., 2019).

(5) **Lack of connectedness between learning objectives and learning content.** Teachers might need a clearer view of why and how to teach or use ET within the context of the DT (Sabuncuoglu, 2020). For example, a study by Sabuncuoglu (2020) pointed out that in the beginning, helping teachers figure out the rationale, objectives, and content of the curriculum relieved their worries. Besides, pre-service teachers found it challenging to connect the design challenges to real-life contexts (Xiao et al., 2022).

(6) **Difficulty in changing mindset and balancing different modes of teaching.** Some teachers need to see the necessity of improving their methods to conform to the constantly shifting environment we all live in (Milara et al., 2020). One challenge teachers perceived was moving from the role of a teacher to that of a facilitator, sharing authority, and allowing students to try and fail in their own (Bosch, 2022). They mentioned how attempting to implement these approaches in educational settings significantly questioned their traditional roles and authority and required them to reconsider their expert roles to become co-learners on an equal footing with their students and shift from teaching to facilitating learning (Andersen & Pitkänen, 2019).

To adapt to the new situation and be prepared for this challenge, teachers need to switch from various responsibilities, including coach for each design group, activities facilitator, and instructional classroom teacher (Smith et al., 2016). To support students' processes through dialogue and reflection questioning, they had to manage and switch balance between different modes of teaching frequently depending on the context (Hjorth et al., 2016). Classroom observations (Campos et al., 2019) revealed a consistent association between activities facilitator and lack of authority, teacher identity, and an orientation towards command and control in DT classroom activities. Accordingly, this often-limited student autonomy and seemed to obstruct learning of underlying concepts behind tasks and activities.

(7) **Insufficient competencies building and training.** Teachers need to be trained to provide the next generation with adequate tools for facing a rapidly changing, unknown future. Their inability to give the students the required knowledge and competencies can make them unempowered (Pitkänen & Andersen, 2018). However, many institutions that offer teacher education lack the resources and skills necessary to make this shift. For example, DT and other related topics, such as programming, must be taught in teacher education because most teachers, especially those who teach maths, arts, and technology, will need to be able to teach it (Kjällander et al., 2018).
In addition, teachers commented on the overwhelming amount of content they had to deal with throughout the training. Some stated that the time allotted to them to complete the activities (intervention, writing documentation, reading articles), attend the training, and prepare for it was insufficient, so they had to use their own spare time to learn more (Milara et al., 2020) and they should dedicate more time and prepare ahead (Xiao et al., 2022).

4.3.3. Lack of Support for Adopting DT to the School Curriculum

(1) **Time management.** In open-ended and non-linear DT projects, time management is one of the biggest challenges. School education is very time-structured; there are many special days for various occasions, and losing a few lessons can be critical. Therefore, a study by Andersen and Pitkänen (2019) suggested that teachers should provide 1-3 extra lessons for such projects to provide more flexibility. In some circumstances, the time has to be set aside for these activities for teachers and principals because such development processes don't occur in a vacuum for a few hours but rather in the immersion and social contact (Andersen & Pitkänen, 2019).

(2) **Difficulty in building consensus on curricular goals and values.** In a study by Andersen and Pitkänen (2019), the educational stakeholders called for national definitions of the field and central strategies and curricular goals. Besides, OECD (Andersen & Pitkänen, 2019) also mentioned that harmonising curricular values with evolving values aligned with society´s and economic developments can be challenging.

(3) **Lack of materials, resources, and finances.** A survey in China (Li & Fu, 2020) pointed out that 51.7% of DT practitioners recognised the deficiencies, including the teaching materials, facilities, and equipment for DT. This similar challenge was also identified in the study of Andersen and Pitkänen (2019). Lack of time, money, digital fabrication machines, and other resources to implement the visions were highlighted as significant impediments to undertaking DT and digital fabrication activities at schools, as they were in many different contexts (Andersen & Pitkänen, 2019).

(4) **Lack of support from the external policy.** Some teachers in the study (Andersen & Pitkänen, 2019) found it frustrating that while having the knowledge and motivation to carry out the activities, external savings and rules stopped them from doing so.

(5) **Inequalities among socioeconomic status and genders.** The most obvious challenge is creating a curriculum that each student can equally benefit from. For example, there are disparities among various socioeconomic levels (Sabuncuoglu, 2020). In addition, while some tools are necessary for DT programs in school education, not all students have equal access to these tools.
In addition, we need to ensure that technology-enriched DT activities are appealing and relevant to both boys and girls (and others) to promote equal possibilities for all young students in formal and informal education to comprehend and learn about 21st-century skills and technologies. For example, special attention should be paid to involving underrepresented groups of students, such as girls in technology-involved programs. One study by (Eriksson et al., 2018) showed that girls are more likely to attend if boys are not invited, so gender-specific activities may affect whether or not girls are interested in attending.

4.3.4. Lack of Suitable Tools and extending ET

(1) **We have limited quantities and types of technology and materials.** Digital technologies have yet to cover all stages of DT, such as empathising with the users. Moreover, there needs to be more use of virtual robotics and LA to support online and blended DT education. Even though there is a lot of technology and software, only a few of them have been used within DT. For example, the procurement practices proposed by Eriksson et al. (2018) can significantly impact expenditures in technology for education. Therefore, to speed up equipping future DT education with ET in a shorter amount of time while keeping the degree of administration at a minimum, it may be helpful to identify the typical technologies and materials needed to create and construct classroom activities.

(2) **Lack of suitable tools and most technologies need to be ready to be adopted.** Tools used for DT should consider young students' cognitive and physical development. For example, Weibert et al. (2014) indicated that teachers had to demonstrate another hand position to certain young children to help them overcome their problems with hand strength and the pliers being too large for their smaller hands. In addition, the initial anxiety was associated with a triumphant moment when they overcame their reluctance to handle delicate objects and use tools (Weibert et al., 2014).
Additionally, most DT toolkits now in use are designed for something other than a classroom setting and concentrate on a narrow range of abilities and knowledge (Scheltenaar et al., 2015). For instance, tools like LittleBits and Arduino/Raspberry Pi, for example, do not provide teachers with clear instructions on executing the related learning activities. Connectivity ensures that a DT toolkit for schools covers more topics than only technology (e.g., encouraging 21st-century skills and supporting DT in education), which makes it more appealing for schools to use.

(3) **Lack of communication and collaboration tools for online settings.** Students who are used to face-to-face learning approaches may find online environments more challenging (Roumelioti et al., 2022). While teachers direct their students in a formal educational context, students in an informal educational setting, such as an online co-design workshop, are expected to use their computers at home without having easy access to adult assistance. However, communication and interaction between facilitators and students can be vital in fostering students´ learning experiences.

(4) **Lack of progress tracking and learning analytics facilities.** According to the case study by Roumelioti et al. (2022), it was only possible to track the student participants' progress if they voluntarily opted to share their screens. There was no way for the facilitator to check their progress to see if anything went wrong and step in at the right moment to avoid any frustration. Due to the limited visibility and lack of complete control during the process, the facilitator had to assess how well participants were doing periodically. This, in turn, may be hampered by students´ ability to communicate their progress and problems and overcome their shyness when expressing thoughts with others.

(5) **The full potential of emerging technologies has not yet been achieved in DT.** The focused learning goal on the technical skills of 3D printing and modelling affects how students utilise their creativity and DT (Leinonen et al., 2020). For example, the results of a study by Leinonen et al.(2020) suggested that task-based designs somewhat inspired the students to create their ideas and innovations but did not fully unlock the creative potential that 3D printing activities are supposed to bring.

4.4. Requirements

This deliverable aimed to identify requirements to enhance DT learning with ET in a valuable way for students, teachers, and educational stakeholders' digital literacy. In this section, we present the requirements and needs for students (subsection 4.4.1.), teachers (subsection 4.4.2.), educational stakeholders (subsection 4.4.3.), technology development (subsection 4.4.4.), and for creating inclusive DT projects and ethical implementation of technologies (subsection 4.4.5.) as described in the relevant literature and gives thoughts for possible actions to be taken.

4.4.1. For Students

(1) Requirement for students' development of technological competencies and 21st-century skills.

According to the recent report from OECD Future of Education and Skills 2030 Concept Note[12], students need to be able to apply their knowledge, skills, attitudes,

[12] https://www.oecd.org/education/2030-project/teaching-and-learning/learning/learning-compass-2030/OECD_Learning_Compass_2030_concept_note.pdf

and values to act coherently and responsibly to be prepared and competent in the year 2030. The following summarises the main areas of knowledge and competence to technological competencies and 21st-century skills[13] in young students.

- Technological knowledge and know-how: the capacity to comprehend and apply digital technology as a building block for creating digital artefacts. For example, according to students´ reflections described in a study (Leinonen et al., 2020), the technical skills for mastering 3D printing properties made their learning experience successful.
- Digital empowerment is the examination and analysis of how technology is infused with values and intents and how it impacts our lives in a critical and constructive manner (Smith et al., 2020).
- Digital design and design processes: the capacity to formulate issues within a broad domain and, via iterative procedures, to produce fresh concepts that may be translated into form and content in interactive prototypes (Smith et al., 2020).
- Computational thinking involves abstracting from occurrences and linkages in the real world and using a computer to interpret this data, which is the capacity to turn a complex problem into a potential digital solution (Smith et al., 2020).
- Transformative competencies are reflected in the following two main aspects: (1) Reconciling tensions and dilemmas: Balancing competing, contradictory or incompatible demands, and (2) Taking responsibility: considering the ethics of action.

(2) Requirement for students' design literacy.

In the work of Christensen et al. (2016), they proposed the concept of design literacy, which refers to transferring ideas from DT to the fields of education and literacy in general. Similarly, Eriksson et al. (2019) claimed that design literacy could be seen to educate students on the values of participatory design. In other words, design literacy aims to raise awareness about decision-making in technology design, the potential impact of technology and, ultimately, whether it contributes to meaningful relationships. They argued that this is best achieved when students step into the design process and collaboratively make decisions in real-world settings (Eriksson et al., 2019).

4.4.2. For Teachers

(1) **Requirements for defining learning goals and providing instructions.** Teachers need to identify the objectives, plan the activities to allow for pauses and time for reflection and creativity and communicate the goals to the students in the beginning (Pitkänen et al., 2020). Trial-and-error and iterative processes are a part of DT

[13] https://measuringsel.casel.org/wp-content/uploads/2019/08/AWG-Framework-Series-B.9.pdf

activities, which prompted students to take more ownership of their learning. In this sense, students also need to help manage their time and projects because of the open structure and timetable (Pitkänen et al., 2020). The practical challenges students may experience (e.g., group conflict and frustrations, etc., while being introduced to DT projects at the early phase) and teachers need to consider (e.g., managing groups and issues such as group size and dynamics, time management etc.) pointed out the need for guidance and support from teachers in DT projects.

(2) **Requirements for pedagogical considerations.** When adopting DT in schools, pedagogical considerations are required. These considerations include how the *design, degree of instruction, and facilitation* of DT activities differ from conventional, well-structured lessons. Pedagogical considerations play a significant role in achieving learning objectives (Pitkänen et al., 2020). For example, teachers need to identify the teaching methods that are best suited to the material and the students.

(3) **Requirements for scaffolding for teachers in authoring educational materials.** The results in a paper (Veldhuis et al., 2022) suggested that an essential factor to consider while creating instructional materials is the amount of scaffolding offered, especially in choosing the topics for the design brief. Furthermore, some teachers expect to have technologies that are capable of assisting the creation of curriculum materials and customised to how they teach. Materials could meet these demands with differing degrees of design decision openness. This indicates that instructors might benefit from open-ended design brief subjects (Veldhuis et al., 2022).

(4) **Requirement for critically choosing a framework for describing DT curriculum development.** We found that the reviewed studies used different theoretical frameworks when they reported or developed their DT interventions. Therefore, there is a need for a consistent theoretical framework for DT curriculum development. Besides, some components (e.g., assessment, learning objectives, materials & resources etc.) in reviewed studies need explicit clarification to exchange ideas and promote the adoption of DT to school curricula globally.

(5) **Requirements for appropriately preparing the teacher's mindset.** There is a need to support teachers' 'coach's mindset', following students' ideas (Suero Montero et al., 2020). The key to becoming a DT educator is to prepare teachers with mindsets that include openness, curiosity, responsiveness, and willingness to employ technology and resources in regular professional practices for teaching DT. This relates to appropriately preparing teachers for using them with students but also to have an open mindset and leverage the functionalities of the tool, such as the LA capabilities in the teaching and learning process.

(6) **Requirements for digital competencies.** According to the DigCompEdu framework (Joint Research Centre (European Commission) et al., 2017), there are six digital competencies teachers need to develop to foster efficient, inclusive and innovative teaching and learning strategies.

- Professional Engagement: Using digital technologies for communication, collaboration, and professional development.
- Digital Resources: Sourcing, creating and sharing digital resources.
- Teaching and Learning: Managing and orchestrating digital technologies in teaching and learning.
- Assessment: Using digital technologies and strategies to enhance assessment.
- Empowering Learners: Using digital technologies to enhance inclusion, personalisation and learners' active engagement.
- Facilitating Learners' Digital Competence: Enabling learners to creatively and responsibly use digital technologies for information, communication, content creation, well-being and problem-solving.

4.4.3. For Educational Stakeholders and A Community

(1) **Requirement for establishing a coordination team to kick off the community.** Schools need to allocate financial and time resources, plan collaborative activities to foster a sense of community and get to know one another, coordinate, notify the relevant community members, and distribute the findings (Milara et al., 2020). Besides, it may be necessary for not only to train teachers and also other educational stakeholders, e.g., principals and policymakers, involved in this educational innovation.

(2) **School values, culture and visions.** In a study by Milara et al. (2020), they reported a case of scaffolding the development of a local community of practices for STEAM-based fab labs. The principals in this study expressed that machinery is not a key to starting STEAM activities at school. Still, they can be started from a superficial level and even without machines at all. They realised that it is more important to start from the school's vision and values, engage a wide range of people and consider what are the needs of users regarding the machinery.
It is important to note that changing the school culture is not only in the hands of the teachers, but other actors have an important role to play as well. This challenge has been identified by teachers in this study (Milara et al., 2020). They argued that without a change of culture, and given the rigidity of schools (e.g., schedules, space), it is difficult to implement new ideas.

4.4.4. For Technology Development

(1) **Requirements for tools to support all stages and scenarios of DT.** This review pointed out that technologies did not fully cover all stages and scenarios of DT in education, for instance, no specific tool was found to support the stage of empathising with the users**,** and no dedicated tool was found to support capturing students learning progress in real-time or support distributed collaboration during DT activities.

(2) **Requirements for LA tools and systems design in general.** The design requirements from educational stakeholders were elicited from a case study (Chalvatza et al., 2019) to inform the design process of dashboards and LA tools. These include:

- The dashboard should have clear visualisation containing simple graphs and straightforward information. In addition, there should only be minimal visualisation enhancement with assistive indicators to avoid confusion.
- The dashboard should enable progress tracking and analysis comparing entities (schools. classrooms, teachers, subjects).
- The dashboard should have a navigation menu, preferably one that is multidimensional and interactive, to comprehend how the information is organised.
- The dashboard should have a configurable presentation of analysis results enabling them to find the organisational level of information (e.g., level of dimension, factor, and question) easily and quickly. And
- The dashboard should have a search engine enabling them to find answers and providing them with the maximum selection of options that can be combined during the search.

It is commonly assumed by designers that teachers and students will be able to understand visualised data without difficulty (Mangaroska & Giannakos, 2019). However, this assumption overlooks the fact that individuals who lack experience with data may find it challenging to take action particularly when they can only make sense of data “at a glance” (Schwendimann et al., 2017). Even with data literacy teachers may still struggle to understand the necessary actions that need to be taken as a result (Greller & Drachsler, 2012; Mavrikis et al., 2022).

Relevant to Exten. (D.T.)^2, Echeverria et al. (2018) introduced the concept of educational data storytelling, which involves using data analytics and visualisations to present students' data in a visual and easily understandable manner or even as responses to specific teacher queries (Pozdniakov et al., 2022). This approach is relatively new and is gaining popularity.

Furthermore, an essential aspect is the involvement of all the relevant key users in the design of the LA systems, for example, students and instructors (Knight et al., 2016; Roberts et al., 2017). Participatory design for co-designing authoring intelligent support environments and the involvement of users with little or without previous programming experience is essential (Mavrikis, Karkalas, et al., 2019).

More specifically, a review study by (Yoo et al., 2015) suggested four general design principles for LA dashboard development, including:

- dashboards are visual displays;
- dashboards display the information needed to achieve specific objectives,
- a dashboard fits on a single computer screen, and
- dashboards are used to monitor information at a glance.

(3) Requirements for 3D printing. According to (Tsybulsky & Levin, 2019), TPD programs should be modified to incorporate practices relevant to the digital age while taking into account changes in teachers' worldviews and their implications for education. As a result, it is imperative to conduct practical studies to examine the combination of teaching strategies and designs that will help learners understand 3D-printing technologies when incorporated into curricula. In addition, in practice implementation is required to determine how teaching techniques and 3D printing technology might be integrated to aid student learning (Huang & Wang, 2022).

(4) Requirement for AR and motion sensors. The development of an AR experience requires tracking sensors, user movement tracking, and techniques for modelling 3D objects (Krevelen & Poelman, 2010). Due to these characteristics, there needs to be more tools to quickly iterate and create new ideas utilising low-fidelity prototype methods, which leads to the first requirement for educational AR authoring toolkits (Dengel et al., 2022).

(5) Requirements for Virtual Robotics. Robotics-based education has much potential and has produced effective learning results in various academic areas. However, the ability of robotics programming learning contexts to develop generalised computational thinking skills ultimately remains a crucial empirical question, given the limited opportunities for meaningful computer science learning and the general lack of teachers with both content and pedagogy training (Witherspoon et al., 2018).

(6) **Requirements for virtual co-design space.** The study by Rötkönen et al. (2021) pointed out that some learners expressed that they enjoyed the sessions in the VR environment the most. However, several affordances need to be created for an intuitive and supportive VR co-design space. On a technical note, the learners frequently commented on the "bad" audio quality, partially due to background noise. Although headphones might be practical for individual calls, they are not suited for group-to-group calls; thus, other equipment needs to be found to facilitate hybrid sessions. This can be extended to using platforms and any other environment to facilitate possible collaboration and co-design experience (Rötkönen et al., 2021).

(7) **Requirements for real-time progress tracking and monitoring tools**. About the opportunities that the development of learning environments can offer, it is possible to benefit the learning process for both students and teachers with real-time monitoring, feedback and sharing functionalities. This opportunity needs to be leveraged, and its application should be explored. For example, this is possible in exploratory learning activities. Using learning analytics, a user can author the collected data, give feedback, and do retrospective analysis and real-time monitoring (Gutierrez-Santos et al., 2016; Karkalas et al., 2016, 2017). However, further investigation is needed to explore its feasibility and appropriate use (e.g. type of data collected, visualisation, time appropriateness etc.).

4.4.5. For Inclusiveness and Ethical Consideration

(1) Requirement for promoting inclusion of all students. Lee et al. (2020) reported that student disengagement was a common challenge for teachers as they mentioned the difficulty of engaging students with disabilities or at-risk in the activities. The necessity for initiatives that gave students more choices, allowed for cultural relevance and promoted equal involvement was further supported by repeated observations of students' disengagement. The possible obstacle to the implementation of DT activities successfully also indicated a need for TPD with maker-related materials and instructional and behaviour management tactics for students with disabilities or at-risk in the activities. This would enhance the inclusion of students of all genders, hard-to-reach populations, and geographical and societal barriers (Lee et al., 2020). Accordingly, as seen in Figure 14, Lee et al. (2020) proposed the TPD framework to support inclusive maker K-12 classrooms with instructional strategies (i.e., universal design for learning, explicit instruction, culturally responsive teaching, customised accommodations for diverse students).

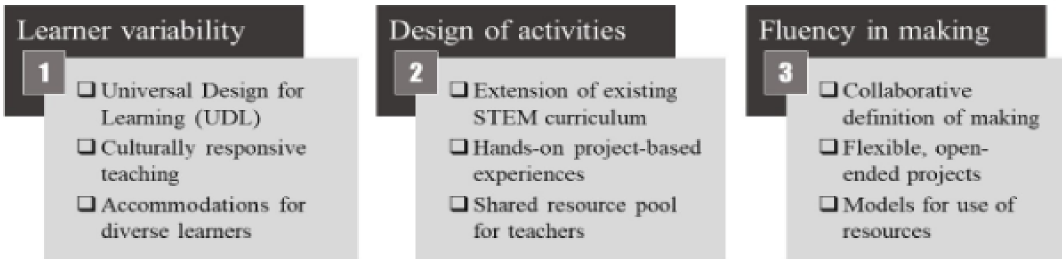

Figure 14. Professional development framework (Lee et al., 2020)

Requirements for the ethical and social implications of the technologies. However, many models used for educating DT focus on producing innovative ideas as a design solution to products or services and uncovering the tacit knowledge generated from collaborations with stakeholders. Therefore, there is a need to develop a meaningful alternative model that accounts for the ethical and social implications of the technology under consideration (Eriksson et al., 2019). Furthermore, a recent review by Van Mechelen et al. (2022) on ET in K-12 education advocated that we need to bring to light the ethical and societal implications of new technologies, such as complicated questions of democracy and power as well as the fact that no technology can ever be designed in a value-neutral way. As a result, students would have a deeper grasp of ET, including how new and unexpected ethical and social problems develop, while the uncertainty around potential applications, effects, and implications of an ET declines (Van Mechelen et al., 2022). For example, the essential requirements for trustworthy AI in the education (Directorate-General for Education, 2022) include (1) human agency and oversight, (2) transparency, (3) diversity, non-discrimination, and fairness, (4) societal and environmental wellbeing, and (4) privacy and data governance.

More specifically, there may be ethical issues when collecting data from many sources in the case of LA for DT classrooms. For instance, combining de-identified data from various sources increases the possibility of re-identifying individuals (Flanagan & Ogata, 2017). Due to the data's great granularity and temporal nature, multimodal LA has been linked to a potentially increased risk of ethical issues (Alwahaby et al., 2022). Accordingly, we must look at and problematise the ethical considerations of teachers, students, and other stakeholders and any learning biases they may have.

5. Discussion

This section aims to give a high-level summary and mapping of the overall related means to reach Exten. (D.T.)[2] project objectives, as they are described in the proposal (see the texts below inside the tables), with what was found in the relevant literature regarding best practices, challenges, and requirements to enhance DT with ET in a valuable way for students, teachers, and other educational stakeholders. The focus is to avoid repeating the findings of this deliverable; details and references can be found in the respective mentioned sections that will be used as a starting point for critical thought for the future actions and decisions of the project and all the WPs.

As mentioned in the earlier sections, different challenges exist for students (section 4.3.1.). For example, they may be frustrated and confused, need more dynamic engagement with digital resources and creative ideas, conceptualise design outcomes, and deal with problems in teamwork and collaboration. At the same time, there is a requirement for equipping students with technology competencies, design literacy and 21st-century skills (section 4.4.1.). As shown in the best practices, students can have a fruitful experience when they are provided with different modalities in the technologies used, their learning is effective and playful, self-efficacy and reflection are promoted, and they all have equal opportunities (section 4.3.1).

When it comes specifically to technology and tool development, many benefits are shown in the best practices identified in this deliverable (section 4.2.6). However, the challenges in this aspect showed that there is still a lack of suitable tools and utilisation of the full potential of ET for DT (section 4.3.4). Consequently, the requirements derived from the possibilities that each ET relevant to the project has and can be used, for example, the LA component and the real-time monitoring (4.4.4).

Related means to reach the project's objectives: o *extend technological tools, namely MaLT2, ChoiCo, SorBET, and Cyberbotics, with emerging technologies that bring added value into DT, i.e. ARs, 3D printing/scanning and Virtual Robotics.* o *mobilising and extending the online platform nQuire, where tools and DT activities will become available for wide use and learning at scale and create a network of schools and out-of-school organisations connected. It will also be a safe space for students to share digital productions and engage in discussion.* o *systematic evaluation of how students' design thinking knowledge, skills and attitudes are stimulated and enabled using technologies (e.g., LA, surveys, interviews).* o *critical analysis of the gendered, cultural, geographical and societal effects regarding the use of AI, AR, 3D printing and Virtual Robotics in DT activities.*

These are also highly related to the teacher's perspective and the challenges that have been identified (section 4.3.2). For example, there is a lack of the appropriate experience, respective knowledge, proper mindset, assessment strategies and training, to mention a few, for the delivery of DT activities with ET. Therefore, the requirements are towards the direction of supporting teachers, for example, with the essential pedagogical considerations, enhancing their digital competencies, making connections with the curricula and school context, monitoring the activities with regards to the student's experience, progress, and collaboration, together with the outcomes and evaluation (section 4.4.2). Best practices (section 4.2.2) show the different opportunities existing to apply appropriate frameworks and approaches to prepare teachers who want to implement DT with ET and educate them through TPD.

Related means to reach the project's objectives:

- *mobilising the co-creation Planet, designed to support DT projects, to be used in teacher professional development courses.*
- *developing an Authorable Learning Analytics (ALA) system and a customisable dashboard enables different educational stakeholders to get involved in designing digital resources for DT with the capability of customisation.*
- *all digital learning environments will be tied together in one Learning Platform to generate and provide data for analysis that can streamline the experiences of students and teachers.*
- *offering free online course*
- *integration of the Exten. (D.T.)² approach and technologies in existing academic courses about effective pedagogies to pre-and in-service teachers*
- *designing and developing specialised TPD modules providing oriented knowledge*
- *providing teachers with Exten. (D.T.)² experts research knowledge on teachers' needs and challenges and proposing evidence-based mitigation actions*

The role of different stakeholders is important to support the digital implementation of DT activities. A coordination and collaboration among all stakeholders involved (e.g., teachers, principals, instructors, leaders, researchers) is highly required to support the feasibility and sustainability of actions together with knowledge transfer. Best practice can establish a community and the stakeholders' involvement in aspects such as the co-design of the activities and technologies (section 4.2.3).

Related means to reach the project's objectives:

- *co-designing with stakeholders a set of DT activities and associated material.*
- *actively involving teachers in a participatory process of design, data collection, analysis and feedback for DT activities.*
- *co-producing with stakeholders a set of digital resources to support the digital implementation of DT activities.*

All the above are also associated with the general aspects of deploying DT with ET that are presented in the best practices section regarding the current trends in DT, using references to design-based learning and maker-based curriculum that show an example of the critical elements, e.g., learning goals, pedagogical materials, collaborations, roles etc. (section 4.1.1.) and how can be connected for delivering DT activities with technologies in general. The same overall association applies to the requirements for promoting the inclusion of all students and the ethically and socially appropriate use of technologies (section 4.4.5).

6. Conclusion

Based on a theoretical review, the findings of this deliverable report regarding the best practices (Section 4.2), challenges (Section 4.3), and requirements (Section 4.4) for enhancing DT with ET in a valuable way for students, teachers and educational stakeholders' digital literacy. In addition to that, as presented in Section 4.1., the deliverable also briefly presents the overview of current DT projects with the use of technologies referring to the spider web model for curriculum development proposed by Van den Akker et al. (2010).

The deliverable demonstrated promising impacts of DT, e.g., increasing students' self-efficacy (Tsai & Wang, 2021) and interest in STEM subjects (Schlegel et al., 2019) and developing 21st-century skills. Additionally, education research increasingly reports opportunities for applying and teaching DT in digital contexts (Dragičević et al., 2023). This deliverable presents the promising outcomes of teaching DT with digital resources. DT offers more dynamic, immersive, and connected learning combined with digital technologies. For example, the digital-enriched environment provides opportunities for fostering DT skills (Hatzigianni et al., 2021). Furthermore, DT projects facilitated through computer-based environments help students learn mathematical concepts and principles (Chiu et al., 2013). More specifically, the deliverable reported that computer-aided drawing and 3D printing could help students understand concepts, offer them the opportunity to showcase their creativity, spark their motivation to learn, and enhance their DT skills (Huang & Wang, 2022). Overall, we recognise that utilising technologies effectively is an essential aspect of DT education and society in general, contributing to the digital education action plan (2021-2027).

However, there are some challenges this deliverable identified for adopting DT into the school curricula and extending existing tools and ET. As an illustration, it is challenging for teachers to talk about what they are doing and their professional development (Landwehr Sydow et al., 2021). Given that most studies used different theoretical frameworks when they reported or developed their DT interventions, we also need a framework for describing DT curriculum development across studies. Concerning ET and digital tools, most DT tools need to be integrated into a classroom setting and concentrate on a narrow range of abilities and knowledge (Scheltenaar et al., 2015). Additionally, some tools are now borrowed from tools developed for adults and need to consider young students' cognitive and physical development. For example, (Weibert et al., 2014) indicated that teachers had to demonstrate another hand position to certain young students to help them overcome their problems with hand strength and the pliers being too large for their smaller hands. Furthermore, we discovered that technologies only partially cover DT in education. For example, no specific tool was observed to support empathising with the users. Furthermore, no dedicated tool was found to support tracking students' learning progress in real-time, LA with feedback, or supporting distributed collaboration. To the best of our knowledge, DT education has not yet adopted virtual robotics and AR motion sensors.

DT practice may also have a lot to offer in terms of fostering the skills needed to handle the difficulties of digital transformation (Dragičević et al., 2023). This is not only meant for students but also teachers. For example, some practices used DT to educate teachers and reframe their engagement with curriculum planning. This has been regarded as a viable path for teachers to work through in redesigning or rethinking their curricula to move toward more STEAM-based learning (Kelly et al., 2019). In addition, using DT as a strategy can also help construct teachers' technological pedagogical content knowledge in technology-integrated lesson design and 21st-century learning (Koh et al., 2015). In short, based on the promising findings in this regard, this deliverable suggests future TPD could consider DT as a framework for teachers to blend the analytic with the creative in how they think about a technology-integrated curriculum.

There is a chance to combine DT with digital technologies to equip teachers and students with 21st-century skills and address societal issues (Dragičević et al., 2023). To foster this, this deliverable ended up with some requirements and action points for future work. For instance, we argued the requirements for developing students' and teachers' digital competencies and the requirements for cultivating school values, culture and visions on DT and technology adoption. Besides, we also articulated a set of requirements for technology development and considerations for extending DT with ET inclusive, feasible and accessible for all students and teachers. To summarise, to achieve this vision of extending the pedagogical values of DT with emerging technologies, the follow-up steps of the Exten. (D.T.)^2 project will uniquely integrate pedagogically valuable digital solutions, such as coding, modelling, and game design, with AI analytics algorithms, AR for embodied learning, and 3D printing for rapid prototyping.

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