Towards a sustainable model of education in the XXI century: Combining Design Thinking with Emerging Technologies ⋆

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Abstract. The use of emerging technologies such as Artificial Intelligence, Augmented Reality, and 3D printing are amongst the EU targeted actions for supporting the digital transformation of education. Yet, despite these technologies being accessible to education stakeholders, there is a lack of concrete pedagogy and teachers' professional development for their meaningful integration into the current educational context. *Extending Design Thinking with Emerging Digital Technologies* – Exten (D.T.)^2 - is a European funded project aiming to use emerging technologies to enhance the pedagogical value, sustainable digitization, and potential for wide deployment of Design Thinking (DT). DT is a promising pedagogical innovation, based on interdisciplinary co-creation, that can lead to sustainable educational innovation and development of students' 21st century skills. In this paper, we describe the main components of the proposed educational transformation as developed during the first year of Exten (D.T.)^2 including the theoretical foundations of the approach, the co-creation processes for meaningful engagement of teachers with educational innovation. Moreover, we present the educational technology tools (design, extensions, architecture) that are used in the project and the evaluation approach for capturing impact on improving students' skills and competencies.

Keywords: Design thinking · Emerging digital technologies · Digital transformation · XXI century skills.

1 Introduction

While emerging technologies are rapidly evolving and diffused in our daily practices, their potential has not yet been harnessed to improve K-12 educational practice, enable students to develop the so-called 21st century skills - much needed in an ever-changing society, and create sustainable models of education

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bulletproof of future disasters (e.g., a pandemic) and flexible enough to achieve learning for all, anytime and anywhere. The project *Extending Design Thinking with Emerging Digital Technologies* - Exten (D.T.)^2 aims to bring innovation in secondary education by combining design thinking and emerging digital technologies and provide an evidence-based paradigm of how teaching and learning could be sustainably transformed. Design Thinking (DT)consists of the following distinct, interconnected, iterative stages: empathizing with users, ideation and brainstorming, prototyping, testing and refinement of a solution/product. It has originated from industry [25] with a few implementations in education. Such implementations are accompanied by considerable challenges such as a lack of appropriate teachers' training, constraints in resources and time, minimum integration with current curricula, limited evidence on developing creativity, fast convergence on a single idea, student confusion and frustration, and collaboration tensions [27]. To address these challenges, Exten (D.T.)^2 aims to enhance DT pedagogy with emerging technologies and address the following Research Objectives (ROs):

RO1: Design, implement and scale-up a transformative pedagogical intervention, supporting the implementation, monitoring and evaluation of DT projects extended with emerging technologies.

RO2: Bring together different stakeholders to rethink the nature of emerging technologies for designing co-constructionist activities i.e., co-creating resources and technologies.

RO3: Support Teacher Professional Development concerning competencies needed for the meaningful integration of DT projects at schools.

RO4 Create a network of schools and organisations to collaborate on designing projects during and beyond the project timeframe.

RO5: Develop a framework for stakeholders and policy makers including guidelines on how to set up, monitor and evaluate DT projects supported by the project's emerging technologies.

To illustrate the Exten (D.T.)^2 approach we provide a concrete example of a learning scenario: A group of four students works on a DT educational project about *"biodegradable, but attractive jewelry"*. To understand the problem (why do we need environmentally biodegradable jewels?), they play a Tetris-like interactive (using gesture-based interaction techniques) game in which they sort with their body "falling" jewelry made of different materials (e.g. iron, wood, gold, plastic) into different categories that represent the time each material group needs to be degraded by the environment. Through an embodied experience, they realize that most of the jewels are made with slowly degradable material causing long term environmental pollution. While they play, a Learning Analytics (LA) component captures all data related to how students interacted with the game. The teacher has configured the LA component with necessary interaction indicators for real-time support to be available to students. In the next DT stage, students use an online modeler to rapidly prototype 3D models of different jewelry. Students upload these digital models on a citizen science platform and ask other students, teachers, parents for feedback. When 3D models are finalised, students print them with a 3D printer that uses biodegradable filaments. This example has been presented to just illustrate the core ideas of our project and how design thinking and emerging technologies could be combined to support digital transformation processes in education. The remaining of the paper structured as follows, in the next section, we summarise how DT has been used in education and how emerging technologies could address some of the DT-related challenges. In section three, we detail how educational innovation could be facilitated through the meaningful engagement of teachers in the process of design and research and how tools such as the Activity plan template (section four) could scaffold research practices with teachers. In section five, we present the emerging technologies we plan to use to enhance DT, their architecture, and enhancements and in section six give an overview of the evaluation approach of the project. Section seven concludes the paper by presenting our final remarks.

2 Theoretical foundations related to DT and emerging technologies in Education

DT is a dynamic process that emphasizes human-centered and user-oriented design and presents clear steps for collaboratively creating novel, sustainable and practical product solutions [3]. Prior studies using design thinking in education have highlighted the significance of DT in equipping younger generations with essential 21st-century skills to thrive in a rapidly evolving era. DT is perceived as a crucial educational resource and a highly esteemed way for preparing students for the demands of the 21st century [25]. Additionally, DT empowers students to adopt a user-centered approach to address wicked problems, which are complex, real-world, contested, and socio-scientific issues. This approach is particularly relevant in developing innovative solutions to sustainability challenges that require further experimentation [4]. Some educational concepts, such as maker education, constructionism, and design-based learning, have been used interchangeably or blended with DT. For instance, both maker education and DT share similar features such as ideation, making, and the fostering of 21st-century skills. One study [37] reported that many practices had employed both approaches of DT and maker education in various educational settings, including after-school activities and school environments. A couple of case studies illustrate the use of these pedagogical concepts, such as the Fab Lab Oulu in Finland [20, 29]. DT is widely acknowledged as a crucial link in multidisciplinary education, particularly in STEAM subjects. Its application in K-12 education is diverse, with a strong emphasis on STEM and STEAM education in most DT programs [27]. Some of these programs employ the DT process to engage students in engineering problem-solving [26], teach physics concepts [32], and programming [13]. DT has also been integrated into other subjects such as design [7], geography [12], technology [24, 11], and multidisciplinary curricula [8, 22].

The promising impacts of DT in education include improvements in students' self-efficacy [33] and interest in STEM subjects [31], as well as the development of 21st-century skills. Moreover, education research is increasingly reporting on the opportunities for teaching and applying DT in digital contexts [9]. For instance, digital-enriched environments offer prospects for fostering DT skills [14], while DT projects facilitated through computer-based environments have been shown to facilitate the learning of mathematical concepts and principles [6]. Specifically, computer-aided drawing and 3D printing can aid students' comprehension of concepts, enable them to express their creativity, foster their motivation to learn, and improve their DT skills [15]. The effective utilization of technologies is acknowledged as a critical component of DT education and society in general, contributing to the digital education action plan (2021-2027). Although the integration of DT into school curricula, and the use of technologies offer many potential benefits, several challenges have been identified. One such challenge is that it can be difficult for instructors to discuss their activities and professional development [19]. The use of DT as a pedagogical approach, in this context, has the potential to enhance teachers' technological pedagogical content knowledge in technology-integrated lesson design and 21st-century learning [17]. A finding that has emerged from reviewing relevant literature is that digital tools have only been used in specific stages of DT and mainly when teaching takes place online. For instance, no specific tool has been used to support the process of empathizing with users or no dedicated tools have been designed to track student progress and collaboration in real-time (learning analytics) and provide feedback as needed. Also, emerging technologies such as augmented reality motion sensors and virtual robotics have not yet been incorporated into DT education.

3 Actively engaging teachers with educational technology innovation

Amongst the key stakeholders of Exten(DT)^2 are practitioners, that is secondary school teachers interested in developing and testing new approaches to teaching and learning using emerging digital technologies. The project team (researchers, academics, developers) aims to collaborate with teachers in two ways: *(a)* in a co-creation capacity, aiming to co-develop and test innovative teaching approaches, and *(b)* in a co-production, capacity exploring ways practitioners could be actively involved in the research process and the production of scientific knowledge. Co-creation refers to engaging participants (here teachers) in a process of defining and finding a solution to a problem [21], that is identify a topic they would like to examine and address with students using design thinking and emerging technologies. Teachers produce a set of educational materials for exploring, understanding, and finding workable solutions to a problem relevant to students' needs and interests or of a broader scientific significance, such as a societal challenge (e.g. climate emergency, decline of biodiversity, misinformation and inter alia). Co-creating educational innovation with teachers addresses the need to develop design thinking approaches that are compatible with formal education and are grounded in student, teacher, and school needs [23] - teachers are defining the process of innovation drawing from their own expertise and experience. A co-creation approach can be a valuable experience for teachers and a means through which they can engage with leadership practices in an informal (or formal) capacity by showcasing agency to lead change and create conditions for improving learning (e.g., [10]).

Co-production refers to secondary teachers being actively involved in the research process and the production of scientific knowledge, alongside the project team. This encompasses co-defining how evaluation data should be collected to capture the impact of innovation on student learning, supporting the process of data collection in the classroom by allocating e.g. a survey and contributing to data analysis and interpretation also by getting engaged in learning analytics. These processes may result in joined dissemination outcomes such as co-authoring publications, co-presenting and co-disseminating project outcomes [35]. A co-produced approach is likely to be time-demanding for teachers [5] and thus a few of them may express interest in getting involved. Yet, when implemented well, co-produced research can empower and give voice to those with "lived experiences" – in our project, teachers who are experts in how teaching and learning takes place within a specific learning context. Research outcomes will have immediate impact on intended stakeholders as those have been involved in a proposed innovation [36]. Special attention should be given to issues of power and ethics to ensure that equitable relationships are developed between practitioners and researchers in terms of responsibilities, efforts, and benefits [34].

Overall, our approach to working with teachers is informed by participatory principles of research [30]. We seek to understand who our teachers are (what are their needs, requirements, skills, expectations, technology expertise etc.?) and what challenges and needs their schools and students face, co-decide the topics we are going to examine using proposed design thinking, enable flexibility and support through professional development activities, identify how teachers would like to be involved in research and dissemination processes and provide compensation where applicable. These participatory principles informed the organisation and delivery of online and face-to-face workshops during which teachers receive training about design thinking, are given time to experiment and raise questions about emerging technologies, share their experiences of working in specific schools in regards to student needs, technology use etc, identify (and justify) a topic to be the focus of a design thinking project and come up with technology-based activities to support each phase of design thinking. This process was supported by the Activity Plan template, a tool developed to structure interactions and communication during the workshop implementation.

4 Scaffolding teachers' engagement with DT and technologies: The activity plan template

To support teachers in designing and organizing DT activities with technologies, we developed a strategic document that we called "Design Thinking Activity Plan Template". It is a generic but well-structured template that identifies the critical elements, structure, and flow of a DT activity with emerging technologies that could be implemented in a school context. Unlike a traditional learning plan, the DT Activity Plan Template addresses the teacher's personal pedagogy, beliefs, knowledge, reflections, and practice throughout its structure, serving as a tool for expressing and communicating personal pedagogical agenda.

Previous research work in the field of education has shown that using the Activity Plan Template approach can support teachers to design and implement learning activities using new technologies [38]. Additionally, it can facilitate conversations between researchers and teachers for activity design, enhancing co-creation processes [18]. It can be a valuable tool for researchers to evaluate empirical interventions as it provides a thorough document not only for the activity setting, but also for the teacher's rationale behind the integration of technology with pedagogy for each activity. In the Exten $(D.T.)^2$ project, we have developed a tailored version of an Activity Plan Template for use in DT enhanced with emerging technologies. It is expected to become a mediating artefact between the Exten $(D.T.)^2$ researchers and the stakeholders interested in designing DT activities. The main pedagogical theory underlying the design of the DT Activity Plan Template is constructionism [28], where learners put concepts into use and generate powerful ideas through constructing and tinkering with digital artefacts with personal meaning. Through that view, in DT projects, students utilize technology as an expressive medium to experiment with, develop and exchange several personally meaningful artefacts. These artefacts evolve and change during the DT project and through them, children express ideas and meanings on the DT topic. In addition, the template puts emphasis on the social dimension of the co-construction process with technologies aiming to cultivate a specific learning attitude of sharing, discussing, and negotiating during the DT process [16]. The current version of the DT Activity Plan Template includes the following aspects structured under separate sections: the description of the Design Thinking project with reference to the different domains involved, the issue it concerns, and the targeted audiences; different types of learning objectives, duration of activities and necessary material; contextual information regarding space and characteristics of students; expected use of Exten $(D.T.)^2$ Technologies as part of the whole DT process, rather than only the develop stage which is usually done in traditional DT approaches [27]; social orchestration of the activity (group or individual work, formation of groups, etc); a description of the teaching and learning procedures structured in the different phases of DT methodology; expected student constructions; means of student evaluation and assessment.

During the Exten $(D.T.)^2$ project, the DT Activity Plan Template is expected to have multiple roles, rather than only that of a lesson plan. It is expected to be used as a) a tool for organizing and implementing a DT activity in the classroom or online with emerging technologies, b) a tool for designing and reflecting on activities as part of teachers' professional development, c) a tool for evaluation of the learning and teaching practices designed for the interventions, as it provides the means to keep track of what has happened in a classroom or online, d) a tool to present the school activities to a wider audience in a structured way, as it provides metadata for different kinds of DT activities with students (e.g. age, technology used, final DT product, topic of DT project, related subjects) and enable peer learning amongst educators. The evaluation of project activities during the first year is expected to provide feedback on the efficiency of the current version of the DT Activity Plan Template that will inform its iteration in subsequent years.

5 The digital tools and the architecture of the Exten (D.T.)^2 platform

The Exten (D.T.)^2 platform integrates a set of game-based educational tools such as ChoiCo, SorBET, and MaLT2 that have been previously developed. In addition, nQuire application allows learners to design a project or study for the last stage of DT learning activities. All game-based educational tools provide two modes: the playing mode, where the players can play the default game, or a game designed by the teacher, or a game designed by the players; and the *designing mode*, where players can design their own games. The different games can be played collaboratively in groups of several players using one computer or can be played individually. The different game-based education tools are described in detail below.

ChoiCo (Choices with Consequences) is an open-source, online authoring tool that provides an opportunity to play, design and modify choice-driven simulation games related to complex real-life issues. In these games, the player navigates through different map-based areas making choices that affect the game parameters (e.g. money, health, fun etc.). In the design mode, the user can modify a game or design a new one by using 3 interconnected computational affordances: a GIS map designer, an editable database, and block-based programming [18].

MaLT2 (MachineLab Turtleworlds2) is an open-source online tool of symbolic expression in mathematical activity by means of programming for the creation and tinkering of 3D dynamic graphical models.

SorBET (Sorting Based on Educational Technology) affords the play and design of Tetris-like sorting games in which the player scores by 'pushing' elements falling off the top of the screen to drop into the right container according to the right category. 'Pushing' elements can be done by picking and dragging on a screen and will be extended to also include body movements interaction. The gameplay builds on quick decision-making, pattern recognition, and abstraction of the characteristics of falling objects.

nQuire [4] is a web-based community and citizen science platform designed and maintained by the Open University UK. This tool will be used by students and teachers to support specific stages of the design thinking processes. For example, students could use nQuire to design studies with the aim of understanding the needs of the target group for which they are designing a solution for (this is the Empathise stage of design thinking). Students can work collaboratively or individually to design a study on nQuire.

The educational tools are extended by some of the emerging technologies such as *Augmented Reality* (AR), 3D *printing/ scanning*, and *virtual robotics*

[4] https://nquire.org.uk/

(vRobotics). For example, the SorBET tool will be extended to support AR game playing and designing mode in the form of body interaction with the falling objects and voice control of the game settings (e.g. speed). The extension will enable students to engage with the game physically, in larger or smaller visual settings, and will support multiple people to simultaneously engage with the same game, supporting embodied collaborative learning experiences.

In addition to these educational tools, the Exten $(\text{D.T.})^2$ platform contains the Authorable Learning Analytics (ALA) component and the Authorable Visualization Dashboard (AVD) component to leverage the digital implementation, monitoring, and assessment of the different learning and activities DT projects that will be implemented in the schools.

The **ALA** component gathers data on student activity generated from the educational tools (described above). The component integrates high-level authoring tools, such as drag-and-drop UI tools, that enable different types of users (teachers, researchers) to author: *(a)* which data to be captured for a learning activity and *(b)* when to provide feedback to students and what feedback for each activity, aiming to enhance students' engagement with the Design Thinking stages.

The **AVD** component will effectively analyze and display the collected data from the educational tools (described above). The component support high-level authoring tools for different types of users (teachers, researchers, and students). The users can create their own customizable visualization dashboards by drag-and-dropping widgets. Each widget has a configuration where the user can specify the widget's style, colors, background, font size, and chart type (e.g., bar chart, pit chart, etc.)). In addition, some of the widgets will support real-time visualization of students' performance in DT activities for teachers. The visualization for teachers and students is more explanatory, and for researchers is more exploratory. The high-level architecture of the Exten $(\text{D.T.})^2$ platform is shown in Fig. 1 and it consists of three main layers:

- *The Presentation layer* is the web-based user interface (UI) for user authorization and accessing the game-based education tools, and other Exten $(\text{D.T.})^2$ services (ALA, AVD).
- *The Educational Tools Layer* is the layer where the education tools are deployed. This layer provides seamless integration of another new educational tool to be added to the Exten $(\text{D.T.})^2$ platform. The nQuire platform will be deployed outside of the Exten $(\text{D.T.})^2$ platform but accessible only through the authentication in Exten $(\text{D.T.})^2$ platform.
- *The API Gateway* is used to enable the interoperating software components in the system to combine with each other following a Software Oriented Architecture (SOA).
- *The Server component* contains the database service with PostgreSQL database, other third-party services, and a business logic layer.

- *The Business logic layer* implements the "business" logic of the system. That is any process or decision not related to data operations with the back-end DBMS.

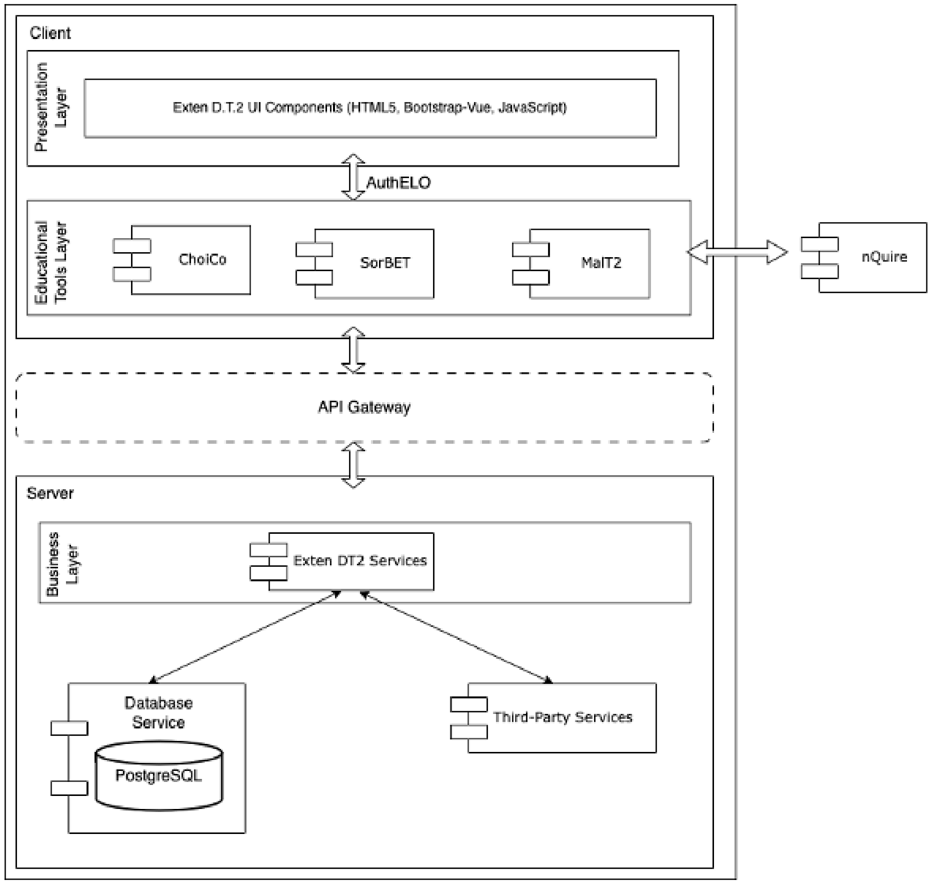

Fig. 1. High-level Exten (D.T.)^2 platform architecture overview

In the next section, we present the project evaluation plan, its core underlying ideas and its corresponding three cycles.

6 Evaluating the use of emerging technologies and design thinking in Exten (D.T.)^2

Exten (D.T.)^2 evaluation aims to develop a critical understanding of the potential, opportunities, barriers, accessibility issues and risks of using ET in DT learning activities. It uses a participatory design-based research approach (DBR) [1], comprising three cycles. The first is exploratory. Given the dearth of knowledge at the outset of the Exten (D.T.)^2 project and the need to develop an in-depth and contextualised understanding of the project technologies in action as part of DT learning activities, exploratory case studies are used to find out, at its simplest level, 'what happens'. This same approach is taken during the co-creation of such learning activities and the early development of teacher professional development activities. Qualitative data, primarily from observations, reflections, and interviews, provide an opportunity to explore in-depth the interactions between participants and technology as well as with each other, as students engage in co-creation, teaching and learning activities. It provides an opportunity to consider not just what, but also how students learn, including subject specific knowledge, Design Thinking attitudes and 21st Century skills.

To demonstrate the efficacy of DT and ET to develop skills and attitudes is a significant challenge in any intervention-based research study that does not extend to the scale of a randomised-control trial. Given that the context of each school intervention will differ significantly, from mode of delivery to subject, from school culture to the length and timing of such intervention, etc, there are many potentially confounding variables at work. Thus, at this stage the research team remains open to exploring several data collection approaches. One approach suggested in the literature is to avoid standardised testing and to focus instead on self-reported confidence [2]. In cycle 1 we pilot the use of an established instrument for 21st Century skills across contexts as well as a purpose-designed instrument in short surveys, for comparison with more qualitative approaches including open survey questions, observations, interviews, and evidence from learning artefacts.

Using constant comparative analysis, critical incidents and thematic analysis, findings of the Cycle 1 data analysis will be used to inform the development of tools, materials, pedagogy, and procedures across the ExtenDT^2 project. Cycle 2 remains primarily qualitative, using an instrumental case study approach to explore the impact of project developments. However, it also provides an opportunity to pilot large-scale quantitative instruments, explore the input-output of the LA system and co-design evaluation tools with and for teachers. Again, findings from the analysis will be used to inform the development of tools and resources for the third and final cycle. Finally, Cycle 3 focuses on quantitative data to evaluate the efficacy of the final tools and pedagogic approaches developed through the first two years of the project. Drawing on evidence from large-scale surveys and teacher's toolkits across six countries, we will evaluate the impact of using DT with ET on teachers' self-efficacy and students' knowledge, attitudes, and skills. Throughout, one of the challenges within this research is that of ethics. While the basic research design which draws on established Social Science research methods does not raise any unusual ethical issues, the specific context of the research does - the use and development of LA/AI within classrooms. Specifically, the intersection of disciplinary norms in education and computer science research ethics, together with the implementation of developing ET in real-world settings and pedagogic requirements and expectations of stakeholders, all within different cultural settings, results in a tangled set of issues. Emergent issues in Cycle 1 include tensions between stakeholder groups on the use of LA/AI in education; parental consent and student assent to participate in research activities; and balancing the pedagogic requirements of the teacher with the rights of the child/parent when exploring teachers' decision making. While approaches such as value-sensitive design are used from the beginning, as the technology and its use develop over the lifetime of the project, the ethical entanglements will need to be continuously reviewed.

7 Conclusions and Final Remarks

In this paper we have presented and discussed the theoretical foundations and initial development stages of the the Exten $(D.T.)^2$ project. Exten $(D.T.)^2$ is using emerging technologies to enhance the pedagogical value, sustainable digitization, and potential for wide deployment of DT in educational contexts with a focus on secondary education. We have described the main components of the proposed educational transformation as developed during the first year of Exten $(D.T.)^2$ including the theoretical foundations of the approach, the co-creation processes for meaningful engagement of teachers with educational innovation. The educational technology tools (design, extensions, architecture) that are used in the project have been presented including an introduction to the authorable earning analytics and the authorable visualization dashboard. These components will help to leverage the digital implementation, monitoring, and assessment of DT projects by teachers in schools and 21st century skills. leverage the digital implementation, monitoring, and assessment of the different learning and activities DT projects that will be implemented in the schools. We finalized the paper by describing our evaluation approach for capturing impact on improving students' skills and competencies. At the time of writing, we have started with the implementation of the first pilot projects to be deployed in secondary schools at six different European countries with more than 300 students. The next steps in the project comprise the analysis of the data collected during these pilots including also different aspects of the co-design of the pedagogical activities. The findings of these analysis will guide us in the coming phases of the project related to both pedagogical and technical aspects of developing and implementing the project at a bigger scale.

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