Deliverable Report

Extending Design Thinking with Emerging Digital Technologies

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Deliverable 7.2
Cycle 2 Evaluation Report

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1 Abbreviations

Abbreviation	Definition
DMP	Data Management Plan
DBR	Design-Based Research
DT	Design Thinking
Exten.(D.T.)^2	Extending Design Thinking with Emerging Digital Technologies
IB	International Baccalaureate
LNU	Linnaeus University
NKUA	National and Kapodistrian University of Athens
NTNU	Norwegian University of Science and Technology
OU	Open University
PD	Professional Development
RRI	Responsible Research and Innovation
SLR	Systematic Literature Review
TCD	Trinity College Dublin
UGent	University of Ghent
VRobotics	Virtual Robotics

2 Summary

The Exten.(D.T.)^2 project aims to meaningfully enhance the pedagogic value of Design Thinking through the use of emerging technologies and in doing so, develop a concrete pedagogical approach which supports the digital transformation of education. In the context of Exten.(D.T.)^2, these emerging technologies include Artificial Intelligence, Authorable Learning Analytics, Augmented Reality, Virtual Robotics and 3D printing. The ultimate aim is to increase the uptake of such technologies in secondary education and develop young people's 21st century skills.

This report presents the evaluation of the project in Year 2/Cycle 2 of the Design-Based Research (DBR) process, in which the enhanced project technologies are piloted in Design Thinking (DT) activities in classrooms and teachers engage in Professional Development (PD) activities, concluding with recommendations for Year 3/Cycle 3 of the project. In addition, it reports on three systematic literature reviews undertaken and the resulting development of the school and PD surveys, piloted in Cycle 2, ready for implementation at scale to evaluate the impact of Exten.(D.T.)^2 activities by the end of the project.

3 Introduction

3.1 Purpose and Objectives

Deliverable 7.2 (D7.2) presents the evaluation of the Year 2/Cycle 2 of the Exten.(D.T.)^2 project. The primary aim of this deliverable is to take an in-depth look at the implementation and impact of the school interventions and PD, with a particular focus on impact of recommendations made at the end of Cycle 1. The deliverable provides a series of recommendations and best practice examples to inform the final development of WPs 2, 3, 4, 5 and 6 and implementation of school interventions and PD activities. It also provides an opportunity to report on the research undertaken to develop surveys which address the needs of the project in Cycle 3 where the focus is on scaling interventions as well as the nascent development of the teacher's evaluation toolkit.

3.2 Connection to Other Project Activities

D7.2 draws on data collected from the school interventions (WP5) and PD activities (WP6) carried out in Year 2/Cycle 2 of the project. It aims to inform the development of WPs 2, 3, 4, 5 & 6 in Year 3/Cycle 3. These developments should impact the outcomes of intervention, as per the DBR approach adopted across the Exten.(D.T.)^2 project.

3.3 Structure of the Document

This deliverable commences with the foundations of the evaluation, presenting the results of the systematic literature reviews (T7.2) and resulting survey development (T7.4), before describing the development of the Cycle 2 Toolkit (T7.5). An evaluation of the Year 2 project activities which have taken place through school interventions (WP5) and PD activities (WP6) is then detailed, with individual case studies presented in the Appendixes. This is followed with an update on the status of the teacher's evaluation toolkit (T7.3). Finally, there is a discussion of key points with reference to the literature presented in D2.1 and the recommendations from the Cycle 1 evaluation. In the concluding section, a series of recommendations to be considered by the project consortium are made, along with next steps and a statement on RRI.

Note: Appendixes can be accessed through the following PDF Link. They are labelled according to the lettering A-Q: [Link to PDF Document](#).

4 Evaluation Methodology

In Cycle 1, the project adopted an exploratory case study approach, prioritising qualitative data, to provide insights into the novel approaches being trialled in the Exten.(D.T.)² project. The ambition in Cycle 3 is to scale the practices and technologies developed in the project, necessitating a primarily quantitative approach to data collection. Thus, Cycle 2 aims to bridge the gap between these DBR cycles, providing an opportunity to: reflectively respond to the results of the Cycle 1 evaluation; focus on key recommendations from Cycle 1 and project developments in Cycle 2; inform developments in WPs 2, 3, 4, 5 and 6 that would take place at the start of Cycle 3; and pilot a scalable survey ready for the Cycle 3 evaluation.

To achieve these aims, the Cycle 2 evaluation adopts an intrinsic case study approach. Intrinsic case studies are used where the phenomena under study is of intrinsic interest. In this project, it enabled each project team working with local teachers to identify particular issues (pre-identified from the recommendations resulting from the Cycle 1 evaluation – D7.1) that were pertinent to their own context. For example, in the school interventions in Ireland the focus was on students' technology use, as it was the only intervention which allowed students to choose their own technology to develop their solution; while in Greece the focus was on evidencing learning and feedback; and in the UK the focus was on students' technology use and rapid prototyping.

As in Cycle 1, Cycle 2 utilises observations (written, video, audio and screen recorded), interviews (with teachers and students) and artefacts of learning (digital and physical) to generate qualitative data. These utilised slightly refined protocols following on from partner feedback and the results of the Cycle 1 evaluation. Again, surveys provided quantitative data which could be analysed as part of the case studies but also at a country and project level. The surveys were furthermore substantially developed following the results of the systematic literature reviews, as described in Sections 5 and 6.

5 Systematic Literature Reviews

Three systematic literature reviews (SLRs) were undertaken by the TCD and NKUA teams with the aim of identifying short quantitative survey instruments designed and validated for use with young people between the ages of 11 and 18 (the project's target age range in schools), to measure attitudes and/or performance in the following three areas: **21st Century Skills**, **Design Thinking** and **Digital Competence**. Overall the SLR process was led by TCD, with each of the three SLR teams including a lead and between 2 and 3 assistants who supported the searches, screening and analysis. The three leads met to define the initial search terms, review the results and finalise the search terms at the start of the process. Through the screening and analysis there were regular meetings with all team members to ensure consistency across the three teams. This section provides a high-level overview of these SLRs and uses the 21st Century Skills SLR to provide illustrative detail. Finally, it presents the key results which informed the development of the school student and teacher PD surveys. Three journal articles are currently in development following this work.

5.1 Research Aims and Questions

The aim of the three SLRs respectively were to identify high-quality, quantitative instruments to measure secondary school students' attitude to and knowledge of 21st Century Skills, Design Thinking and Digital Competence.

The research questions for each included:

- Who were the surveys designed for?
- Who were the surveys designed by and for what purpose?
- What is the quality of the instruments?
- To what extent have they been used?
- How do the skills/competencies measured compare to common frameworks?

5.2 Eligibility Criteria

Inclusion and exclusion criteria for the three SLRs were established prior to the search process, based on the requirements of the Exten.(D.T.)^2 project.

Table 1 presents the inclusion and criteria for 21st century skills, which was replicated for the other two searches on design thinking and digital competencies with only the focus changed.

Table 1 Inclusion and exclusion criteria for 21st Century Skills

21st, Century Skills		
Criteria	**Inclusion**	**Exclusion**
Participants	Young people between the ages of 11 – 18	Quantitative instruments designed for adults, higher education, professional corporate or organisational innovation Ages 0 – 11
Study design	Published between 2000 – 2023 Quantitative instrument used as part of an empirical study Educational purpose Peer-review journal articles, conference papers and PhD theses Available in English language	Published before 2000 (to maintain some criteria related to state of the art) No quantitative instrument Purely qualitative research No empirical research Focus on 21st century literacy (due to definitional muddying between 21st century skills and literacy in the 21st century) Only 1 skill or skill category measured

5.3 Sources

In total, four databases were searched: EBSCOhost, Web of Science, Proquest Dissertations and Theses and IEEE XPLORE. Within the EBSCO database, Educational Resources Information Centre (ERIC) and PsychInfo were searched.

5.4 Search Strategy

The three systematic searches were conducted between January and August 2023 for studies that focused on the quantitative measurement of a) 21st century skills, b) design thinking and c) digital competencies in young people ages 11-18. The search strings were derived from the search strings of related existing SLRs in 21st Century Skills in education (Amelia & Santoso, 2020; Chalkiadki, 2018, Gonzalez-Salamanca, et al., 202; Teo et al, 2021; van Laat et al., 2017, van Laar, 2020), Design Thinking in schools (Almedia et al., 2019; and Rusmann & Eising-Dunn, 2022), and the measurement of Digital Competencies (Matter et al., 2022; and Saltos-Rivas, 2021). The results of an initial search in 2022 were reviewed and the search strings revised before running the final searches on the 20 January 2023 (digital competencies), 4 April 2023 (21st century skills) and 18 August, 2023 (design thinking).

The search strings used for the search on 21st century skills are listed in Table 2 below. Given the context and purpose of the SLRs, the search strings used for the searches on design thinking and digital competencies were the same, except "21^{st} century skills" was replaced with "design thinking" or "digital competences."

Table 2: Search strings for 21^{st} century skills

21^{st} century skills	Education	Measure or instrument
("21st century" OR "twenty first century") NEAR/3 ((skill* OR competenc* OR learn* OR teach* OR educat*) OR (thesaurus terms where applicable)	((Education) NEAR/3 (secondary OR "post primary" OR postprimary) OR K-12 OR "high school*" OR highschool* OR "middle school*" OR middleschool* OR "informal learning" OR "out of school*" OR "semi formal learning" OR outreach OR college* OR "post compulsory" OR "maker education" OR school* OR adolescen* OR "young people" OR "young adult*" OR youth* OR teen*) OR (thesaurus terms where applicable)	Measure* OR instrument* OR evaluat* OR survey*OR questionnaire* OR quant* OR scale* OR test* OR assessment* OR valid* OR " factor analysis"
Search techniques Proximity search finding words near each other in any order: (EBSCO d/b Psycinfo and ERIC use N3 for proximity search/ SCOPUS uses W/3, Proquest D&T and Web of Sci (core collection) use NEAR/3. IEEE XPLORE uses NEAR/3. No thesaurus terms for Web of Science, Scopus.		

5.5 Selection Process

This section provides an overview of the 21st century skills SLR procedure followed, used as an example below, followed by figures with the PRISMA flowchart for each SLR. The same procedures followed by all researchers conducting the other two SLRs.

From the initial search in the mentioned databases, the documents (N = 13,181) were imported into Covidence, a tool that allows for storing, screening, and documentation during the systematic review process. Covidence identified 1808 duplicates and the research team manually identified 628 duplicates. 10745 studies were then screened against title and abstracts; ten percent which were double screened for eligibility and to maintain consistency, with the remainder screened by one researcher. Studies that clearly failed to meet the inclusion criteria were rejected at this stage and those that required further examination were retained.

Full texts of the remaining studies (N = 358) were obtained and screened by the same researcher and forty percent of this sample was double screened to ensure consistency. During the full-text screening, additional criteria were established regarding how many 21^{st} century skills were measured by the quantitative instrument. Due to an overwhelming number of full texts, any articles that did not involve the measurement of at least two 21^{st}

century skills were excluded due to project requirements. Instruments measuring only one 21st century skill (e.g., creativity) were considered irrelevant to the overall research aim. All judgements were made based on the criteria laid out in Table 1. Any conflicts were discussed between the research team and then articles were either confirmed or excluded, resulting in 28 studies included for the final review. Figure 1 represents these steps through a Preferred Reporting Items for Systematic Reviews and Analyses (PRISMA) flowchart.

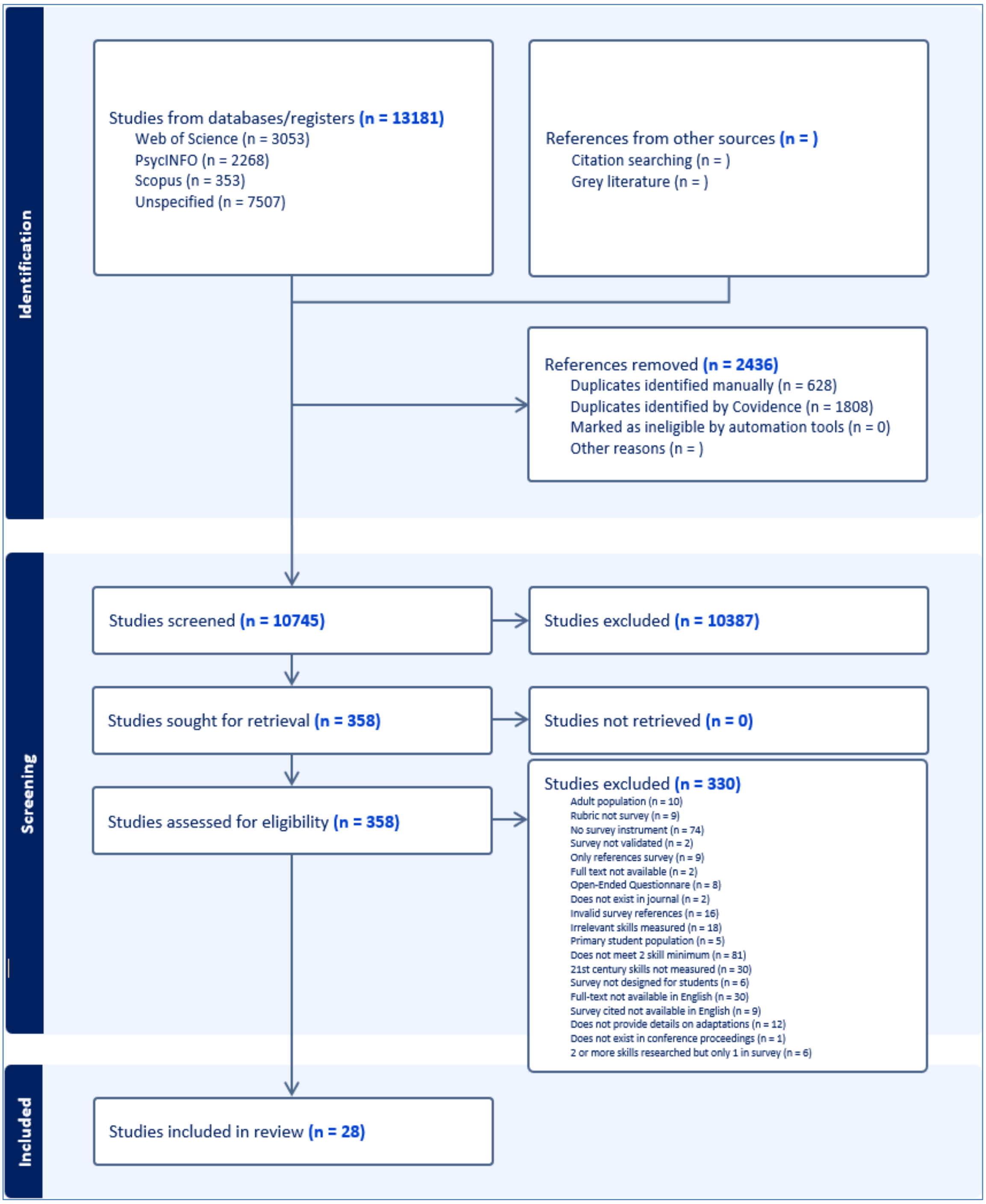


Figure 1: PRISMA flowchart - 21st century skills

Figure 2 and Figure 3 show the PRISMA flowcharts of the systematic searches for design thinking and digital competencies.

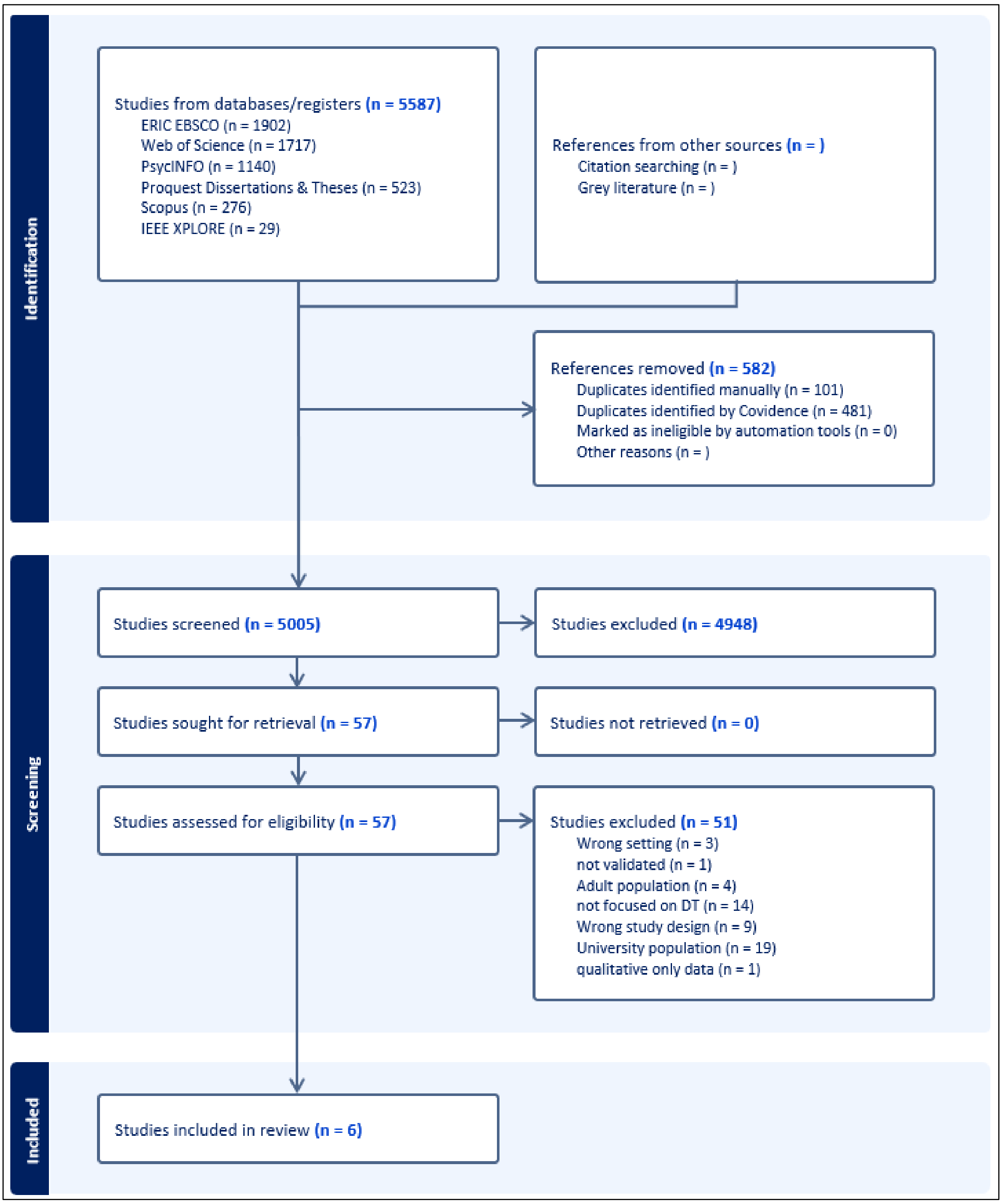


Figure 2: PRISMA flowchart - design thinking

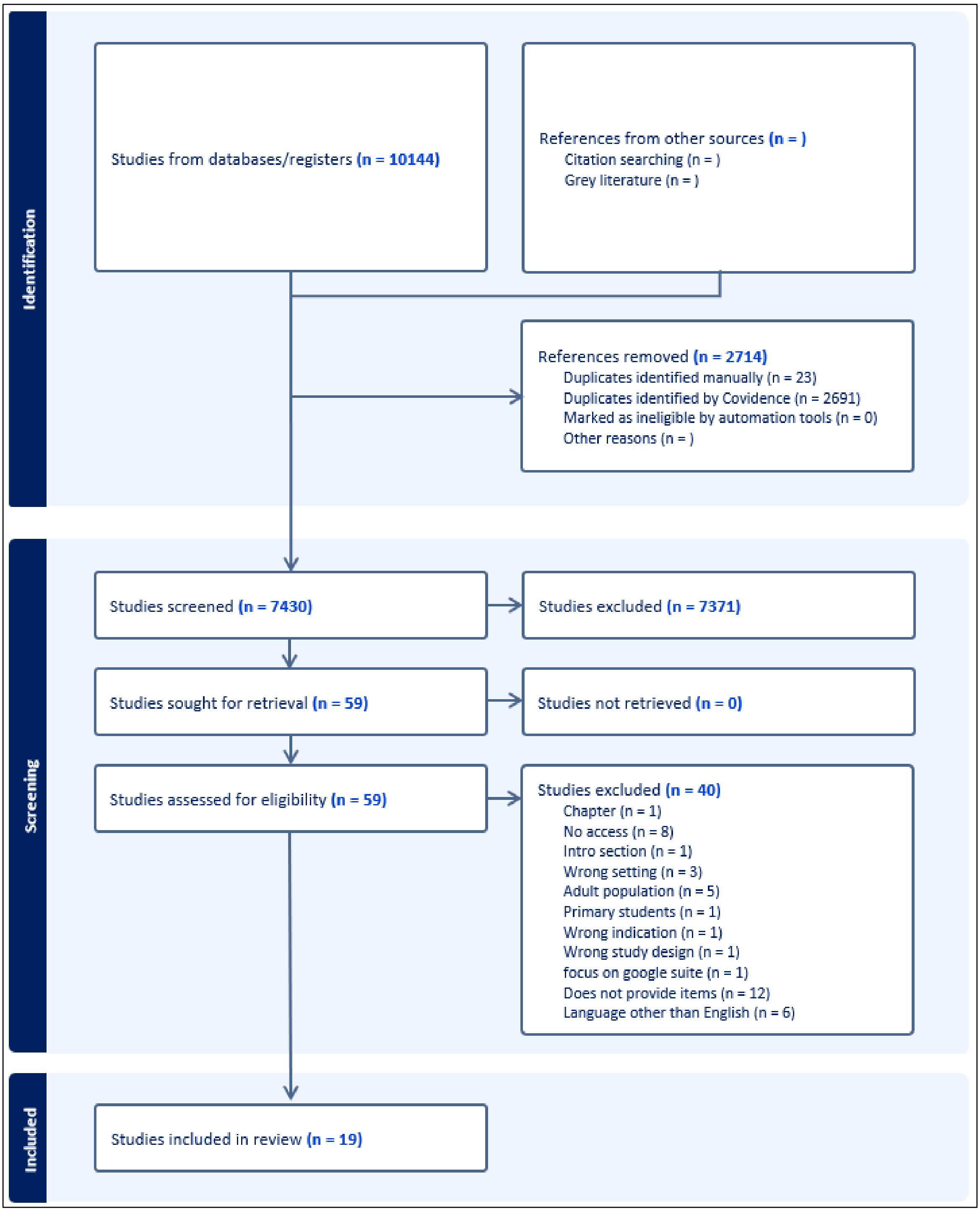


Figure 3: PRISMA Flowchart - digital competencies

5.6 Extraction

For data extraction and analysis of the survey instruments, a spreadsheet for each of the three areas was created. The following information about the articles and characteristics of its survey instrument(s) were included:

- Source
- Research aims and questions
- Research design
- Survey demographic
- Survey design
- Implementation
- Number of survey items
- Original source if adapted
- Original population designed for, if adapted
- Validation approach:
  - Number of participants
  - Age
  - Country
  - Context
  - Validation approach
- Links to frameworks, curriculum or policy
- Use beyond the original research
- Survey items and categories

5.7 Results

The SLRs revealed 4 key findings which are most relevant to the development of the 2nd and 3rd Year surveys (which was the purpose of the SLRs):

1. Surveys identified under 'digital competencies' rarely assessed competencies, but instead focused on skills and specific applications.
2. Both 'design thinking' and '21st century skills' surveys excluded at least one phase or skill set (respectively), with no survey addressing all phases or skills identified in the Year 1 survey.
3. Instruments are rarely aligned to an existing framework, curriculum or policy.
4. There are few short surveys available. This is a critical point related to both the time available and likelihood of survey fatigue, given the breadth of topics that the final Exten.(D.T.)^2 surveys must cover.

Having removed overlap (where studies presented only minor adaptations to an instrument already included in the SLR), 26 survey instruments across the SLRs were identified for secondary extraction which is described in the following section on survey development.

6 Survey Development

Based on the results of the SLRs, it was clear that there were no pre-existing survey instruments which met the project team's requirements (identifying short quantitative survey instruments designed and validated for use with young people between the ages of 11 and 18 (the project's target age range in schools), to measure attitudes and/or performance in **21st Century Skills**, **Design Thinking** and **Digital Competence)**. Thus, the TCD and NKUA teams participated in a series of meetings to: a) assess what was feasible given time constraints and project requirements; b) identify and adapt existing validated surveys; and c) create new survey items. These were then integrated with the pre-existing Cycle 1 surveys, retaining what was valuable from Cycle 1, creating new sections and removing sections that did not provide valuable information for Cycle 2. The full surveys are available in Appendixes A-D. Attribution for the SLR team members who created these surveys is included in the appendixes and should be noted in all publications where the surveys are included.

6.1 Extraction

For the purposes of survey development, data analysis and extraction of 53 papers and their survey instruments were undertaken by the TCD and NKUA teams.

The following information about characteristics of the survey instrument(s) were included:

- Source
- Survey item and group category
- Intervention details
- Use beyond the original study
- Adaptations from another source
- Links to existing frameworks

26 survey instruments were included in the spreadsheet for 21st century skills (2 survey instruments were removed as the survey items were already extracted from another article included in the review). 4 survey instruments were included in the spreadsheet for design thinking (2 survey instruments were removed as the survey items were already extracted from another article included in the review). 18 survey instruments were included in the spreadsheet for digital competencies. Following the extraction of survey items, specialists identified the most relevant surveys of the sample based on the following factors: number of items; clarity of survey items; survey validation; survey use; breadth across 21st century skill categories, design thinking and digital competencies; and alignment with existing frameworks, curricula and policies.

This resulted in the identification of 10x 21st century skills, 3x design thinking and 5x digital competencies instruments. These surveys were then analysed to identify similarities between surveys, gaps within individual surveys and cross-overs between surveys on different topics (for example several surveys on 21st century skills included items on digital competencies). The aim was to find the strongest surveys for the purposes of the project.

6.2 Results

At the end of the process, 3 instruments were identified for inclusion in the Year 2/Year 3 surveys:

- SICKS by Bray et al. (2020) which focuses on students' confidence when it comes to working with others/collaboration, communication, creativity, self-management, information management, critical thinking, and technology use for educational purposes
- Missett el al.'s (2013) post-intervention instrument for creative thinking, problem solving and teamwork
- Tsai and Wang's (2021) pre-intervention instrument focused on four phases of design thinking: empathising, defining, ideating, prototyping

A decision was made to augment these surveys with validated categories (and when necessary, single items) from other surveys to address any missing elements. For instance, researchers found that communication, a frequently cited 21st century skill among relevant frameworks, was not adequately addressed in the selected surveys with skills such as 'listening' excluded. They therefore sought out survey items from other similar instruments (outlined in Table 3) which covered these skills. Ultimately, the team needed to create 3 items themselves which covered aspects of communication and feedback. This process continued until the team felt confident that all the skills laid out in 21st century skill frameworks and the project's own design thinking process were covered.

Table 3: Source of additional survey items

Source	Area	Items retained	Single item from category?
Bethune (2021)	Design thinking	2	Yes
Glaittli (2018)	Time management; communication	2	Yes
Niruttimatee (2022)	Communication	1	Yes
Peart et al. (2020)	Communication	2	Yes
Our research team	Communication; feedback	3	N/A

A decision was made by the team that as there were no instruments which adequately addressed digital competencies, and that these were already addressed to some extent in the

Year 1 survey and Bray et al. 2020, these existing instruments would be used as it is beyond the scope of this project to develop a completely new instrument to assess digital competencies.

6.3 School Survey Development

In total, 57 items were collated and adapted for use in the pre and post school intervention surveys, including 3 items generated by the research team (Table 4).

Table 4: Source of new survey items

Survey item extraction						
Source	**Area**	**Items retained**	**Single item from category?**	**Items removed**	**Revised for pre-survey?**	**Revised for post-survey?**
Bethune (2021)	Design thinking	2	Yes	8	No	Yes
Bray et al. (2020)	21st century skills	17	No	0	No	No
Glaittli (2018)	Time management; communication	2	Yes	17	No	Yes
Missett et al. (2013)	Problem solving; interacting with others	12	9 from single category; 3 single items	9	Yes	Yes
Niruttimatee (2022)	Communication	1	Yes	27	No	Yes
Peart etl al. (2020)	Communication	2	Yes	53	No	Yes
Tsai & Wang (2021)	Design thinking	18	No	0	Yes	Yes
Our research team	Communication; feedback	3	N/A	N/A	N/A	N/A

As none of the instruments were designed for pre/post testing, all except SICKS by Bray et al. (2020) required adaptations. Additionally, some items had linguistic inaccuracies and/or lacked clarity and so were revised by the project team. For example, in Tsai and Wang (2021), the item “I usually try to consider the practice of the work” within the category of ‘empathy’ was revised to “I usually try to consider how someone might use what I am going to create”. To create a functional pre and post stem for this item in the context of this research project, the original stem “When I design a work….” was changed to “When I work on a project in a team, I….” (pre) and “By working on the ExtenDT2 project, I….” (post), which aligned more closely to the original post-intervention stem by Missett et al. (2013) and was similarly adapted for the project context and pre/post testing.

Other items included in the pre/post surveys were based on the Cycle 1 surveys and their results, with effective items retained. The following sub-sections outline the changes that occurred between the Cycle 1 and Cycle 2 surveys:

6.3.1 Summary of Changes to Pre-intervention Survey from Year 1

Overall – lengthened*
Additions:

- Learner ID/username used on the Exten.(D.T.)^2 platform (this is a group ID for logging into the platform and does not personally identify the student)
- Country student resides in (this is only in the online version of the survey)
- Likert scale (1-5) statements which covered aspects of communication and feedback developed in response to results from Year 1 (9 items)
- Questions on interacting with others in teams (33 items from validated surveys)

******18 items from Year 1 pre-survey were retained and added to 57 items developed from SLR*

It was estimated that this survey would take 15 minutes to complete – in practice, on average the survey was completed in 13.5 minutes by students in Ireland, the UK, Sweden and Greece (the data from Belgium did not arrive in time for analysis).

6.3.2 Summary of Changes to Post-intervention Survey from Year 1

Overall – shortened*
Additions:

- Learner ID/username used on the ExtenDT2 Platform (this is a group ID for logging into the platform and does not personally identify the student)
- Country student resides in (this is only in the online version of the survey)
- The advantages and challenges of using the project tools
- Students' confidence in using the project tools to create and adapt their solutions

Removal:

- What subject knowledge students used to complete their projects
- Ease-of-use questions about each of the technologies

Replacement:

- Questions on what students did during the project regarding design thinking, constructionism, teamwork and feedback; with validated items on design thinking and skills, replicating the same questions added in the pre-survey (42 items)
- Open-ended questions about skills confidence with closed-questions which replicate items from the original pre-survey (18 items).

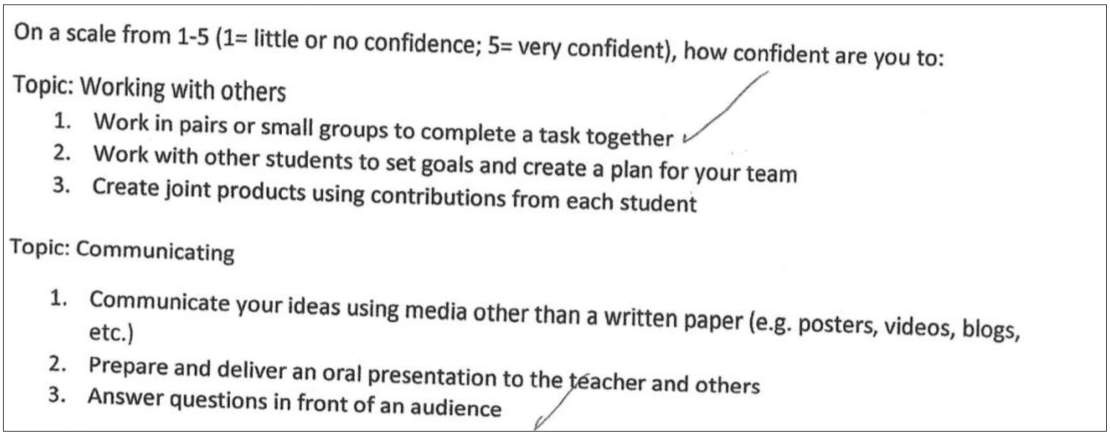
******18 items and 2 open-ended items from Year 2 post-survey were retained and added to 57 items developed from SLR*

It was estimated that this survey would take 22 minutes to complete – in practice, on average the survey was completed in 15 minutes by students in Ireland, the UK, Sweden and Greece.

6.3.3 Validation

A short validation exercise with 6 students (3 male, 3 female) in Ireland and the UK, who were between the ages 11-13, was undertaken following the creation of the survey to evaluate the age-appropriateness and clarity of survey items. The following list includes changes made to increase the legibility and organisation of the survey as a physical copy as well as justification for the change.

- Questions that allow for the selection of more than one answer were grouped together and instructions were bolded. In the original survey, students were unaware of when they could select multiple answers vs one answer.
- Questions that require a number-rating were changed into matrices (i.e., "On a scale from 1-5, how confident are you to:"). In the original survey, students treated said questions as multiple choice and failed to provide a rating. See Figure 4 as an example.


On a scale from 1-5 (1= little or no confidence; 5= very confident), how confident are you to:

Topic: Working with others

1. Work in pairs or small groups to complete a task together
2. Work with other students to set goals and create a plan for your team
3. Create joint products using contributions from each student

Topic: Communicating

1. Communicate your ideas using media other than a written paper (e.g. posters, videos, blogs, etc.)
2. Prepare and deliver an oral presentation to the teacher and others
3. Answer questions in front of an audience

Figure 4: Student response in pilot survey

Additionally, minor revisions were made to increase the clarity of some survey item. Table 5 shows the original survey items students provided feedback on, the students' feedback and the changes made as a result.

Table 5: Changes in survey items with student feedback

Original survey item	Students' feedback on item	Resulted change
"Design a preliminary model"	Simplify preliminary	"Design an early version model"
"Invent a solution to difficult problems"	Simplify invent	"Come up with a solution to difficult problems"
"I can ask questions to help me understand other people"	Did not know what about other people statement was referring to	"I can ask questions to help me understand what other people say"
"Track your own progress and change things if you are not working the way that you should be to complete a task"	Specify "working the way that you should be"	"Track your own progress and change things if you are not on schedule to complete a task"

The final survey was translated by partners and made available to students online or on paper.

6.4 Professional Development Survey Development

6.4.1 Pre-intervention Survey

The pre-intervention survey for students engaged in PD activities largely remained the same from Cycle 1 as the focus was on understanding teachers' and student teachers' past knowledge, beliefs and expectations. However, given that teachers involved in PD activities are expected to learn and develop their digital competencies, there was a need to add items that went beyond digital skills and application use.

Given the need for a brief instrument to assess teacher and student teacher digital competence as part of a wider survey, a decision was made to adapt SELFIEforTeachers (European Commission, 2023). SELFIEforTeachers is used extensively by classroom teachers across Europe and is linked to the European Digital Competence of Educators (DigCompEdu). However, it is designed for classroom practitioners, and we needed a survey which could be used with student teachers as well. Additionally, SELFIE is long, and we required an instrument which could be integrated into a larger survey. Other instruments are focused on skills, particularly the use of specific technologies to do specific tasks, not competencies. Thus, an adapted version of SELFIEforTeachers was created.

The solution was to use the 22 DigiCompEdu competencies from SELFIE and adapt the B1 statement for each, to create a confidence statement that utilises a 5-point Likert scale, with an option to select "this is not relevant to the subject(s) I teach". Additionally, given the focus of Exten.(D.T.)^2, all items from the emerging technologies category were included.

Due to time constraints, the UGent team were unable to pilot the revised pre-survey but it was piloted by NKUA as part of their PD activities in Cycle 2.

6.4.2 Post-intervention Survey

Changes made to the post-intervention survey from Cycle 1 included replacing the open questions about the advantages and challenges of using the project tools with multiple-choice questions based on the results from Cycle 1; the addition of questions about the perceived benefits and barriers to their own students using these tools; the addition of questions about their confidence in designing and delivering each of the 5 phases of the Exten.(D.T.)^2 model of design thinking; and the addition of the adapted SELFIEforTeachers questions asked in the pre-survey but with a focus on whether their confidence had changed following the PD activities.

Both UGent and NKUA piloted this survey as part of their PD activities in Cycle 2.

7 Cycle 2 School Intervention Results

In Cycle 2, a total of 26 Exten.(D.T.)² school interventions took place, involving 19 different activity plans and utilising all project technologies. More details on the school intervention activities are available in D5.3 which provides a report on the 2nd Year implementations. Table 6 provides a summary of the activities and data collection that occurred in each country. Each partner provided at least one case study report from an intervention (see the Appendixes) except for LNU (which was not completed in time for analysis) and implemented the survey with all students participating in each of the school interventions.

Table 6: Summary of School Interventions and Data Collection by Country

Country	Partner	No. of School Interventions	No. of Activity Plans	Technologies to be Used	Survey Participant Numbers	Case Study Reference	Case Study Foci
Belgium	UGent	4	4	ChoiCo	n/a	Appendixes E, F and G	New knowledge, programming, 21st century skill development, DT mindset
Greece	NKUA	8	8	ChoiCo, GearsBot, MaLT2, SorBET and nQuire	78	Appendixes H, I and J	Evidence of learning, teamwork, feedback, reflection
Ireland	TCD	2	1	Open choice	37	Appendix K	Technology use
Norway	NTNU	9	3	SorBET, GearsBot and nQuire	206	Appendixes L & M	Feedback, teamwork
Sweden	LNU	1	1	ChoiCo and NQuire	12	n/a	n/a
United Kingdom	OU	2	2	SorBET and nQuire	26	Appendix N	Technology use, rapid prototyping

In total, 10 case studies were undertaken covering the following topics: 21st century skill development, DT mindset, new knowledge and evidence of learning, teamwork, feedback, reflection, technology use and rapid prototyping. In addition, 234 students participated in the pre- and post-surveys (respondents who completed less that 20% of a survey were excluded).

This section provides a summary of the case study results (with the full reports available in the Appendixes) and the cross-country quantitative data analysis.

7.1 Case Studies

In Cycle 2, as described above in Section 4 Methodology, the intention was to carry out intrinsic case studies. That is to say that each case study was intrinsically interesting and there is no intention within the case study itself to create generalisable findings. For this reason, this section provides a summary of the findings from each country's case studies, with the full reports available in the Appendixes. Each summary provides the case study focus and context, followed by the key findings, key challenges and best practices/insights. They are presented at a country level to recognise the importance of national context. The aim on the individual case studies is not to generalise. These case studies are in-turn treated as data and combined with the quantitative survey data (Task 7.2) and evaluation of the Cycle 2 PD activities. These combined data are used to evaluate the Cycle 2 activities and produce recommendations for Cycle 3.

7.1.1 Belgium

7.1.1.1 Case Study 1 (Appendix E)

Focus	New knowledge, 21st century skill development through Exten.(D.T.)² approach
Context	Occurred during special project week on UN sustainable development 2 days, 8 hours total 65 students, 3 teachers

Key Findings

- Students were introduced to novel concepts and the intervention broadened their educational experience
- Opportunity to tackle complex/wicked problems
- Students learned to use specific tools (ChoiCo) and applied skills practically
- Students engaged with issues in their city in ways they had not before, real-world learning motivated and increased student engagement, empowered students to think about their contribution to sustainable solutions
- Critical to involve users in the development process - students found that they needed direct interaction (i.e., interviews) with end users to empathise & create effective designs
- Feeling a sense of ownership over their project motivated students & fostered a deeper engagement

Key Challenges

- Time, some students said too much time and others said not enough time
    - Challenging to accommodate work paces & intervention within a single event structure
- Confusion – students found it difficult to grasp the aim of the intervention & unclear instructions
- Unfamiliarity with or disinterest in digital technologies
- Complex programmes led to frustration & negative feelings
- Collaboration and managing group dynamics

- Brainstorming and defining the problem, "*looking from a different perspective was not easy*"
- Generating ideas

Best Practices

- Introducing novel concepts
- Engagement with complex problems through collaboration
- Integrating real-world tools and societal relevance
- Utilising game-based learning
- Focusing on user involvement
- Foster ownership and accomplishment

7.1.1.2 Case Study 2 (Appendix F)

Focus	Design thinking mindset, programming, and related skills
Context	5 sessions, "the world of music and sound" 11 students

Key Findings

- Learning outcomes (as described by students) focused on computer science and programming skills
- "Making mistakes is allowed" – evidence of design thinking mindset and pedagogic approach
- Sense of ownership and personal connections increases student interest and engagement
- Hands-on activity of "making the game" was frequently mentioned as an interesting aspect of the intervention

Key Challenges

- Initial hurdle in understanding the digital tools
- Understanding "*the rules of the game*" (ChoiCo)
- Practicality issues (i.e., finding the game)
- "*Creating layers and writing code*" and managing complexity caused by bugs in ChoiCo

Suggestions for ChoiCo made by Students

- Greater functionality, more ways to add complex code, more options/blocks
- Increase ease of use, unifying interface to minimise tab switching
- Interactive and customisable game design elements, "controlling a character"
- Change variable in code
- Clearer guidance/instructions

7.1.1.3 Case Study 3 (Appendix G)

Focus	Learning towards the Belgian goals of research competencies and sustainability, 21st century skill development
Context	3rd grade, "open hours" seminars focusing on research and research competencies 8 sessions, addressed 3 global challenges: sustainable fashion, sustainable food, sustainable school management 20 students

Key Findings

- Students gained significant insights into sustainability
- Students developed skills
    - "Conduct interviews", "check data", "critical thinking", "being creative" "programming", give and receive constructive criticism
        - Students appreciated the opportunity to be creative which "sometimes we miss at school"
    - "Teamwork, communicating with the team"
    - Enhanced technical proficiency
        - Supplementary resources (e.g. YouTube videos) were engaging and taught programming language
- Students were enthusiastic to learn through digital technologies and have a completed prototype by the end of the project

Key Challenges

- Defining the problem to be addressed in their project, "*in the beginning, I didn't know exactly what to do*" "*difficult to start*"
- Technical issues and frustration with ChoiCo
- Although technology felt accessible there was limited ways to advance programming
- Idea generation
- Collecting and analysing data

Best Practices and Insights

- Collaborative activities as a core component of learning process
    - Encourage division of tasks
    - Regular feedback sessions
    - Structured collaboration tools
- Incorporate technology into learning process frequently and provide variety whenever possible
- Maintain focus on critical analysis and problem-solving with explicit instruction of tasks unfamiliar to students
- Promote student independence, provide tangible outcomes and create dynamic learning environment

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7.1.2 Greece

7.1.2.1 Case Study 1 (Appendix H)

Focus	Evidence of learning, teamwork
Context	● Challenge: students adopted role of designer and builder to create 3D print pieces of jewellery in MaLT2 ● After-school hours (2 sessions of 4 hours each) ● 22 students, 14 – 15 years old ● Students and teachers have prior experience with MaLT2, teacher was familiar with DT

Key Findings

Mathematics

- Evidence reports students' ability to apply theoretical knowledge to create artefacts that were visually appealing and mathematically sound in instances corresponding to: a) properties of a rhombus, b) properties of parallel lines, and c) angle conceptualisation
- Interplay and simultaneous development of mathematical and computational skills enabled a higher level of creativity and led students towards generalisation
- Students did not look for underlying causes of an undesirable outcome in their models, preferred trial/error rather than taking part in extended discussion or higher-level inquiry of issue

Computational thinking

- Repetition in algorithmic structure was a key-concept for students to design complex shapes and solids, fostered sense of ownership & creativity
    - Students used repetition to:
        - Create different shapes one inside another
        - Break repetition so as to make changes in the repetitive unit
        - Create a 2D pattern
        - Create a 3D object
- Students used decomposition as technique to facilitate debugging or identify their mistakes in codes

Collaboration

- According to students, collaboration enhanced the quality and creativity of their designs, collective brainpower, diverse perspectives
- Participating in a joint-construction simplified the prototyping and designing process
- Evidence of students combing different skills to achieve common goals

Key Challenges

- Challenge of prototyping linked to trial and error approach
- Mathematical reasoning – challenge of argumentation and reasoning within groups
- When team members failed to fulfil their commitment
- Incorporating feedback from all members
- When divergence between students' skills was too great, it led to disruption or disengagement
- Students and teacher experienced some technical problems when using platform

Best Practices and Insights

- Enhancing collaboration between groups
    - Students learned from members of their group, teacher but also from the constructions/artefacts of other groups
    - Student suggestion to receive external collaboration during "feedback" phase and teacher noted students develop collaboration mainly by receiving feedback
- Students' engagements with 3D printing led them to consider its potential limitations and recognised the need to avoid the risk of constantly changing the whole code to produce different sizes of the artefact (this in turn enhanced students' mathematical abstraction)
- Student suggestion to be more involved in actual 3D printing process and have another round of printing before their final result
- Didactic design of "half-baked" microworlds had an added value for students mathematical meaning making and competence, triggered students to think about their own model

7.1.2.2 Case Study 2 (Appendix I)

Focus	Teamwork (primary), feedback (secondary)
Context	• Challenge: create SorBET game addressing cyber security dangers (online phishing, strong passwords, firewalls) • Two 1st Grade middle school classes (30 total participants), 12 – 13 years old • Computer science teacher with experience in STEM and robotics projects, not familiar with DT or project technologies • 2 researchers

Key Findings

Collaboration

- Group 7 revealed that the project's demands (i.e., constant communication, sharing digital tools, agreement) encouraged more collaboration than other simpler tasks

- Students found it valuable to work with people they were not familiar with
- Teamwork allowed students to view project from a dual perspective (designer/user)
- Adjusting game dynamics / iterative design facilitates collaborative decision making

Flexibility (mutual respect)

- Flexibility & ability to listen / compromise were crucial to students overcoming challenges in teamwork
- Teacher assigned groups challenged students to be more flexible and adapt to - working with different personalities / skill sets, encouraged to practice respectful communication and compromise

Communication

- When faced with conflict, students showed a willingness to resolve disagreements through dialogue & compromise
- In Group 7, decisions were guided by 1 student, yet everyone contributed ideas / had to agree or disagree, maintained group cohesion
- In Group 10, roles were fluid and decisions were made on merit of ideas

Roles

- Assignment of specific tasks / roles to different group members occurred intentionally or by specific events based on students' skills and strengths

Feedback

- Despite initial negative reactions to feedback, student & teacher comments demonstrated an understanding of the value of feedback for improving work
- When feedback was contradictory or lacked clear directives, students sought out a comprise that reached middle ground

Key Challenges

Feedback

- Students exhibited varying degrees of resistance to feedback
    - Initial frustration and defensiveness towards negative feedback
    - Conflicts arose when feedback was challenging
    - Discomfort of receiving critical feedback from peers
- Teacher also observed students struggled to accept negative criticism
- Digital feedback was not successful (i.e., students avoided answering open-ended questions, added random letters, or made unhelpful comments like "I didn't learn anything" or "I would change everything")

Technology

- In general, students encountered some issues while using SorBET's hand–tracking technology in the school computers due to older versions of the machines, poor connection to the internet or the technical readiness of the digital tools
- nQuire seems to have worked seamlessly from the students' point of view

- Teacher found nQuire platform difficult to use due to complex login process, multiple passwords, layout & organisation were confusing

Best Practices and Insights

- DT project allowed students to recognise a different, more powerful kind of collaboration
- Collaborating on design of various project outputs allowed students to see value of combining multiple perspectives
- Group formation of students not familiar with each other was a crucial element of fostering effective collaboration
- A more flexible approach to role assignment within group, higher trust among team members
- Work delegation – students felt less overwhelmed by workload
- Roles within groups can emerge naturally based on students' interests and strengths

7.1.2.3 Case Study 3 (Appendix J)

Focus	Reflection (primary), feedback (secondary)
Context	• Challenge: students designed a ChoiCo game to simulate the practice of an entrepreneur • Vocational school (students attend various specialties courses) • 6 sessions, total 12 hours (2 hours each) • 14 students, 16 – 22 years old, 12 male & 2 female, behavioural issues • Teacher was familiar with ChoiCo, students had no prior experience with ChoiCo nor DT models

Key Findings

Reflection

- Students engaged in various reflective practices throughout intervention such as: reflective questioning, evaluating others' ideas and reflecting on consequences a choice can have; reflective summaries; and perspective taking

Feedback

- Benefits
  - Learning through failure
  - Empowerment, developing a sense of persistence
  - Critical thinking (deciding which suggestions / critiques were helpful or not)
- External feedback
  - Physical presence of all groups in the classroom provided context where groups often asked for feedback during prototyping. During these cases, students were involved in feedback discussions with:
    - People directly involved in the issue

- An expert
- The player (other groups in the classroom)
- The survey (from the define & ideate phases)

Relationship between feedback and reflection

- Feedback provided the context where students could identify weakness in their work through external perspectives. Understanding the perspectives, evaluating them and then finally integrating them required reflective practices
- Feedback session provided context for reflective discussions and in turn, reflection provided the context where students identified their work weaknesses and areas of improvement

Best Practices and Insights

- Reflective thinking was expressed through personal reflective practices, perspective taking practices
- Use various types of feedback according to students' goals
- Personal connections encourage reflective thinking
- Feedback provides a rich context for reflection & critical thinking

7.1.3 Ireland

7.1.3.1 Case Study 1 & 2 Combined (Appendix K)

Focus	Technology use
Context	• Topic: Fast Fashion • Aim: To increase awareness • After the empathy stage (using nQuire), students had free choice in the project technologies they could choose to use to complete their projects. • 2 classes, same age group, same activity plan with the same teacher • 35 students in total, 1 teacher

Key Findings

- Without a predetermined technology, students had the freedom to choose the project technology to meet their challenge, thus fostering creativity
- ChoiCo's limited functionality (low-ceiling) provided a valuable challenge but also caused significant frustration
- Students were able to apply and enhance their knowledge of Fast Fashion
- Students demonstrated an improvement in their problem-solving skills, interpersonal skills, time management, communication, giving and receiving feedback and refining their work, from their pre-survey levels

- When asked about their confidence in these skills there was no change
- In both pre and post-survey results, girls are statistically significantly more confident than boys in managing themselves
- There was no change in students' sense of self-efficacy in terms of design thinking mindset or activities
- There was a statistically significant difference between the girls' and boys' empathy levels which seems to have disappeared in the post-survey indicating that the girls continued to maintain higher levels of empathy after the intervention and that the boys may have increased

Key Challenges

- Using nQuire to undertake a 'whole class' activity to collect survey responses from outside the class limited the authenticity of the "empathise and understand" phase of DT
- Limitations of ChoiCo
- Contextualising design thinking for students – why it is important

Best Practices and Insights

- Without the technology predetermined, students had the space to design a solution that was unique and personal to their specific issue
- Explicitly using DT as an overarching framework for the activities
- Providing a sandbox or "experimentation day" or session to familiarise students with the technologies in advance
- Modding games is a powerful way to become familiar with the technologies
- Worksheets to document student understanding and progress in each DT phase
- ChoiCo development suggestions:
    - Add the option to create an event triggered by a variable which affects other variables
    - Provide a timer or limit the number of turns
- Presentations provide an opportunity to share, evidence and listen

7.1.4 Norway

7.1.4.1 Case Study 1 (Appendix L)

Focus	Feedback (primary), teamwork (secondary)
Context	DT activity on accessibility using GearsBot Participants have previous experience working on DT projects (i.e., teachers participated in Year 1 and students have worked on projects following the International Baccalaureate (IB) model of design)

	20 students, 11 – 12 years old 1 teacher, 2 assistants

Key Findings

- Reactions toward feedback varied
    - Some felt grateful, while others felt resistance towards it
- Process of giving / receiving feedback triggered conversation and clarification with others on their work
- Some students felt upset when given feedback that they did not agree with
- Self-confidence in the skill of "communicating ideas" statistically decreased after the project ($Z = -2.283$, $p = .022$) - this might be because the limited time is given for students to communicate and present their ideas in this project and the challenges of feedback

Key Challenges

- Giving constructive / quality feedback to others
    - Teacher + some students found the feedback non-constructive

Best Practices and Insights

- Results highlighted significant role of constructive feedback in learning process
    - Guides improvements and fosters a sense of appreciation among students
- Students struggle to distinguish between constructive feedback and opinion / criticism (lack of depth or judgemental)
- Feedback through text or digital platforms may lack personal touch of face-to-face interactions, leading to misunderstandings or reduced impact on recipient

7.1.4.2 Case Study 2 (Appendix M)

Focus	Teamwork (primary), feedback (secondary)
Context	DT activity on accessibility using GearsBot Participants have previous experience working on DT projects (i.e., teachers participated in Year 1 and students have worked on projects following the IB model of design) 20 students, 11 – 12 years old 1 teacher, 2 assistants

Key Findings

- Division of labour was often based on students' strengths/interests
- Successful groups supported each other both verbally and through their actions
- Where opinions differed, students leveraged the affordances of the technology which enables rapid prototyping and the pedagogy which fosters rapid prototyping, to try two different solutions and ultimately combine the best parts of both.

Key Challenges

- Struggled with having different opinions, agreeing upon things
- Absence of a team member

Best Practices and Insights

- To navigate group conflicts, the teacher acted as a mediator, defining student roles and responsibilities, establishing clear expectations, incorporating summative and formative assessments to structure feedback & evaluation of member's performance throughout the project
    - Integrate intelligent role assignments and tracking functionalities into system to distribute tasks
- Foster communication in teamwork
    - Activities should promote opportunities for students to combine their opinions, offer compliments and demonstrate enthusiasm
    - Encourage constructive dialogue (e.g., brainstorming sessions)
    - Develop tools to facilitate peer recognition (give shout-outs or compliments)
    - Incorporate gamified elements that offer rewards for collaborative problem-solving and communication
    - Implementation of features that encourage reflective practices (prompts or spaces for students to share what they appreciate about each other)

7.1.5 UK

7.1.5.1 Case Study 1 & 2 Combined (Appendix N)

Focus	Students' technology use, rapid prototyping
Research	2 classes, Year 7 and 8, class 1 focused on recycling, class 2 focused on types of forces 6 one-hour sessions 42 students total, 12 – 15 years old Year 7 physics teacher had no prior experience with DT, Year 8 biology teacher participated in Year 1 on the project and thus was familiar with DT and technology

Key Findings

- Teachers' technological skills had an impact on which tools they used in DT project (both chose SorBET as they understood it easily)
- Students' technological capacity impacted their engagement with specific tools and successful development of their DT project
- Ease of SorBET was the main reason why students chose it
- nQuire was helpful for collecting and receiving feedback
- Mixed ability groupings provided opportunities for building digital skills
- Teachers saw students develop skills in providing and acting on feedback, communication

- Students' responses showed evidence of learning through failure, problem solving, persistence, addressing feedback, informed decision making, teamwork, communication
- Activity plans provided an opportunity to reinforce the new curriculum launched in Wales in 2022. Teachers acknowledged the relevance of DT to the curriculum and impacts for children

Key Challenges

- Limited time before activities hindered teachers' confidence going into a lesson
- Lack of time hindered the growth of students' capacities with technologies
    - Lack of instruction for technology and teacher in-class instruction
    - Lack of understanding impacted their ability to engage with the technology
- Activity plans were length but not specific enough and had no specific instructions
- There were no extension activities for early finishers
- Access to supporting materials may be blocked by schools or local authorities (e.g., YouTube)
- The number of links and credentials required

Best Practices and Insights

- Teachers need time to familiarise themselves with the project technologies, and develop a game start to finish
- Provide class time for students to "play around" and practice other games
- Consider access of links within schools' technology guidelines

7.2 Survey Results

Surveys were implemented as part of each school intervention (WP5). Where the case studies provide a depth of understanding into individual phenomena, the surveys provide a much broader picture of the impact of DT activities with emerging technologies in these small-scale interventions, across 5 countries. Data from surveys were integrated into individual case studies, however this section takes a wider look at all data collected during the interventions on a per country basis and at the level of the whole project.

Due to the limited length of each intervention, pre/post comparisons are unlikely to yield significant results, however, where appropriate these have been reported. The variety of learning activities implemented, cultural differences between countries and between individual schools, etc., are all factors that will also limit the results. In Cycle 3 the survey will become the primary data collection tool as the number of interventions scales up. However, it should be noted that in Cycle 2 the survey results provide only an indication of the impact of Exten.(D.T.)² activities, while the case studies provide the depth. For example, in the first Norwegian case study it is noted that "The signed-rank test showed that participating students' self-confidence in the skill of "communicating ideas" statistically decreased after the project ($Z = -2.283$, $p = .022$). This might be because limited time is given for students to communicate and present their ideas in this project." (Appendix L). It could also be attributed to the challenges students faced in giving and receiving feedback. While the cause cannot be specified, a decrease in confidence should not be regarded as necessarily negative, as it could be interpreted as students becoming more aware of what is required for communication of ideas, due to participating in the Exten.(D.T.)^2 activities, thus a negative result could in fact indicate growth.

7.2.1 Pre-Intervention Survey

7.2.1.1 Demographics

The Exten.(D.T.)^2 School Student Pre-Project Survey was administered to 424 students at secondary schools in Ireland, the United Kingdom (UK), Greece and Norway. In each of the schools, and classes every student was asked to fill in their student number and/or their group ID. Out of the 424 students who participated in the pre-survey, 233 of them identified as "male", 183 identified as "female" and 8 students preferred not to identify themselves as either male or female. For the analysis of this data, we ignore the third gender category as it has less than 10% of observations in it. The country-wise division of the sample can be seen in Figure 5 below. Given the skewing between countries, the survey results for each country are presented alongside the combined project results, for clarity.

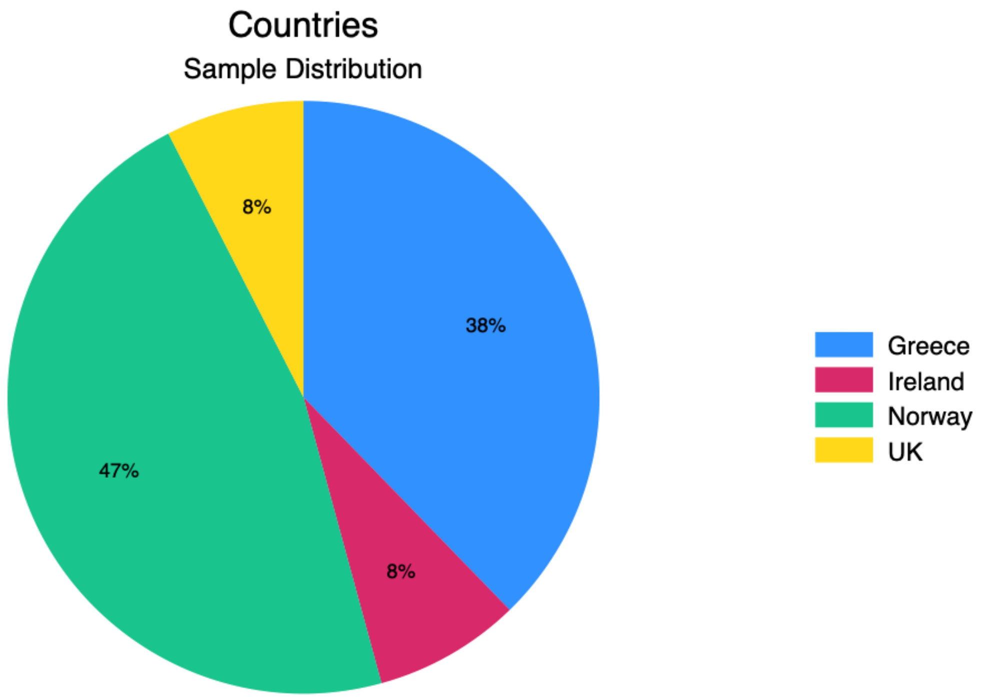

Figure 5: Country distribution of the sample

All students who participated in the activities were either in year group 12-14 (in UK, Greece, Norway) or in year group 14-16 (Ireland). The mean age of the participants was 12.73 years, and the sample median was 13 years. English was the most common language spoken in the sample, with students in Norway and Greece typically speaking their national language while sometimes speaking English or other languages at home or in other contexts. This is significant given that the digital tools used by students need to be accessible to all.

7.2.1.2 21st Century Skills

After collecting the above demographic details, the survey gathers data on the students' levels of confidence over six design thinking and technology categories.

Table 7: 21st Century Skills (Bray et al. 2020) by Country and by Gender [pre-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Working with others					
Male	3.879	3.591	3.863	3.712	3.771
Female	3.734	4.034	**4.125***	3.692	3.884
Total	3.833	3.729	3.983	3.703	3.821
Communication					
Male	3.182	2.894	3.51	3.346	3.348
Female	3.867	3.134	3.56	3.161	3.355
Total	3.396	2.969	3.533	3.26	3.351
Creativity					
Male	3.864	3.619	3.843	3.522	3.681
Female	3.8	4.034	3.977	3.484	3.725
Total	3.844	3.753	3.904	3.504	3.7
Managing self					
Male	3.303	3.508	3.619	3.388	3.476
Female	**4.534***	3.933	**4.093***	3.502	**3.814***
Total	3.688	3.645	3.837	3.441	3.625
Critical Thinking					
Male	4.061	3.429	3.687	3.265	3.511
Female	3.933	3.7	**3.893***	3.279	3.579
Total	4.021	3.516	3.781	3.271	3.541
Using Tech					
Male	4.015	3.73	3.863	**3.872***	3.869
Female	4.067	4.1	**4.111***	3.688	3.898
Total	4.031	3.849	3.977	3.786	3.882

*Note: * - statistically significant difference between girls' and boys' mean scores*

These categories were adopted from Bray et al (2020). To analyse these categories, we used additive indices that ranged from scores 1-5. To calculate the scores in the indices presented in Table 7 we aggregate the self-reported scores over the subcategories within each index and then compute the average score for the category. For instance, if a category has 5 subcategories, we add the students' scores in each of the subcategories and divide it by 5. The scores range from 1 (not confident) to 5 (very confident).

In the first category, the survey measures the level of confidence the students display while working with others. For this category, we added the scores (1 to 5) that the students gave themselves in the subcategories "work in pairs or small groups to complete a task together", "work with other students to set goals and create a plan for your team" and "create joint products using contributions from each student, to reach the aggregate score. To reach the final score, we divide the aggregate score by 3 (number of sub-categories). On average, the students in the sample feel neutral, tending towards confident in working with others. At an aggregate level, there seems to be no statistically significant difference between girls' and boys' confidence levels in working with others. However, girls in Greece seem to be statistically significantly more confident than boys when it comes to working with others.

The next category that we analyse is the students' confidence levels in communicating. We use the method described above to reach the final score for this category. Overall, the students feel neutral and the least confident in all the skills about communicating their ideas, preparing, and delivering oral presentations and answering questions in front of the audience. There seems to be no difference based on gender at an aggregate level.

On average, the students, have neutral levels of confidence when they are asked to score their confidence levels for creativity. This category asks students to score themselves on subcategories such as "Test out different ideas and work to improve them," "Invent a solution to difficult problems" and "Create something new that can help you express your ideas." The levels of confidence do not seem to differ between male and female students in the creativity index.

The fourth category asks the students to score themselves on managing themselves. It involved students to score them on their levels of confidence in tracking themselves, assessing the quality of their work and using peer and teacher feedback to improve their work. Overall, the students feel neutral about their confidence levels. However, there is a statistically significant difference between girls' and boys' mean scores in this category. This difference is perhaps driven by the sample in Ireland and Greece. In both these countries, the girls report statistically significant higher levels of confidence in managing themselves.

When taking all four countries' data into account, the students feel neutral in their confidence levels when asked about managing information and critical thinking. However, in Greece, girls report a higher level of confidence in this category. The last category in this section asks students to score themselves on using technology for educational purposes. While at an aggregate level, both boys and girls feel neutral about their levels of confidence in this category, the girls in Greece seem to have reported feeling more confident than the boys. However, in Norway, boys have statistically significant higher levels of confidence than girls, perhaps counterbalancing Greece's effect at the aggregate levels.

7.2.1.3 Technology Usage

In Figure 6, the comfort levels with technology are visualised by country. As can be seen, more than 50% of the students in the sample are either comfortable or very comfortable in using the technology.

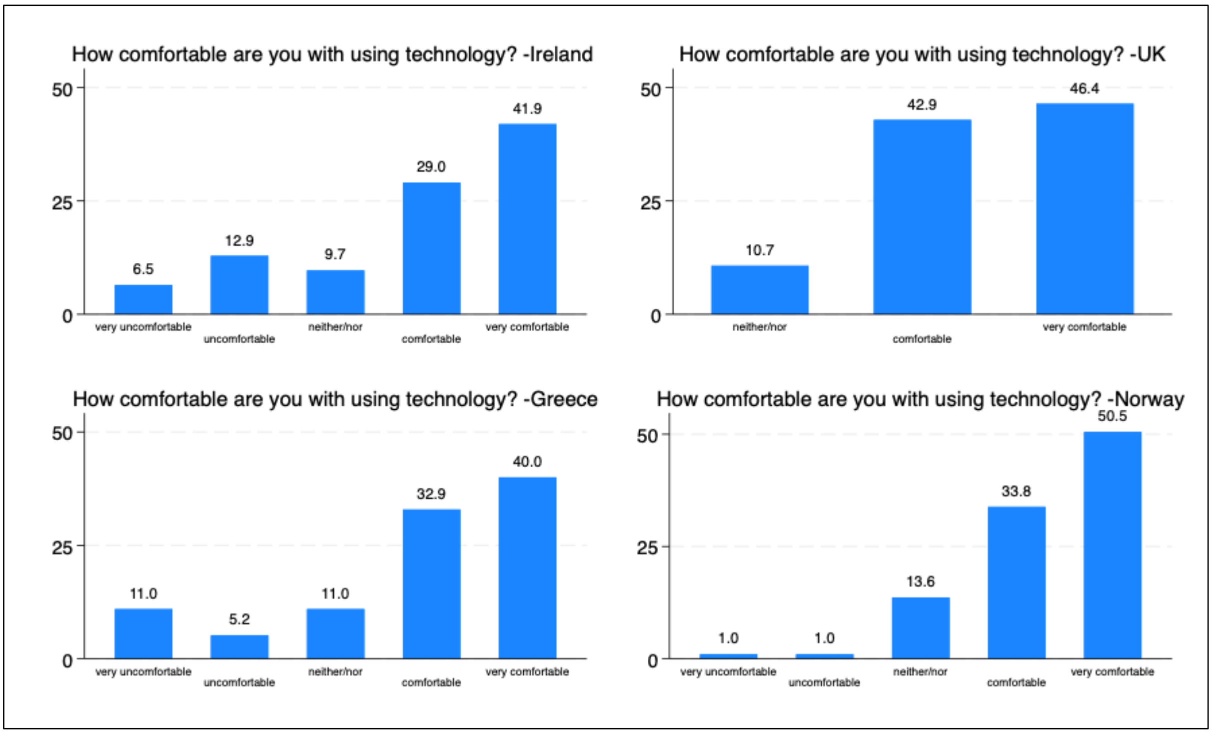

Figure 6: Comfort with using technology by country

Although more than half of the sample is comfortable with technology, 48% and 46% of students in the UK and Greece respectively rely on others to solve their problems with technology. It seems that students in Ireland and Norway tend to solve their problems related to technology on their own (Figure 7). In all four countries in the sample, less than 10% give up if they face challenges with the technology.

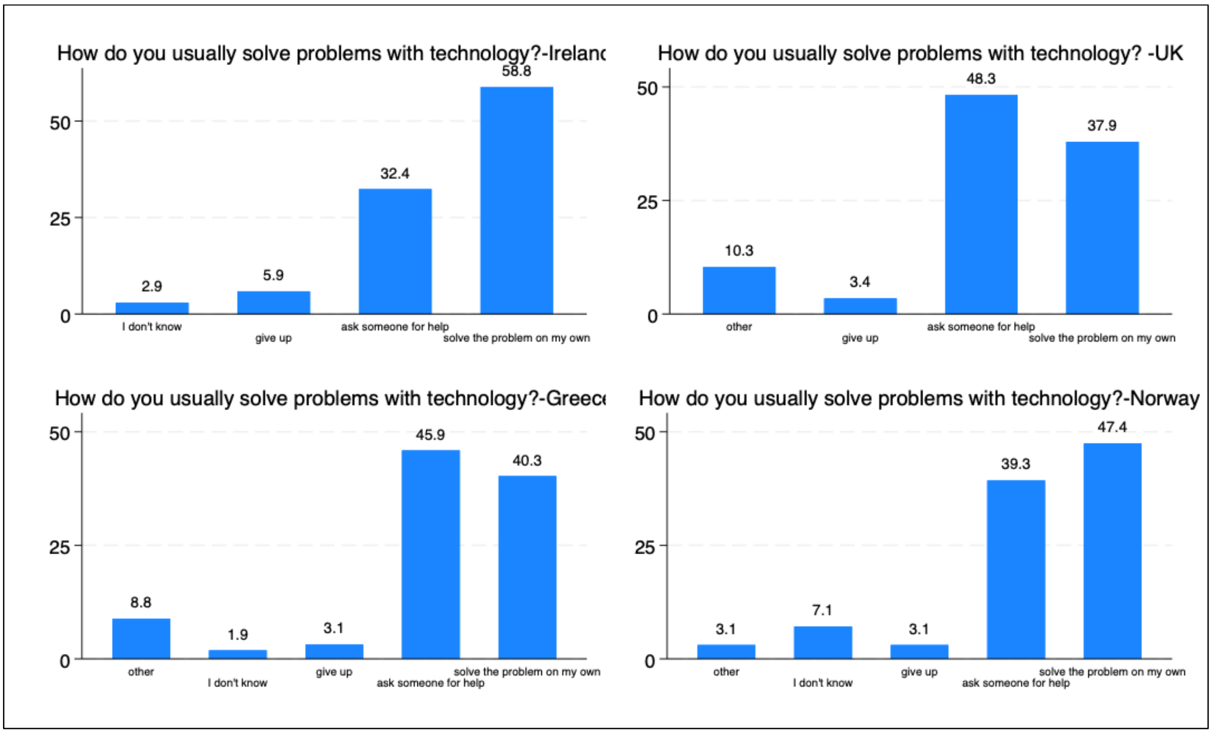

Figure 7: Solving problems with Technology by country

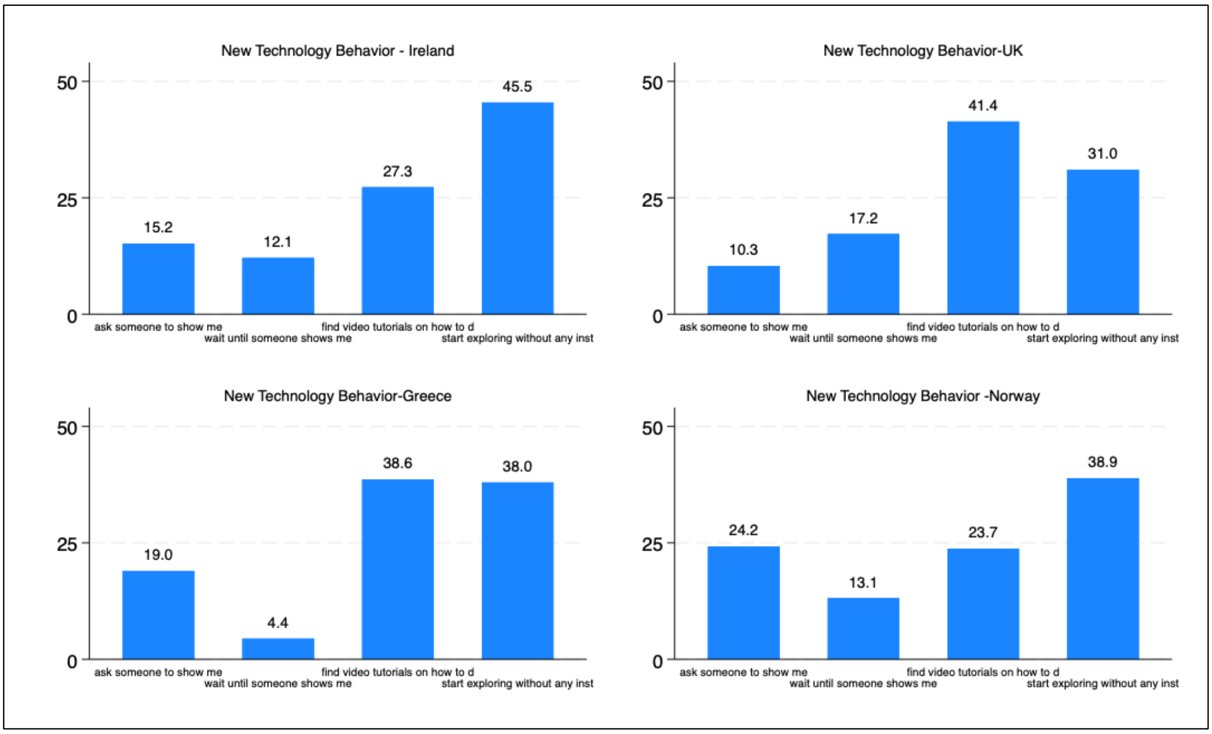

Figure 8: Students' behaviour when faced with new technology

In line with Figure 7, Figure 8 shows that 46% and 39% of students in Ireland and Norway respectively start exploring new technology without any instructions. 42% and 39% of students in the UK and Greece respectively rely on video tutorials on using the new technology. Less than 20% of the students in all countries wait till someone shows them how to use the new technology. Additionally, less than a quarter of the sample in all countries asked someone to show them the new technology.

The survey asks students about the technological devices they use; more than half of the students in the survey use desktop computers/laptops and smartphones. Moreover, less than 15% of students use tablets and smartphone devices. Less than 20% of students in countries Ireland, Greece and Norway use Games Consoles, however, 22% of students in the UK report using Games Consoles.

When it comes to using "applications" on technological devices, in all four countries more than three-quarters of the sample uses the Microsoft suite, followed by more than 70% of students who use social media platforms. More than 70% of the students say that they find "online research and reading" as the most popular way of using technology to learn or be creative. This is closely followed by "watching video tutorials or walkthroughs."

7.2.1.4 Design Thinking

The next section of the survey focuses on design thinking in teams (Missett et al., 2013; Tsai & Wang, 2021; Glaittli, 2018; and Niruttimatee, 2022). As for the 21st century skills, in this section we again use additive indices to analyse and report students' levels of agreement and frequencies with each phase of design thinking (see Table 8 for the detailed scores).

When students were asked about their past experiences with the different phases of design thinking, on average, they were able to solve problems and interact with their teams sometimes. There seems to be no statistically significant difference between girls' and boys' scores. When the survey asks students about their frequency of interacting with others to show them appreciation, help them to highlight their unique strengths and, resolve conflicts and reach an agreement positively; they report doing the same sometimes. However, girls report interacting with others more than the boys. This result seems to be driven by significantly higher scores reported by girls in Norway.

Communication not only involves communicating one's ideas to others (as seen in Table 8), but it also involves listening to others' ideas and discussing the same. In this section, the scores on "communication" indicate the scores that the students give to themselves on their levels of agreement to "listen." Overall, girls report being better listeners while on average everybody in the sample agrees to listen to others. These results are perhaps driven by the UK and Greece where girls report a statistically significantly higher report than boys when it comes to listening and discussing their issues. Overall, students in the sample agree that they can manage their time effectively. When it comes to dealing with feedback and adding to work concerning feedback girls report significantly higher scores than boys at an aggregate level.

Table 8: Design Thinking Skills Missett et al (2013) and others [pre-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Problem solving					
Male	2.217	2.236	2.313	2.087	2.191
Female	2.167	2.524	2.385	2.15	2.257
Total	2.201	2.324	2.347	2.117	2.221
Interacting with others					
Male	2.357	2.562	2.377	2.123	2.267
Female	2.45	2.679	2.474	**2.319***	**2.401***
Total	2.387	2.598	2.423	2.214	2.327
Communication					
Male	3.576	3.798	3.824	3.774	3.776
Female	3.784	**4.266***	**4.037***	3.839	**3.937***
Total	3.641	3.96	3.921	3.804	3.847
Time Management					
Male	2.728	3.737	3.53	3.471	3.444
Female	**3.4***	4	3.695	3.484	3.59
Total	2.938	3.828	3.605	3.477	3.508
Design Thinking					
Male	3.068	3.842	3.506	3.49	3.485
Female	3.35	3.85	**3.841***	3.571	**3.68***
Total	3.156	3.845	3.659	3.528	3.571

*Note: * - statistically significant difference between girls' and boys' mean scores*

Table 9 presents the self-reported scores of the students in the sample during different phases of design thinking. A noteworthy difference is between girls and boys at the aggregate level when it comes to designing prototypes of the models.

The sample in Ireland, the UK, Greece, and Norway report that they do DT projects in school sometimes (~43%). More than 50% of the students said that only sometimes in school do they identify problems (> 50% in Ireland say often in school they identify problems). 47% of the students said that they often find out the needs of others in school in Ireland whereas in three other countries, almost half of the sample reports that they find out needs of others in school.

Table 9: Design Thinking Skills Tsai & Wang (2021) [pre-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Ideate					
Male	3.124	3.587	3.46	3.154	3.289
Female	3.6	4.057	**3.655***	3.198	3.433
Total	3.277	3.736	3.552	3.174	3.354
Define					
Male	3.553	3.867	3.626	3.335	3.496
Female	3.58	4.057	3.785	3.348	3.559
Total	3.561	3.927	3.701	3.341	3.524
Empathy					
Male	3.207	3.778	3.459	3.234	3.349
Female	3.8	3.285	**3.812***	3.081	3.414
Total	3.398	3.621	3.626	3.162	3.378
Prototype					
Male	2.619	3.8	3.27	3.071	3.148
Female	3.12	3.715	3.455	3.251	**3.341***
Total	2.781	3.773	3.358	3.155	3.235
Feedback					
Male	3.429	3.867	3.844	3.337	3.562
Female	3.8	4.285	4.029	3.517	3.763
Total	3.548	4	3.932	3.421	3.652

*Note: * - statistically significant difference between girls' and boys' mean scores*

Approximately half of the students said that only sometimes they used the needs of other people to develop their ideas in all four countries. Approximately three-quarters of students in Greece reported that they often worked as a team in school, whereas lower percentages of students in the other countries report the same. Almost half of students reported that only sometimes they were involved in brainstorming to generate ideas. 25- 30% of the students in Greece and the UK respectively report that they often create a prototype in school to solve a problem, whereas the sample in Norway and Ireland report that they do the same only sometimes. Fifty percent of students say that sometimes, they get a chance to present their work to other students in school. The majority (~50%) of the students said that sometimes they give feedback to their peers. Less than half the students (~44%) in the sample often used feedback from their peers to improve their work. Lastly, 47% of students reported that they often used technology to support their learning in school.

7.2.2 Post-Intervention Survey

The Exten.(D.T.)² School Student Post-Project Survey was administered to 392 students at secondary schools in Ireland, the United Kingdom (UK), Greece and Norway. There was less than 10% of attrition from pre-survey (424 participants in pre-survey). In each of the schools, and classes every student was asked to fill in their student number and/or their group ID. Out of the 392 students who participated in the pre-survey, 202 of them identified as “male”, 177 identified as “female” and 13 students preferred not to identify themselves as either male or female. For the analysis of this data, we ignore the third gender category as it has less than 10% of observations in it. The percentage of the sample distribution is consistent with the pre-survey sample distribution as presented in Figure 5 above. The age and home language of the participants remained consistent with those of the pre-survey cohort.

7.2.2.1 Tools

The tools that were introduced in the intervention were ChoiCo, MalT2, nQuire, SorBET and Gearsbot. Among the various tools introduced during the intervention, 50% of students from the sample of Ireland used ChoiCo, where they had free choice over the technologies that they used. In all other cases, the teachers chose the technologies that the students would use.

When the survey asks about the advantages of using digital tools, 17% of the students mentioned that they liked the digital tools because "it was easy to use". Approximately 16% said "it was fun," closely followed by 14% who said that they “learned new skills”.

In terms of challenges, 37% of students reported encountering technical problems or bugs. Sixteen percent found the tools difficult to use. Approximately 12% mentioned that “it took too long to create a prototype/solution”.

The survey also inquired about the students’ confidence levels in using the tools to create something and to modify or adapt their solutions. 49% of the students agreed that they are confident in using the tools to create something. 43% agreed that they can use the tools to adapt their solutions. For both statements around 30% of the sample reported that they neither agree nor disagree with the statement.

7.2.2.2 Understanding students’ experiences on the project

To better understand students' experiences on the project, the survey asks the students about some of the challenges previously identified in the literature (see D2.1 and D7.1) that come with DT projects in a classroom. Around 49% of the sample disagreed that they felt frustrated and did not know what to do. 53% of the sample said that they did not feel frustrated using digital tools, and only 20% of them felt the opposite. Around 47% of students said that they did not find it difficult to think of ideas. Around 61% of the sample felt like their team worked well together. 44% of students disagreed that they did not like redesigning the solutions. Around 66% of students said that other people listened to them. When asked about getting feedback on their ideas from peers and teachers, 52% of the students said that they agreed with the statement. 36% of students reported not getting feedback on how to work as a team, while only 28% said that they got feedback as a team (this result is driven by samples in Greece and Norway). Many students (~63%) had a good idea of what they were expected to do. When asked about organizing their time 47% of the students reported no difficulties in organizing their time and ~35% said they neither found it difficult nor easy to organize their time. 53% of students had time to think about what they were doing and what they could do better. 45% of students had time to assess the quality of work before it was completed. Only 22% percent of students found it difficult to do everything in the available time, while 43% reported they did not face this problem, leaving around 30% of the sample neither agreeing nor disagreeing with a time constraint.

7.2.2.3 New Skill Development

In addition to the objective questions, the survey asked the students to write down the top three skills or any new learning that they developed during the project. As seen in Figure 9, the students learned an essential 21st century skill - coding. Along with coding, they acquired life skills of teamwork and became more confident.

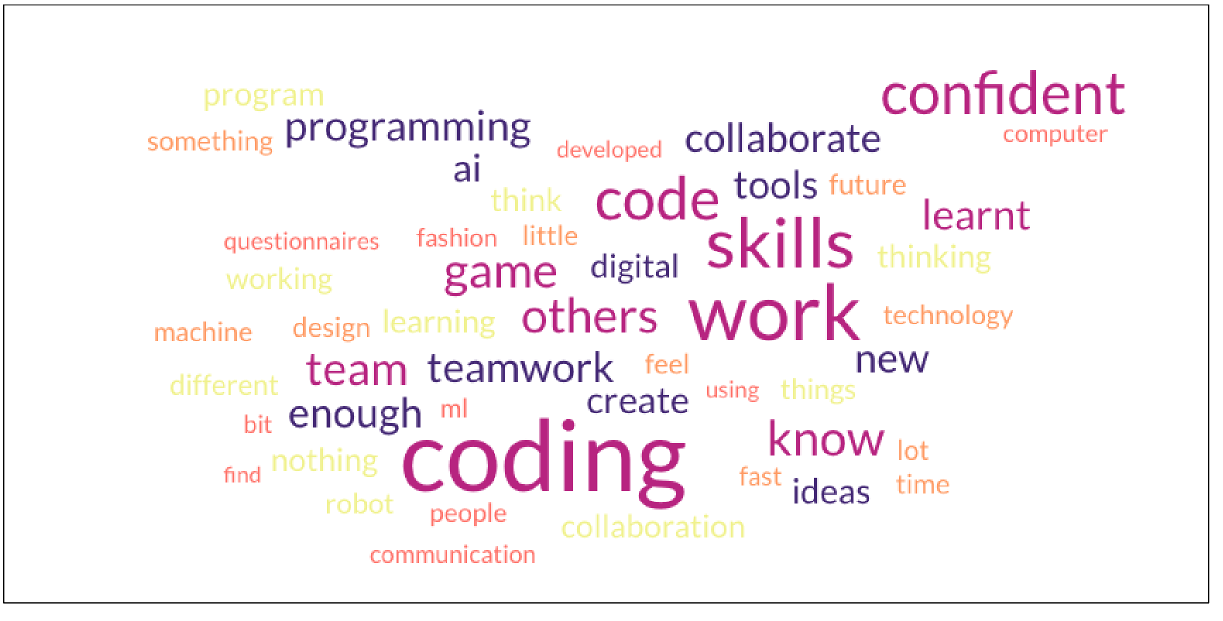

Figure 9: WordCloud based on all the new skills reported by sample in Ireland, UK, Greece, and Norway

7.2.3 Pre Versus Post Comparison

7.2.3.1 21st Century Skills

In this section, the questions administered in the post-survey ask the students to report if they feel a lot less confident (1) or a lot more confident (5) in their 21st century skills (Bray et al., 2020) compared to their confidence levels in the pre-survey.

Table 10: 21st Century Skills (Bray et al. 2020) by Country and by Gender [post-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Working with others					
Male	3.567	3.333	3.905	3.543	3.65
Female	3.923	3.637	4	3.599	3.745
Total	3.707	3.462	3.947	3.571	3.694
Communication					
Male	3.4	3.311	3.538	**3.33***	3.405
Female	3.718	2.879	3.724	2.96	3.238
Total	3.525	3.128	3.619	3.146	3.327
Creativity					
Male	3.517	3.4	3.761	3.53	3.595
Female	3.769	3.303	3.814	3.377	3.531
Total	3.616	3.359	3.784	3.454	3.566
Managing self					
Male	3.45	3.311	3.671	3.393	3.485
Female	3.923	3.515	**3.962***	3.286	3.549
Total	3.636	3.397	3.798	3.34	3.515
Critical Thinking					
Male	3.8	3.222	3.542	**3.413***	3.48
Female	3.769	3.061	**3.833***	3.098	3.364
Total	3.788	3.154	3.669	3.256	3.426
Using Tech					
Male	3.767	3.445	3.572	3.63	3.611
Female	3.615	3.515	**4.038***	3.387	3.606
Total	3.707	3.474	3.776	3.509	3.608

*Note: * - statistically significant difference between girls' and boys' mean scores*

We follow the same method of aggregating the scores in the subcategories and calculating the average score for each category by country and by gender. For instance, a score of ~3 means that the student feels the same level of confidence compared to his/her pre-survey levels. A score less than 3 means that he/she feels less confident in their skills.

When asked about students' confidence levels for the 21st century skills as compared with their pre-survey levels, the students feel about the same level of confidence about working with others, their communication skills, their creativity skills, managing themselves, their critical thinking and using technology for educational purposes (Table 10).

However, it is interesting to note that compared to their pre-survey levels, boys have gained more confidence in their communication skills as compared to their female counterparts. The girls' mean scores have dropped to below 3, indicating a deeper self-awareness of this skill. When asked about managing oneself, the girls in the sample from Greece felt even more confident than the boys. Their confidence levels seem to significantly rise compared to the boys and their pre-survey levels when it came to using technology for educational purposes. In the pre-survey, there was a higher confidence level in girls for managing themselves than in the post-s survey, as the scores seem to not distinguish between the mean scores of the girls and the boys in the sample.

7.2.3.2 Problem-solving, Interacting with Others, Time Management, Communication, Design Thinking

On average, all students in the sample demonstrate an improvement in their problem-solving skills from their pre-survey levels (Table 11). When they were asked how much the DR project taught them about problem-solving, they scored themselves ~3.3 points on a 1-5 scale, which ranged from "nothing (1)" to "a lot (5). According to their reported scores (~3.4), they have gained a better understanding of interpersonal interactions, including showing appreciation, resolving conflicts, and facilitating team agreements compared to their pre-survey responses. Additionally, students indicate enhanced skills in time management (a score of 3.4), communication (3.6), and design thinking (3.6), particularly in giving and receiving feedback and refining their work. While at an aggregate level, there is no statistically significant difference between the means of boys and girls in these skills, girls in Greece seem to have reported that they have learned more about problem solving and interacting with others through this intervention.

Table 11: Design Thinking Skills Missett et al (2013) and others [post-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Problem solving					
Male	3.2	3.134	3.554	3.224	3.324
Female	3.342	3.434	**3.921***	3.074	3.369
Total	3.256	3.261	3.714	3.149	3.345
Interacting with others					
Male	3.288	3.3	3.552	3.205	3.336
Female	3.385	3.568	**3.957***	3.217	3.472
Total	3.326	3.413	3.729	3.211	3.399
Communication					
Male	3.458	3.555	3.813	3.44	3.575
Female	3.628	3.728	4.032	3.494	3.678
Total	3.525	3.628	3.909	3.466	3.622
Time Management					
Male	3.4	3.534	3.508	3.29	3.391
Female	3.462	3.272	3.712	3.323	3.446
Total	3.424	3.423	3.597	3.307	3.416
Design Thinking					
Male	3.35	3.567	3.865	3.42	3.572
Female	3.654	3.591	4.019	3.49	3.666
Total	3.47	3.577	3.933	3.455	3.615

*Note: * - statistically significant difference between girls' and boys' mean scores*

7.2.3.3 Design Thinking

At an aggregate level, the students in the sample felt that they neither became better nor worse at ideating, creating prototypes, showing empathy, defining a problem, or working with feedback as compared to their pre-survey levels (Table 12). On average, there seems to be no statistically significant difference between girls' and boys' scores for different phases of design thinking skills. However, there appears to be a statistically significant difference during the post-survey in the sample of Ireland indicating that girls in the sample feel that they have become better at prototyping after the intervention. In Greece, the girls report that they have become even better at empathy by comparison to boys.

Table 12: Design Thinking Skills Tsai & Wang (2021) [post-survey]

Country Indices' scores	Ireland	United Kingdom	Greece	Norway	Combined scores for all countries
Ideate					
Male	3.37	3.574	3.552	3.456	3.488
Female	3.646	3.655	3.731	3.323	3.489
Total	3.479	3.608	3.63	3.39	3.489
Define					
Male	3.64	3.64	3.708	3.432	3.559
Female	3.8	3.563	3.934	3.268	3.525
Total	3.703	3.608	3.807	3.351	3.543
Empathy					
Male	3.667	3.622	3.552	3.284	3.436
Female	3.897	3.606	**4.019***	3.269	3.56
Total	3.758	3.615	3.756	3.276	3.493
Prototype					
Male	3.14	3.2	3.248	2.57	2.898
Female	**3.677***	3.328	3.531	2.542	2.969
Total	3.352	3.254	3.371	2.556	2.931
Feedback					
Male	3.5	3.667	3.791	3.47	3.594
Female	3.385	4	4.096	3.373	3.629
Total	3.455	3.808	3.924	3.422	3.61

*Note: * - statistically significant difference between girls' and boys' mean scores*

8 Cycle 2 Professional Development Results

PD activities for qualified and student teachers took place at two sites: UGent in Belgium and NKUA in Greece. In addition to the pre-existing academic courses that students were enrolled on, UGent conducted a non-academic workshop with teachers. The evaluations of each are presented in Appendixes 0, P and Q. This section provides an overview of the key findings.

8.1 UGent Academic Professional Development (Appendix O)

At UGent, 60 students (from two courses, participating in the one class) participated in a series of bespoke PD activities. One of the highlights of these activities was the opportunity for participants to work as a group, providing them with an opportunity to collaborate and get to know their peers. Participants valued the creative elements such as brainstorming (which was a significant challenge in Cycle 1) and the opportunity to create something and the accompanying sense of achievement. Students valued the opportunity to personalise their learning experience and directly apply what they learned to a "playful context", something which is similarly observed in the school intervention case studies. Both DT and the new technologies were unfamiliar to students, but they enjoyed the opportunity to explore this unfamiliar territory (the majority of participants had never heard of DT or were unsure what it was) and acquire new skills that were transferable to the classroom.

As in Cycle 1, PD participants highlighted the value of game design as a pedagogical tool. Participants valued the collaborative nature of the digital tools which they viewed as supporting the development of 21st century skills. The online sharing functionality was also noted for its ability to enable peer-to-peer feedback, enhancing the learning experience through constructive critique.

Participants considered the advantages of DT in the classroom to be linked to the development of 21st century skills such as time management and self-organisation. However, the time-consuming nature of DT activities is still seen by teachers as a barrier to its integration in the classroom (as was the case in Cycle 1). Similarly technical problems such as bugs and language barriers were raised. Participants highlighted the need to have the digital tools available in local languages, specifically in this case Dutch. However, concerns surrounding bugs may also be linked to teachers' technical skills and lack of self-efficacy when encountering problems with technology. From the survey results, most participants were not familiar with using technology to create content and even at the end of the PD activities they were not confident in their own ability to support their students' use of ChoiCo.

8.2 UGent Non-Academic Professional Development (Appendix P)

In addition to the PD activities integrated into an existing course at UGent, the team organised a one-day DT workshop for in-service teachers from various schools in Belgium. In total 12 teachers participated and completed the surveys.

Much like their counterparts on the academic course, the in-service teachers highlighted the bugs, user interface and manual as key areas that required development in ChoiCo. And again, they were unlikely to use digital tools to create their own content. However, they found that ChoiCo helped them to make abstract concepts more tangible.

In terms of their own skill development, teachers reported enhanced teamwork, empathy, brainstorming, reflection and discussion abilities, as well as analytical thinking, computational thinking and programming. The participants learned about problem definition, digital tools, brainstorming, empathy and the definition of DT – all aspects that were challenging in the Cycle 1 PD activities at UGent. Significantly, teachers recognised that the Exten.(D.T.)² approach to DT provided an approach to teach their own students many skills.

8.3 NKUA Professional Development (Appendix Q)

At NKUA the PD activities took place in the context of the first year of a 2-year MSc inter-departmental programme “Digital Transformation and Educational Practice”, with 30 students, the majority of whom were female. Overall, they had a high sense of self-efficacy when it comes to the use of digital technologies and were generally confident about their use of technology to support teaching, learning and assessment, however, few had initiated or promoted strategies and practices within their schools to support the use of emerging technologies.

While VRobotics/GearBots and ChoiCo appear to be popular choices with a high percentage of respondents indicating they would use them, other tools like SorBET, MaLT2, and nQuire show a more varied response, with a significant number of participants unsure whether they would use the tools.

In relation to the literature on challenges of implementing DT in the classroom (see D2.1 and D7.1), while the majority of the participants felt they had a clear understanding of expectations and received feedback, there were mixed responses regarding teamwork, idea generation, and tool usage. Notably, a significant proportion expressed frustration with the digital tools and difficulties in finding new ideas as well as making others listen to them.

As in Cycle 1, collaboration was the main skill that participants felt that they developed. However, there were concerns that their own students would not be able to collaborate effectively, with unspecified “learning difficulties” and “personality issues” cited as the reasons. Yet there was some consideration by the participants as to how careful grouping of students could alleviate these issues, as well as developing students’ abilities through smaller collaboration exercises. This closely relates to another issue raised by participants about equal engagement and ensuring that DT projects are suitable for the students' age and meets their interests. This corresponds with concerns evident in the post-survey results, where the majority of the participants stated they feel confident in engaging students in active learning, but there is a noticeable drop in confidence when it comes to accommodating individual learning needs and promoting equitable and inclusive learning.

The opportunities to gain feedback during the "Respond and Deliver" phase were recognised as valuable for participants but again there were concerns about their own students' ability to provide constructive feedback.

Participants also highlighted a need for age-appropriate material (e.g. audiovisual versus a written guide) which provided both structure and opportunities to explore, for which "half-baked" solutions were seen as a valuable pedagogic tool.

In terms of implementing DT in their own classrooms, infrastructure and pedagogic mindset were key issues. Participants highlighted inadequate infrastructure as the key challenge for Exten.(D.T.)^2 activities due to the reliance on digital tools. However, perhaps more significantly are the tensions between DT and the "traditional" teaching approaches in formal school education. This is an established barrier, yet both literature (e.g. Girvan et al., 2016) and evidence from this case study highlight that experiencing such a project themselves can encourage them to overcome their concerns, as it shows them that not only is it possible, not only how to do it but also the benefits for their own students.

Interestingly, even though, there was a strong preference for feedback mechanisms, real-world applications and contextual learning when asked about their ideal pedagogy in the surveys, when it came to describing their actual teaching direct instruction (step-by-step instructions), teacher-led discussions and focus on theory are the most frequently used approaches, as many teachers use them in every lesson. However, by the end of the PD activities, the participants expressed high confidence in designing and implementing each phase of DT in their own classrooms, which they viewed as a useful approach to increasing students' confidence within subjects, helping students to understand how to apply their subject knowledge to real-world problems, teach transversal/21st century skills and ultimately to teach their own subject.

9 Teacher's Evaluation Toolkit

The teacher's evaluation toolkit was co-produced with teachers and expert partners at the start of Cycle 2; implemented and developed based on teacher and partner feedback; with the plan for it be used at scale in Cycle 3 and as part of the teacher PD resources (WP6). It will be designed to: meet the needs of teachers who need evidence of learning; meet the needs of researchers to understand the practical realities of using Exten.(D.T.)^2 tools and activities in the classroom (WP5); and to be manageable and achievable by busy teachers, inexperienced in research evaluation. Data collection instruments will include short surveys and assessment tools, student voice activities, reflection guides and suggested artefacts of learning. They will be accompanied by an easy-to-follow guide to analysis and template reports. The main users of the toolkit and resulting reports will be the teachers themselves and so an ongoing co-production process which places teachers at the centre, is key to this task's success.

Initial development of the Teacher's Evaluation Toolkit commenced at the start of Cycle 2 with a review of existing toolkits and methodologies used for DT and allied activities in schools, such as Maker activities. This review identified the use of rubrics to assess outcomes; providing students with multiple opportunities to demonstrate their skills, knowledge and attitudinal development; and structured reflections as key approaches (Evans, 2020). While a popular approach to evaluation in this space, work by Ackermans et al. (2019) provides a valuable critique of rubrics. They highlight the challenge for learners to "imagine how to perform a complex skill based on textual information from solely a text-based analytic rubric" (p983) and advocate instead for video enhanced rubrics to effectively communicate the expectations of each level within a rubric.

The Beyond Rubrics Toolkit (The Maker Education Initiative) is designed to be a low-tech approach to evaluation to enable teachers, students and other stakeholders to develop a shared understanding of skills development and how to collect rigorous forms of evidence of student learning. The toolkit was developed in partnership between MIT Playful Journey Lab, Maker Ed, NSF, Albemarle County Public Schools, Portola Valley School District, and the San Mateo County Office of Education and shared under a Creative Commons BY-SA-NC 4.0 license. The toolkit is divided into three types of tools for use in any leaning environment: tools to set the context, tools to collect evidence and tools to interpret and communicate evidence. Teachers and students are expected to work together to interpret the data, reflect on the visible learning that has occurred and use the information to inform teaching and facilitate learner growth. While effective if implemented properly, these approaches require careful integration into DT activities within the classroom. If utilised as part of one-off interventions such as those implemented as part of WP5, they can quickly result in a lot of additional tasks for students and teachers.

While the use of such approaches could be integrated into Exten.(D.T.)^2 activities at the end of each of the Exten.(D.T.)^2 DT phases, they may require additional time as reflection, feedback and assessment activities are not already built-in to activity plans. As highlighted in the Cycle 1 evaluation (D7.1), time was a recurring constraint raised by teachers in implementing Exten.(D.T.)^2 activities. Similarly, it needs to be acknowledged that different school systems expect and require different forms of evidence and assessment of students' learning. For this reason, a co-design approach to the development of the teacher's evaluation toolkit is required.

The Exten.(D.T.)^2 Dashboard should be a key component of the Teacher's Evaluation Toolkit, providing teachers and students with a visual representation of the data collected by the Learning Analytics. The aim was for the Dashboard to have reached TRL4 by M20 and thus for it to be piloted across partner countries during the Cycle 3 WP5 school interventions. With sufficient numbers of teachers having used the Dashboard across partner countries, WP7 is now in a position to recruit teachers from each of the partner countries to form a co-design group for the Teacher's Evaluation Toolkit, which will be published by M28 ready for WP5 interventions commencing in M29.

10 Discussion and Recommendations

10.1 Discussion – School Interventions

Cycle 2 case studies focused more on specific learning outcomes, the application of DT to distinct subjects or themes and there was an emphasis on feedback mechanisms, with detailed explorations of how feedback was given, received and used to improve student outcomes. These are clear indications of how the Cycle 1 recommendations have impacted Cycle 2 activities.

In Cycle 2 we see more targeted use of tools like ChoiCo and nQuire in distinct phases of DT, with more explicit discussion about how these tools were used to achieve specific educational goals. In terms of technology development, there are more specific suggestions from students and teachers in terms of their development beyond simply addressing “bugs”.

Significantly, Year 2 reports place a greater emphasis on tackling real-world problems (e.g., sustainable development, fast fashion), which seems to have deepened student engagement and provided more meaningful learning experiences.

In both Cycles 1 and 2, the gender and age distributions were similar, with around 50:50 split between boys and girls (excluding those who selected the third option), between the ages of 12-14. However, Cycle 2 had a significantly larger sample size (424 in pre-survey, 392 in post-survey) compared to the first year (173 in pre-survey, 152 in post-survey). This allowed for more detailed analysis across different countries and genders.

Between Cycle 1 (reported in D7.1) and Cycle 2 there are a number of consistent findings: both emphasize the importance of DT and the development of 21st century skills like teamwork, collaboration, problem-solving, and communication. Reflection on activities and the impact on student engagement and learning outcomes remains a core theme in Cycle 2. Similarly, the importance of collaboration and teamwork was emphasized in both years, with students noting both the benefits and challenges of working in groups. Managing group dynamics, such as varying levels of engagement or differences in skill levels among group members, was a common challenge, which is addressed in the recommendations below.

In terms of technology use, both reports highlight the use of specific tools and the challenges of using these tools. Technical difficulties and sufficient time to become adequately familiar with the technologies were consistent issues. Students found value in the hands-on, real-world application of these tools, but also experienced frustration due to software limitations.

While the Cycle 1 data showed students generally feeling confident in their 21st century skills (in both Cycles Bray et al., SICK instrument was used), the Year 2 data revealed a more nuanced picture. In Year 2, boys reported increased confidence in communication skills post-intervention, while girls' confidence in this area decreased slightly, indicating a shift in selfperception. It is not possible to say from the data whether the decrease in confidence was due to students becoming more aware of what was needed for successful communication or due to them being in a position where their existing skills were insufficient, or a combination of the two. Similarly, boys may have learned skills and/or had an opportunity to practice skills and thus become more confident or they may have experienced no difficulties and thus re-evaluated their confidence. However, it is worth noting that from the surveys across both cycles, girls consistently reported higher confidence levels in certain skills, such as managing themselves and communication, particularly in Greece. In Cycle 2 a rise in girls' confidence in using technology for educational purposes is also evident, particularly in Greece, which was not as evident in Cycle 1.

In Cycle 2 a more in-depth look at students' DT mindset and skills was made possible by the new survey. This showed statistically significant gains in problem-solving, interacting with others, and time management, particularly for girls in Greece. However, the case studies show that time management continued to be a challenge in Cycle 2. Whether it was insufficient time to complete phases of the design thinking process, or the time needed to become familiar with new technologies, this was a recurring issue.

10.2 Discussion – Professional Development

In both Cycles 1 and 2, the PD activities centred around introducing and implementing DT as a pedagogical approach. Participants in both years valued learning about DT, especially the empathy component, and recognized its potential to develop 21st century skills in students. Again, as with the school interventions, time management was a recurring issue in both years, with participants noting the time-consuming nature of DT activities and concerns about their feasibility within typical classroom time constraints.

Another key component of the PD activities is the upskilling of teachers and increasing their digital competencies/self-efficacy. Participants in Cycle 2, particularly at NKUA, reported a higher sense of self-efficacy in using digital tools and were more likely to consider using DT in their own classrooms, despite the ongoing challenges. In both Cycles, participants highlighted the importance of digital tools like ChoiCo, MaLT2, and others in the PD activities. While Cycle 1 participants were generally cautious about the use of digital tools, Cycle 2 saw more varied responses. For instance, some tools like VRobotics/GearBots were well-received, while others like SorBET and MaLT2 had mixed reactions. This suggests a growing awareness of the strengths and limitations of different tools among Cycle 2 participants. However, participants consistently reported technical challenges, such as bugs, and expressed a need for more support in using these tools effectively. The use of digital tools for rapid prototyping was appreciated, though there was a common concern about the availability of these tools in local languages and the general usability for non-technical teachers.

Collaboration was a major focus in both cycles, with participants noting the value of working in multidisciplinary teams. They recognized that collaboration enhanced communication skills and critical thinking but also identified challenges in managing group dynamics, particularly in larger groups. Both cohorts' participants expressed concerns about whether their own students would be able to collaborate effectively, especially considering different learning needs and personality issues. However, evidence from the school interventions would suggest that while this is a reasonable concern, teachers are able to orchestrate both classroom and groups effectively to alleviate this.

Empathy as part of the DT process was consistently valued across both years. Teachers appreciated how empathy informed the design process and helped make learning more relevant and engaging for students. This was also apparent from the interviews with teachers involved in the school interventions. The real-world context of DT activities was seen as motivational for both teachers and students, with participants in both years recognizing the importance of applying subject knowledge to solve real-world problems.

Cycle 2 placed a stronger emphasis on the role of feedback and reflection in the DT process. Participants recognized the value of these elements but also noted concerns about their students' ability to provide constructive feedback and reflect effectively on their work. The need for structured, age-appropriate materials to support feedback and reflection was recommended to address this.

In both years, participants expressed concerns about the practical implementation of DT in their classrooms. Issues like inadequate infrastructure, the time required for DT activities, and the tension between DT and traditional teaching methods were consistently mentioned and need to be addressed head-on in future PD workshops.

Despite the revised Activity Plan and new 5 phase digital DT model for classrooms, those who participated in the PD activities still requested more structures support, particularly to help teachers and students navigate the challenges of DT. However, it should be noted that by the end of the Cycle 2 PD activities, participants expressed higher confidence in designing and implementing DT in their classrooms compared to Cycle 1. This shift suggests that the PD activities in Cycle 2 were more effective in building teachers' confidence and readiness to use DT with their students.

10.3 Recommendations

The following recommendations from the Cycle 2 results combine the results from the school interventions and those from the PD activities. Both sets of recommendations should be contemplated in the Cycle 3 development of WPs 2, 3, 4, 5 and 6. They are collated from the challenges and best practices observed in Cycle 2 and should be considered alongside the recommendations made at the end of Cycle 1 (D7.1).

10.3.1 Learning Activity Design

The following recommendations are organised by the type of activity or DT phase.

Preparation - Technology

- Consider access of links with schools' technology guidelines (e.g., YouTube is a blocked site at many schools)
- Teachers need time to familiarise themselves with the project technologies and develop a game/artefact themselves from start to finish
- Provide a sandbox or "experimentation day" or session to familiarise students with the technologies in advance. For example, provide class time for students to "play around" around or mod existing games
- Offer "how-to" videos and/or print out instructional manuals for more complex technologies like ChoiCo or MaLT2
- Depending on students' familiarity with code, whole-class demonstrations may be useful to support initial "buy-in" to the technology

Preparation – Design Thinking

- Choose relatable themes and projects – personal connections encourage reflective thinking later on
- Provide a visual of the design thinking model for students and repeatedly refer to the phase students are working on. Incorporate these visuals into PowerPoint presentations, worksheets, etc.
- Provide worksheets to document student understanding and progress

Preparation - Orchestration

- Allow students to take on emerging roles, implement icebreaker activities at the beginning of the project for students to share their strengths with the group, and provide guidance on how to distribute tasks and responsibilities
- Encourage division of tasks but be prepared to allocate roles
- Depending on the abilities, knowledge and experience of students in the class, consider allocating students to groups:
    - Carefully consider student strengths and interests when forming groups
    - Create groups with complementary skills and abilities to foster mutual learning and support
    - Pair experienced students with less experienced ones to provide guidance and support
    - Grouping friends or students with prior collaborative experience can facilitate open communication and efficient teamwork

- Smaller groups tend to be more effective, as they allow for better engagement and focus
- Diverse teams with members from different backgrounds can enhance creativity

Throughout

- Introduce novel concepts and maintain focus on critical analysis and problem-solving
- Provide explicit instruction of tasks unfamiliar to students
- Integrate self-, peer-, and teacher-led assessment at multiple points during activities (e.g., reflection activities, rubrics, use of the Dashboard, portfolio creation)

Empathise and Understand

- Model the use of design thinking vocabulary and explicitly teach unfamiliar words. For example, review "empathy" at the start of the first 3 lessons
- Encourage personal connections to projects

Define and Ideate

- Encourage students to pose questions about their work

Rapid Prototyping and Iteration

- Encourage students to document their design process and share their work with peers and educators
- Encourage thinking around the creation of generic models that can be adapted to different audience needs and rapid testing/modifications of prototypes
- Emphasise the importance of quick prototyping to help students visualize and assess the implications of their ideas, making abstract concepts tangible
- For 3D printing – enable students to be involved in the actual 3D printing process and provide another round of printing before producing their final result. Consider moving printers to the school so students can see the process of printing their creations
- For 3D printing - Review the timeframe of the interventions to ensure there are breaks between sessions to account for longer printing times

Sharing and Feedback

- Schedule regular feedback sessions
- Explicitly teach students the principles of constructive feedback (specific, actionable suggestions, being respectful and supportive)
- Use examples of both effective and ineffective feedback to help students understand the difference

- Provide frameworks or sentence starters, peer assessment rubrics, or reflection prompts
- For younger students, consider visual or interactive feedback methods, while older students may benefit from written or digital feedback platforms
- Reflection activities on feedback including peer review and self-assessment.
- Tailor the feedback process to the age group of students (e.g., nQuire may not be appropriate for younger students)
- Use collaborative and visually engaging feedback tools like Miro or Padlet
- Use online sharing features to facilitate peer-to-peer feedback, encouraging students to engage in constructive critique and collaboration
- Bring in external reviewers (such as the people involved in the empathy stage or experts in relevant fields) during the final presentation to increase the stakes for students
- Provide peer assessment cards to keep students engaged during other groups' presentations
- Encourage students to reflect on the feedback they receive and explain how it can be applied to improve their work

10.3.2 21st Century Skill Development

Communication

- Design activities that combine opinions, offer compliments, and demonstrate enthusiasm (e.g. during the Define and Ideate phase)
- Scaffold constructive dialogue and brainstorming sessions
- Provide hints and guidelines for respectful online communication
- Encourage students to pose questions about their work to each other and as part of their individual reflection
- Encourage students to communicate their ideas by providing summaries of their work

Collaboration

- Where necessary consider clearly defining roles within each group to prevent conflicts and ensure equal workload distribution
- Provide sessions on conflict resolution and effective communication through team-building activities prior to and during DT activities as necessary
- Utilise the collaborative nature of the tools to enhance the development of soft skills through interaction and teamwork

Feedback

- Teach principles of constructive feedback and use examples to help students understand

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- Training sessions on constructive feedback provide examples of useful feedback
- Reflection activities on feedback including peer review and self-assessment

Reflection

- Cultivate a growth mindset through feedback
- Implement perspective-taking activities and reflection sessions.
- Use reflective sheets (also listed under Learning Activity Design)

Organisational Skills

- Encourage organizational skills such as time management by providing scaffolds such as worksheets for students to produce initial plans and refer back to at the start and end of every session

10.3.3 Digital Technologies

- Digital tools used by students need to be accessible to all – not just in English
- Minimise links, user passwords and logins
- Provide troubleshooting guides, online resources, and offer technical support.
- Add instructions/videos accessibility on the actual game page
- Update the game manual to be clearer and more comprehensive, ensuring that users can easily understand and engage with the game mechanics
- Use interactive and user-friendly online platforms, incorporate multimedia elements (video or audio comments)
- Consider how tools can support synchronous or asynchronous collaborative tasking.
- ChoiCo development suggestions:
    - Add the option to create an event triggered by a variable which affects other variables
    - Provide a timer or limit the number of turns
    - Integrate structured guidance and examples within ChoiCo
    - Improve the graphic design features of ChoiCo to make it visually appealing and innovative, aligning with students' expectations of modern educational tools
    - Improve the graphic design features to make tools visually appealing, aligning with students' expectations of modern educational tools
- nQuire development suggestion:
    - Provide a way for students to share the creation and distribution of a “whole class” survey as well as access to the data which does not create a substantial additional workload for the teacher

10.3.4 Professional Development

- Pair experienced DT educators with less experienced colleagues to provide ongoing support and guidance
- Ensure all participants are familiar with the Activity Plan and digital DT models and refer to them frequently
- Collate examples of worksheets, guides and tutorials created by teachers for each DT phase.
- Enhance teachers' ICT skills to better manage potential technical issues and facilitate seamless integration of these tools in the classroom
- Ensure teachers have equivalent opportunities to students to “sandbox”, play games and modify “half-baked” artefacts
- Provide opportunities for regular reflection on learning
- Considering integrating traditional approaches at the beginning of the PD workshop, such as pen-and-paper scoring, into the digital platform to accommodate different user preferences and ease of implementation by also creating a phygital (physical+digital) environment
- Provide additional resources focused on problem definition skills, given its complexity and the necessity for frequent consultation
- Provide opportunities for teachers to experience the feedback process themselves so that they can then support their students
- Highlight the potential for DT and digital technologies to support educational goals and provide educators with tools and resources to integrate these methodologies into their curricula, that would guide the teachers in the process of using DT in their classrooms
- Emphasise the value of DT approaches in fostering a wide range of skills in line with educational objectives
- Discussions on how to adapt their teaching approaches to accommodate the open-ended and iterative nature of DT
- Encourage teachers to share their own resources and best practices with colleagues.
- Include examples and evidence from Cycles 1 and 2 school interventions to demonstrate how other teachers have addressed reasonable concerns about students’ capacity for collaboration, giving and receiving feedback, tensions between DT and traditional teaching methods, infrastructure and time

11 Conclusion

Overall, the Cycle 2 evaluation has demonstrated improvements in school interventions and professional development activities from Cycle 1. Recommendations such as ensuring there is sufficient time and resources for students to effectively engage in the Empathise and Understand, and Sharing and Feedback phases have been beneficial in terms of overall student engagement and learning outcomes. While recommendations suggest areas for further improvement, they represent both challenges and examples of best practice. This reflects the complexity of this research project, where different activity plans are implemented in each country and sometimes there is a different activity plan and different teacher in every school intervention within an individual country. The aim, therefore, is not to create a homogenous set of recommendations but a set of recommendations that can be effectively fed into the development of the framework (WP2), co-design activities (WP3), technology development (WP4), school interventions (WP5) and professional development activities (WP6).

11.1 Next Steps

In Cycle 3 the evaluation will shift from in-depth case studies of a small number of interventions to the evaluation of the Exten.(D.T.)^2 project activities at scale. Based on the recommendations set out herewith, subsequent discussions within the project consortium to define the roadmap for Cycle 3 and with consideration of their own cultural context and implementation experiences, partners will implement school and PD interventions at scale, with data collected from the refined survey piloted in Cycle 2. This will be supplemented by the use of the teacher's evaluation toolkit.

As we move towards a full roll-out of the Authorable Learning Analytics system and Dashboard, there are promising opportunities to utilise valuable data to generate new insights and inform further project development. With these opportunities, it is also important to be aware of and address ethical questions as they arise, in keeping with best ethical practice, which has already been followed throughout this project. While this is a matter for WP4 and WP9, it has a substantial impact on WP7 activities and will need the engagement of all project partners as well as stakeholders.

11.2 Publication Plans

The individual case study reports published in the accompanying Appendixes will be published or presented at conferences by those who conducted each case study. The SLRs and the final school survey development are currently being developed into journal articles, which will include the results of the national surveys.

11.3 RRI Statement

Responsible Research and Innovation (RRI) is interactive, iterative, and involves high levels of transparency with regular reflection on processes and goals. Given the rapidly changing technological landscape, we aim to anticipate potential issues before they arise. The project design has RRI embedded throughout in the following ways: in its structure and organisation; its ambitions in terms of engaging young people in design thinking for societal challenges; its engagement with schools which allows equitable engagement of young people regardless of gender and an opportunity for young people to engage meaningfully with scientists on topics within STEM education; the project design involves co-design and co-production; there is active engagement with the public through dissemination activities; the data management plan (DMP) emphasises the importance of open access data and publications; and finally the project team is actively involved in considering emerging ethical issues throughout the project, guided by an independent external advisor and ethics advisory board. Throughout our activities we aim to be diverse and inclusive, for example, listening to and including diverse groups of people in decision making processes. Through our deliverables, project newsletter, engagement activities website and the research itself, we aim for open and transparent communication. The project partners regularly reflect on the motivations for our research against a backdrop of the wider ethical and societal context that the research is located in. We aim to be responsive and adaptive to the changing needs of our stakeholders and re-evaluate the research trajectories in light of new evidence.

To achieve regular reflection on processes and goals in WP7, the WP7 lead is part of the Ethics Advisory Board (WP9) activities and works closely with WP5 (school interventions) and WP6 (professional development). Ensuring the relevance of our research for our stakeholders is essential and achieved through co-production activities. Participation in school interventions and participation in the research is close to 50:50 gender split. Participation in PD activities is biased towards female participants; 'however this is representative of the teacher population in each country.

12 References

Ackermans, K., Rusman, E., Brand-Gruwel, S. et al. (2019) Solving instructional design dilemmas to develop a Video Enhanced Rubric with modeling examples to support mental model development of complex skills: the Viewbrics-project use case. *Education Tech Research Dev 67*, 983–1002. https://doi.org/10.1007/s11423-019-09668-1

Almeida, F. V., Canedo, E. D., & da Costa, R. P. (2019, October). Definition of indicators in the execution of educational projects with design thinking using the systematic literature review. In 2019 *IEEE Frontiers in Education Conference* (FIE) (pp. 1-9). IEEE.

Amelia, R., & Santoso, S. T. P. (2021, April). 21st century skills in project based learning integrated STEM on science subject: a systematic literature review. In Proceedings of the International Conference on Engineering, Technology and Social Science (ICONETOS 2020) p583-590.

Bethune (2021).

Bray, A., Byrne, P., & O'Kelly, M. (2020). A short instrument for measuring students' confidence with 'key skills'(sicks): Development, validation and initial results. *Thinking Skills and Creativity*, *37*.

Chalkiadaki, A. (2018). A systematic literature review of 21st century skills and competencies in primary education. *International Journal of Instruction, 11*(3), 1-16.

European Commission, Joint Research Centre, Economou, A., *SELFIE for teachers – Toolkit Using SELFIEforTEACHERS – Supporting teachers in building their digital competence*, Publications Office of the European Union, 2023, https://data.europa.eu/doi/10.2760/626409.

Evans, C. M. (2020). *Measuring Student Success Skills: A Review of the Literature on Collaboration. 21st Century Success Skills.* National Center for the Improvement of Educational Assessment.

Glaittli, M. (2018). *Soft skills in high school.* Arizona State University.

Girvan, C., Conneely, C., & Tangney, B. (2016). Extending experiential learning in teacher professional development. *Teaching and teacher education, 58*, 129-139.

González-Salamanca, J. C., Agudelo, O. L., & Salinas, J. (2020). Key competences, education for sustainable development and strategies for the development of 21st century skills. A systematic literature review. *Sustainability, 12*(24), 10366.

Güngör, G. (2020). Problems and Solution Suggestions Encountered in Vocational Skill Training in Vocational High Schools: Teachers' Views. Online Submission, 7(4), 233-253.

Kynigos, C. (2007). Half-baked Logo Microworlds as Boundary Objects in Integrated Design. *Informatics in Education, 6*(2), 335–358.

Mattar, J., Ramos, D. K., & Lucas, M. R. (2022). DigComp-based digital competence assessment tools: literature review and instrument analysis. *Education and Information Technologies, 27*(8), 10843-10867.

Missett, T. C., Callahan, C. M., & Hertberg-Davis, H. (2013). Evaluating the impacts of destination ImagiNation on the creative problem-solving skills of middle school students. *The International Journal of Creativity and Problem Solving, 23(*2), 97-112.

Niruttimatee, P. K., & Sanrattana, W. (2022). An online program to develop teachers to enhance the innovation skills of students. *Education Quarterly Reviews, 5(*2).

Peart, M.T., Gutiérrez-Esteban, P. & Cubo-Delgado, S. (2020). Development of the digital and socio-civic skills (DIGISOC) questionnaire. Education Tech Research Dev 68, 3327–3351.

Rusmann, A., & Ejsing-Duun, S. (2022). When design thinking goes to school: A literature review of design competences for the K-12 level. *International Journal of Technology and Design Education, 32*(4), 2063-2091.

Saltos-Rivas, R., Novoa-Hernández, P., & Serrano Rodriguez, R. (2021). On the quality of quantitative instruments to measure digital competence in higher education: A systematic mapping study. *PLoS One, 16*(9), e0257344.

Schoormann, T., Stadtländer, M., & Knackstedt, R. (2023). Act and reflect: integrating reflection into design thinking. *Journal of Management Information Systems, 40*(1), 7-37.

Shrestha, B. R. P. (2016). Vocational education and training graduates: Challenges in practical skills to the job market. *International Journal of Social Sciences and Management, 3*(3), 141-145.

Strom, P. S., & Strom, R. D. (2011). Teamwork skills assessment for cooperative learning. *Educational Research and Evaluation*, *17*(4), 233–251. https://doi.org/10.1080/13803611.2011.620345.

Teo, T., Unwin, S., Scherer, R., & Gardiner, V. (2021). Initial teacher training for twenty-first century skills in the Fourth Industrial Revolution (IR 4.0): A scoping review. *Computers & Education, 170*, 104223.

The Marker Education Initiative *Beyond Rubrics Toolkit* https://makered.org/beyondrubrics/toolkit/ (last accessed 29/08/2024).

Tsai, M. J., & Wang, C. Y. (2021). Assessing Young Students' Design Thinking Disposition and Its Relationship With Computer Programming Self-Efficacy. *Journal of Educational Computing Research, 59*(3), 410–428. https://doi.org/10.1177/0735633120967326.

Van Laar, E., Van Deursen, A. J., Van Dijk, J. A., & De Haan, J. (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior, 72*, 577-588.

van Laar, E., van Deursen, A. J., van Dijk, J. A., & de Haan, J. (2020). Determinants of 21st-century skills and 21st-century digital skills for workers: A systematic literature review. *Sage Open, 10*(1), 2158244019900176.

Zhang, F., Markopoulos, P., Bekker, T., Schüll, M., & Paule-Ruíz, M. (2019). EmoForm: Capturing Children's Emotions during Design Based Learning. Proceedings of FabLearn 2019, 18–25. https://doi.org/10.1145/3311890.331189.

13 Appendixes A – Q

These are available in the supplementary document.

Appendices can be accessed through the following PDF Link. They are labelled according to the lettering A-Q *Link to PDF*.