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Aekaterini Mavri, Andri Ioannou, and Andreas Kitsis

Cyprus Interaction Lab - CYENS Centre of Excellence, Department of Multimedia and Graphic Arts, Cyprus University of Technology, Limassol, Cyprus

ABSTRACT
In this design case we introduce Assessmake21, a digital self-assessment tool to foster self-reflection for learners' 21st-century skills in K-12 formal and non-formal maker education. We report on the extraction of user requirements and corresponding UI features through a four-phase design process, led by a multidisciplinary team of 29 members from four European countries. Using a methodological UX process model and requirements taxonomy, the design team translated *theory-driven* and *data-driven* evidence - gathered through literature reviews, design thinking workshops, interviews, and expert feedback—into tool design specifications. Assessmake21 aims to promote scaffolded and sustained self-reflection through gamified features (level progression, content unlocking, rewards) and customizable learning design options (approach, duration), while integrating the educator's role into the skills' assessment process. This comprehensive *end-to-end* design case is a valuable resource for researchers and practitioners, offering a precedent for similar long-term, multi-stakeholder and multi-cultural incentives and advancing scholarship in learning experience design.

KEYWORDS
Learning experience design; educational technology; makerspaces; 21st century skills; self-reflection; self-assessment

1. Introduction

Few studies report on the design of educational technology tools, serving as blueprints for future digital products. The study concerns the design of a digital self-assessment tool guided by learning experience and user experience (UX) design principles, in an aim to drive learners (of 12-18 years) to self-reflect on their use and development of 21st-century skills in maker contexts.

Makerspaces are multidisciplinary environments that offer extended space facilities for creative hands-on experimentation, expression, design, and practical development of innovative products (Blikstein et al., 2017; Bowler & Champagne, 2016; Leary et al., 2016; Soster et al., 2020; Timotheou & Ioannou, 2019). Their philosophy concerns shared inquiry, ideation, tinkering, creation, making, and re-making or hacking products, and involves various media such as crafts, micro-devices, and other technologies (Bergner et al., 2019; Cun et al., 2019). Although these types of activities were previously found to promote the development of 21st-century skills (Martin, 2015; Weiner et al., 2018), the identification of specific skills associated with maker learning, their intentional cultivation and their methods of assessment still lack sound evidence in the literature (Adler-Beléndez et al., 2020). Overall, there is still no consensus within the research and practice communities on how these skills can be measured (Binkley et al., 2012; Kipp et al., 2018; Mavri et al., 2020), particularly in maker education and using educational technology tools (Timotheou & Ioannou, 2021; Turakhia et al., 2024).

Meanwhile, although self-reflection and self-assessment are acknowledged as key for self-regulatory and agentic behaviour, what we currently know is that maker learners often prioritize their hands-on making activities, instead of actually reflecting on them (Ioannou et al., 2024; Peppler et al., 2017). Additionally, while makerspaces are populated by people of a diverse age range who may work together or independently, younger participants tend to find it harder to grasp the abstract concept of "reflection" and put it into practice (Baykal et al., 2021; Sheridan et al., 2014). They are also noisy and distractive environments, posing more self-reflection obstacles for learners, compared to quiet and mindful settings, like libraries (Bieraugel & Neill, 2017).

To address these challenges, we present a design case for Assessmake21, a self-reflection tool for makerspace learning. This design case is part of a larger Design Based Research (DBR) work which involves extensive contextual research (Ioannou et al., 2024), a pedagogical framework guiding the design of the tool, and the evaluation of the tool with maker-learners in real life settings (Miliou et al., 2024). All these studies fall within the scope of a European project,

CONTACT Aekaterini Mavri aekaterini.mavri@cut.ac.cy Cyprus Interaction Lab - CYENS Centre of Excellence, Department of Multimedia and Graphic Arts, Cyprus University of Technology, 30 Archbishop Kyprianou Str. 3036 Limassol, Cyprus

under the first ("Assessment and Tool Design") and fourth ("Pilots and Evaluation") intellectual outputs of the project.

Design cases are an emergent method in the genre of research methodologies for instructional design and technology (Moore et al., 2024). With a focus on *documenting the creation process*, the goal of a design case is to generate and curate knowledge around an instructional product, the major design decisions and processes followed, together with its unique characteristics of value (Moore et al., 2024). Likewise, in this case we followed a Learning Experience Design (LXD) approach, as a "human-centric, theoretically-grounded, and socio-culturally sensitive" (Moore et al., 2024) way to align the design of learning to the design of the user interface, and ensure effective knowledge creation through an optimal user experience (Vann & Tawfik, 2020). Through this approach the design built upon an existing product called SkillTrack! (Kipp et al., 2018). While this product was designed to foster the development and self-assessment of 21st-century learning in K-12 formal education, Assessmake21 expands its scope to appropriate maker learning contexts. Given the broad nature of making activities and the diverse set of participants, we adopted SkillTrack!'s primary pedagogical guideline of "vertical and horizontal mobility", which emphasizes the tool's applicability across tasks, grade-levels, ages and subjects (Kipp et al., 2018). Nonetheless, since SkillTrack!'s user evaluation identified challenges related to complex concepts and vocabulary, Assessmake21 incorporates various components to counteract these; specifically, *information points* that clarify abstract ideas, and *learning design customization* options for educators to appropriate all (junior-to-senior) learner needs and foster engagement with the tool (Table 3).

In this study we document the process of Assessmake21's design, driven by the overarching objectives to a) engage learner-makers in systematic self-reflection b) ensure a sound, non-disruptive learning experience and c) promote the sustained use of the tool across multiple sessions and activities.

It is worth mentioning that this study falls under a *two-part design case*, offering a detailed account of the design activities, requirements judgements, and resulting outcomes. The other part focuses on interpreting the design process through the conceptual and methodological lens of *codesign*.

In the next section, we outline theoretical and empirical evidence from the 21st-century learning and self-assessment/reflection areas, both in general and maker education settings.

1.1. 21st-century skills in makerspaces

Current literature suggests that makerspaces constitute optimal environments for the development of 21st-century skills, such as creativity, communication, collaboration, problem-solving, critical thinking, technology, digital literacy, entrepreneurial, social, and citizenship skills, even if the association of these skills with making tasks is not explicitly defined (Adler-Beléndez et al., 2020; Ioannou et al., 2024; Iwata et al., 2020; Martin, 2015; Timotheou & Ioannou, 2021; Weiner et al., 2018). A few research efforts explored 21st-century learning in makerspace environments. For instance, a study investigating makerspace educators' perceptions on the key skills and knowledge for maker learning, revealed that specific 21st-century skills were inherently critical, namely, communication, creative problem-solving and collaboration (Turakhia et al., 2024). Evidently, the "design-make-play" learning phenomenon is perceived to boost problem-solving through a creative attitude around making, modifying, tinkering, repurposing, and play (Martin, 2015; Timotheou & Ioannou, 2019). Iwata et al. (2020) reported on how digital design and fabrication promoted the development of all 21st-century skills classified under "ways of thinking", "ways of working" and "computational thinking". Timotheou and Ioannou (2021) also suggested that the most prominent skills developed during making are "learning and innovation" skills, due to the imaginative approaches needed to address open-ended problems, and the collaborative hands-on construction of artifacts through teamwork. Along the same lines, in their investigation of 21st-century skills development in FabLabs and makerspaces, Rayna and Striukova (2021) suggested that while making cultivated certain entrepreneurial skills, it also reinforced the development of a more extensive set of *digital* skills due to its blended nature which invites digital experimentation and hands-on application.

1.2. Self-assessment and self-reflection on 21st-century skills in makerspaces

Despite the increasing interest in the use and development of 21st-century skills in maker education, the identification of skills associated with making activities, and their assessment methods in making contexts, is still scarce (Adler-Beléndez et al., 2020; Bergner et al., 2019; Timotheou & Ioannou, 2021). In fact, effective approaches that go beyond the mere measurement of computer-centric literacy to address the interdisciplinarity of maker-relevant skills are still absent from the literature (Blikstein et al., 2017; Schad & Jones, 2020). One of the reasons behind this, is the nature of learning typically associated with the maker context which generates diverse learning scenarios and involves "play" and exploration (Moorefield-Lang, 2015), with projects requiring creative and innovative thinking and problem-solving (Bevan, 2009). Such non-structured and open-ended learning processes and outcomes are hard to assess objectively due to their level of openness and ambiguity, when compared to traditional learning and assessment criteria (Adler-Beléndez et al., 2020; Bieraugel & Neill, 2017).

Makerspace learning requires students to develop self-regulation strategies to achieve their goals (Godhe et al., 2019; Marsh et al., 2018). According to Zimmerman (2000), reflection is part of a three-phase (forethought phase, performance phase, reflection phase) cyclical model of self-regulation, taking place in learning. With special attention to the last two phases, previous work aimed to generate knowledge on self-reflection across various learning contexts. For example, Kipp et al. (2018) designed a digital learning tool called SkillTrack! to support the practice, development and self-assessment of transversal skills K-12 formal education. The tool was based on a phased experience, prompting students to identify 21st-century skills from a predefined list, perform benchmarked activities (i.e., multiple-choice questions) and uploading evidence of their work. When triaged in formal-led classroom settings, the tool was found to effectively support the self-assessment practice while fostering informal learning opportunities related to skills development.

With regard to makerspace education, similar self-reflection initiatives were found to enhance learners' critical self-directedness, self-awareness, and responsibility (Peppler et al., 2017; Soster et al., 2020). For example, Cun et al. (2019) generated an assessment matrix for formative and summative use, to detect the development and mastery of generic and specific skills, while recording learners' and instructors' reflections, intentions, and needs in makerspaces. Along the same lines, Fayard et al. (2020) produced a physical apparatus for the visual capturing of the learners' reflections in maker contexts. This invited students to actively think about their making, by adding shaped/coloured cairns to represent various practice categories, temporal slots, and activities on a board; these actions facilitated collective self-reflections through the learners' "over-the-board" discussions. Looking into the digital aspect of self-evaluative methods, Keune and Peppler (2017) examined the role of e-portfolios in maker communities and reported that these proved to be as much of a self-reflection, as a learning tool, since they encouraged learners, teachers, and future employers to critically think of and document their progress, serving as "how-to" guides for peers.

Adopting a more advanced technological approach, Turakhia et al. (2022) built a digital toolkit, that was later enhanced with the affordances of Augmented Reality (AR), to allow educators and experts enhance maker learning for novice students. Specifically, through three main components, the tool provided educators with an interface to a) design reflection exercises for making tasks, b) setting up prompts to ask, inform or warn the learner during making, c) link to a set of fabrication tools that could sense the users' actions, and d) use a diary to record the learner's reflections along the way. While the toolkit's application and evaluation within authentic settings are under way, this research is promising for system-based modes of general reflection in makerspaces.

Overall, research in STEM and maker education has highlighted various barriers to self-reflection and assessment. Specifically, maker-learners often appear oblivious to their own skills development and reluctant to engage in self-reflection, being too immersed in their complex hands-on activities (Cun et al., 2019; Ioannou et al., 2024). Furthermore, the busy and noisy environment of makerspaces is not encouraging reflection which typically requires quiet and distraction-free places for mindful introspection (Bieraugel & Neill, 2017). Self-reflection also demands considerable effort, especially from younger learners, who may lack substantial subject-level knowledge, a good grasp of complex concepts and vocabulary, or prior practical metacognitive experience, therefore, requiring more structure and support for self-reflection (Bowler & Champagne, 2016; Greenstein, 2012). Indeed, recent studies have highlighted differences between younger and older learners in their understanding of the "sophisticated" language used to describe abilities or skills in STEM education (Ioannou et al., 2024; Kipp et al., 2018). However, such age-related findings were not always consistent, especially through the joint lens of self-reflection and *motivational variables*, such as perceived self-efficacy (Bandura, 2000) and emotional factors—both positive (e.g., enthusiasm and pride) and negative (e.g., frustration and anger) - which "in turn, become part of students' self-reflection process" (Vongkulluksn et al., 2018). This became evident in a study involving elementary school students in a makerspace course (Vongkulluksn et al., 2018). The authors deduced that younger students exhibited increased levels of enthusiasm and interest, leading to more positive and sustained self-reflections. Conversely, older students, who opted to work with more complex tasks and encountered more setbacks than successes, produced poorer self-assessments and a decline in self-evaluative practice as time progressed.

With these in mind and based on self-reflection's significance for self-regulatory and agentic behaviour across educational contexts, there remains a gap in understanding how reflective practices on 21st-century learning can practically be integrated into makerspace learning and assessment, particularly through the use of educational technology (Cun & Abramovich, 2018; Fayard et al., 2020; Soster et al., 2020; Turakhia et al., 2022). To address this gap, this design case explores Assessmake21, a tool designed to facilitate self-reflection on 21st-century learning in makerspaces. We focus on the activities and resulting design requirements and features that contribute to the growing discourse around educational technology that supports reflective practices in maker education. This leads to the following research questions:

RQ1: What are the activities involved in the Assessmake21 design process?

RQ2: What are the design requirements and respective tool features resulting from this process?

2. Research framework

2.1. Learning experience design (LXD)

Recently, learning design has moved on from a focus on the instructional and learning materials to the design of the *learners' journey and experience*, as a human-centric approach to motivate and engage learners in reaching their goals faster and better (Quintana et al., 2020). In short, Learning Experience Design (LXD), is a process "concerned with both the effectiveness of designed learning interventions and the interconnected and interdependent relationship between the learner-as-user, the designed intervention, and the learning context" (Schmidt & Huang, 2022). It is a transdisciplinary process that requires input from varied epistemic expertise to blend and align the design of learning for knowledge construction with the design of the user interface (Chang & Kuwata, 2020; Georgiou & Ioannou, 2021; Vann & Tawfik, 2020). As Moore et al. (2024) explained, while some designers work from strongly held theoretical bases and may cite literature to explain their design decisions, equally credible decisions may be based on experience, reasoned judgment, and informed speculation. In this design case, the LXD team relied on both theoretical and experiential knowledge. Our decisions, explained in section 4.1, were grounded on pedagogical models such as Bloom's (Krathwohl, 2002) taxonomy and the gamification of learning. On the other hand, our experience with human-centred design methodologies informed the LXD process, which generated empirical data that informed our decisions. Thus, the LXD-guided design process in this work was theoretically grounded, human-centric and socio-culturally sensitive, as the following sections explain.

2.2. Theoretically and pedagogically grounded design

Firmly grounded in constructivist foundations, the rationale for Assessmake21 followed Bloom's (1956) revised taxonomy, requiring learners to accomplish the easier-attaining skills first—earning an early sense of achievement—and then gradually progressing to more complex tasks, demanding higher-order thinking and self-reflective activity (Krathwohl, 2002). This progressive course is steered through evidence and rewards, as important elements of gamification (Buckley & Doyle, 2016). The tool provides evidence in the form of picture-taking/uploading and portfolios of the learners' artifacts. Likewise, rewards in Assessmake21 come in the form of badges awarded by the educator/facilitator.

2.3. Human-centric and socioculturally sensitive design

This design case is a synergistic result, following recommendations for considering all end-users, as they influence the learning environment, and consequently, impact learners as the primary stakeholders of interest in this process (Schmidt & Huang, 2022). We acknowledge that the end-user is not merely the learner, but also the educator or/and makerspace facilitator—a group of end-users who are often ignored in learning technology design (McCarthy et al., 2020). Sociocultural perspectives might also be overlooked by small teams or individuals who lack sufficient perspective to design for culturally sensitive and diverse learning environments (Schmidt et al., 2023). Our design engaged stakeholders with diverse backgrounds and experiences in both schools and nonformal makerspaces from four European locations. It addressed the varied requirements resulting from their distinct maker environments, which differed in physical and digital setup, social dynamics, teaching methods, languages, and preferences. As such our process integrated and met the pragmatic needs of users as *learners*, *educators* and *facilitators*, considering their rich characteristics and ecologically valid perspectives.

2.4. UX design model

In this study, we considered various UX models that guide and capture the multi-faceted and dynamic nature of UX design. Their common aim is to simplify and make sense of the complex UX phenomena to generate understanding and guide the design process toward specific project demands (Tosi, 2019; Yargın et al., 2019). Amongst these, a few stand out. For example, the Lean UX model (Gothelf & Lean, 2013) is a simplified three-stage framework (*Think—Make - Check*), whose purpose and popularity lies in the rapid development of minimum viable products (MVPs), using minimal resources to gather feedback from potential consumers and make quick "keep" or "drop" decisions (Aarlien et al., 2020). Its strength lies in its adaptability to Agile environments and suitability for minimally resourced projects (Tonkin et al., 2018; Sexton, n.d.).

Another widespread model is Garrett's (2002) 'Five Planes of UX' which organizes the design process, moving from abstract to concrete, through five elements: a) *strategy*: defining user/business needs, b) *scope*: extracting functional and content requirements c) *structure*: designing the information architecture and interaction flow, d) *skeleton*: creating wireframes, and e) *surface*: developing the final design. While this model approaches design in a holistic manner, its original description lacks explicit guidance on iterative workflows (Garrett, 2002).

For the needs of Assessmake21, the design team deduced that a practical and iterative model, placing emphasis on the distinct *evaluation* and *analysis* phases of the design, was required. To address these, we employed Hartson's and Pyla's (2012) lifecycle model, which conceptualizes the UX process in four phases: *Analysis, Design, Prototype* and *Evaluation* (Figure 1). *Analysis* involves user research and contextual exploration and analysis through qualitative data observation and interviews. *Design* focuses on generating information models such as personas, task flows, user scenarios and conceptual maps. *Prototype* concerns the creation of low, medium and high-fidelity prototypes. *Evaluation* assesses the user experience based on the outcomes of previous phases through formative (qualitative data), summative (user performance-driven indicators) and other (i.e., heuristic evaluation) methods. Each phase is inherently iterative, involving internal micro-evaluative cycles, to align user requirements to project objectives.

2.4.1. Interaction design requirements specification

As part of their UX lifecycle model (Hartson & Pyla, 2012) the authors also propose a basic requirements taxonomy termed "Interaction Design Requirements", comprising three broad categories in the design of a system or tool: a) Interaction requirements, which focus on supporting the user in progressing their activities toward their goal, b) Functional requirements, which ensure that the tool is both usable and useful for the user, and c) Phenomenological requirements, which address the user's emotional needs and the impact of the tool on the user over time (Stephanidis et al., 2019).

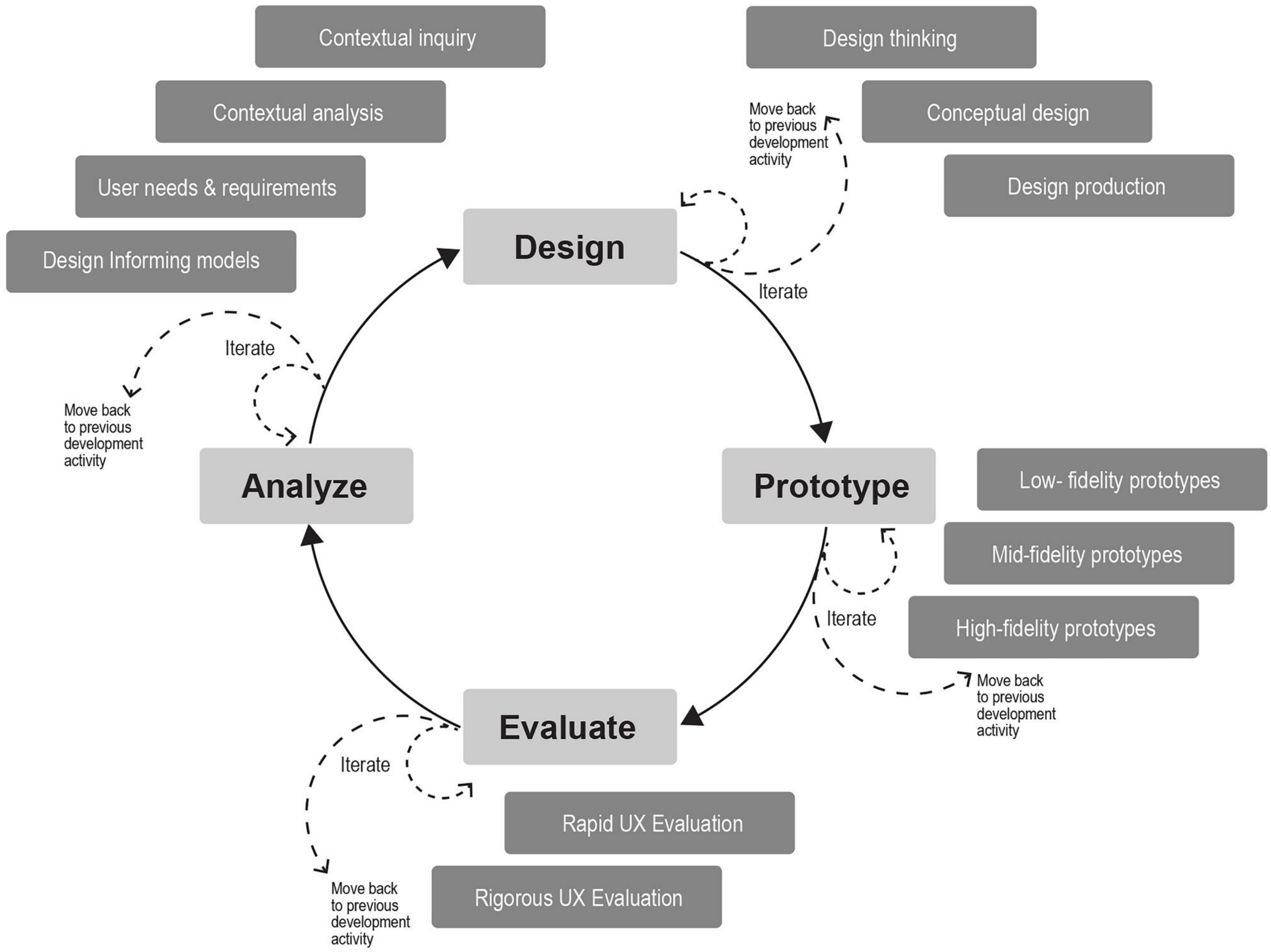

Figure 1. Adaptation of the four-phase UX lifecycle model by Hartson and Pyla (2012).

Table 1. The entire and core design teams as participants in the Assessmake21 development process.

Design team	Core team	Role	Activities	Context	Gender F	Gender M
4	1	DEV	Engineering, software development	University & research centre	–	4
4	2	UX-UI	UX-UI research & design	University & research centre	3	1
5	2	EDT	Educational research, educational technology, education	Educational technology research labs, K12 & Higher education	3	2
14	–	MS	Makerspace/Fablab education & facilitation	Private, public K12, university-based makerspaces, FabLabs	9	5
2	2	PM	Project management & coordination	University & research centre	1	1

3. Materials and methods

3.1. Participants

This study involved 29 participants ($n = 29$, 13 males, 16 females) who were members of a European four-partner project. The entire group (hereafter "design team") included software engineers ($n = 4$), UX-UI designers ($n = 4$), educators ($n = 5$) in higher education, educational researchers, or technologists, maker-educators or facilitators ($n = 14$) from primary and secondary public schools (formal education), university-based or private makerspaces and FabLabs (non-formal education), and project coordinators ($n = 2$) (Table 1). All participants were recruited in the project based on a minimum requirement of five years of *professional* expertise in their fields, with many having more than 10 and some exceeding 20 years of experience. Notably, these roles shared overlap as anticipated, with knowledge from adjacent fields of study (for instance, maker education, educational technology, research, or software engineering). A subset of the entire design team comprised the core team ($n = 7$) of experts (hereafter "core team") for the "Assessment and Tool Design" intellectual output (IO1), due to their project-management and output-related expertise and roles.

The educators and educational researchers drew on theoretical knowledge and models, as well as contextual evidence to create the pedagogical framework of the tool. They also made decisions on skill definitions and their operationalization across the learner's experience. Together with UX-UI researchers, they planned the progressive course of user tasks and activities in the tool, known as the learner's journey and the relevant scripts. Meanwhile, the UX-UI researchers focused on contextual research and analysis to extract interaction design requirements and create design informing models (section 3.3.2), and the design of the graphical user interface (GUI prototypes). The maker-educators provided insights into various teaching approaches, technologies, and the social dynamics in maker-space contexts (i.e., formal/non-formal). The engineering/software development team's role was to implement the final product following the conclusion of output IO1, however, were actively involved in all its activities to ensure the accuracy of the interaction design requirements specification. Finally, project managers oversaw and coordinated the teams to ensure adherence to deadlines and deliverables. The project brought ethical approval from the national research ethics committee (IRB) and all data collection was done upon participants' informed content.

3.2. Research method

A new research paradigm focusing on instructional technology design or learning experience design is the Design case. Design cases, or instructional design cases (IDC), offer a narrative of the design process and outcomes to serve as a precedent for other designers to draw from in the creation of new work (Moore et al., 2024). From a methodological perspective, they differ from traditional scientific research, which typically relies on strict criteria of replicability and validity (Patton, 2002), by serving as a paradigm "research to describe" (Moore et al., 2024) rather than research to prove, improve or test feasibility. This means that the knowledge in IDCs extends beyond drawing on, comparing with or adding to prior literature. While designers may as well choose to base their work on theory, equally valid research can be grounded in the "experience, reasoned judgment, and informed speculation" (Moore et al., 2024) of the designer(s) involved in the process.

In this study, the design case was documented by three core team members. The first author, an academic and researcher in the Design disciplines, also brought in broad experience as a UX-UI designer. The other two members comprised an academic with extensive expertise in educational technology and learning experience design and a UX-UI researcher and designer. While the three members actively participated across the project's 24-month lifecycle, their primary focus was the *Assessment and UX-UI design* intellectual output.

3.3. Technology tools

To assist the overall design process, the core team employed a selection of creativity support tools used in UX-UI design and LXD processes for the development of flow diagrams, sketches, design prototypes and interactive simulations (Mavri et al., 2020). Specifically, the team used Miro (miro.com), a cloud-based whiteboard for synchronous and asynchronous meetings to share knowledge, generate mind-maps, flow charts, wireframes, and collect feedback from other members (Cherry & Latulipe, 2014; Mavri et al., 2020; Shneiderman et al., 2006). The Adobe XD platform was also used for the design and sharing of *mid* to *high-fideli*ty, *static* and *interactive* prototypes, as well as for feedback gathering throughout the *Prototype* and *Evaluation* phases of the project (Table 2). In addition, Microsoft Teams and Google drive (Docs, Sheets, storage) were used for generic communication and productivity/management purposes.

3.4. The design process

The LXD process evolved through four, rather distinct phases while emphasizing continuous collaboration and improvement of the design over the course of five months.

Table 2. Summary of the design process: phases, activities, goals, timeframes, and participants.

Phase	Activities & objects	Goals	Participants	Timeframe
Analyse	Review of related literature	• Assessment of 21st-century skills in general and maker education in particular • Conceptualization and key dimensions in 21st-century skills evaluation.	*Core team*	Months 1-2
	Consideration of existing tools	• Detect useful features that could be adopted or adapted to the maker context and age group of learners (12-18)	*Core team*	
	Design Thinking Workshops	• Situate design to the aspects of the learning space and setup, teaching approach, access to tools (i.e., tablets, cameras etc), maker contexts and experiences	*Design team*	
	One-to-one & group interviews	• Elicit views of the most frequently used and developed 21st-century skills in various maker contexts • Collect different methods and tools of assessment	*Design team*	Months 2-3
Design	Personas Hierarchical task flows Learner's journey Learner's journey scripts	• Iterations of design and refinement (micro-evaluations)	*Core team*	
Prototype	Mid, high-fidelity prototypes	• Iterations of evaluation and feedback using Miro and Adobe XD (micro-evaluations)	*Design team*	Months 3-4
Evaluate	One-to-one and group interviews Asynchronous reviews & feedback	• Evaluate high-fidelity prototypes • Address beneficial/non-beneficial, easy/difficult to follow, detect new or missing features	*Broader team*	Month 5

The four phases were *Analyse-Design-Prototype-Evaluate* (i.e., Hartson's and Pyla's UX lifecycle model) (Hartson & Pyla, 2012) and involved the members of the design team in addressing the pedagogical, instructional, technological, and social specificities of the intended learning context. Each of these stages supported critical advancements to the tool's design up until its full handoff to the software development team. See Table 2 for a summary of the design process and roles involved.

3.4.1. Phase 1 - analyse

The overarching aim of this phase was to gather information about the tool's end users (i.e., educators/facilitators, learners), their aims, preferences, use context, and perceptions of the 21st-century skills linked to making. In this phase, four activities were undertaken as follows:

1. *Review of related literature*. The core design team reviewed studies on the assessment of 21st-century skills in general and maker education, their key conceptual dimensions and evaluation.
2. *Consideration of existing tools*. The core design team studied an earlier version of the tool called SkillTrack! by Kipp et al. (2018), which served a similar purpose, namely assessing 21st-century skills through self-reflection, yet, with K-12 students (up to 12 years old) in school classrooms, rather than makerspaces. The aim was to detect useful features that could be adopted or adapted for the maker context and new target age group (12-18 years old), and any problematic elements that should be abandoned or re-conceptualized (for instance, SkillTrack! running as a desktop app). The examination of SkillTrack! highlighted the need for more contextualized focus, like, considering the specifics of the learning space and setup, the teaching approaches, access to tools and so on.
3. *Design-thinking workshops*. Design thinking workshops were held with all members in the entire team, organized into three sessions of 9-10 participants each. The aim was to explore the contextual factors (mentioned above) and situate the design to these. The workshops uncovered great heterogeneity amongst makerspace contexts (i.e., the learning space/setup, frequency and duration of activities, overall learning goals), reinforcing the need for further, more targeted investigation.
4. *Group and one-to-one Interviews - cycle 1*. Following the preliminary findings of the design-thinking workshops, interviews were held with 13 participants, all 10 experts in maker teaching, facilitation and practice group and one from each of the other groups, to collect targeted information on their environments, experiences, perceptions of 21st-century skills for making, and methods or tools of their assessment. Based on the interviews, five 21st-century skills were perceived to be most frequently used and developed during maker activities (*Collaboration, Creativity, Communication, Life/Social skills, and Problem-solving*). The team also uncovered that robust assessment techniques, instruments, and tools were missing from the makerspace educators' repertoires (Miliou et al., 2024). These findings reinforced the necessity for a customizable tool to appropriate the many different contexts of maker practice (Ioannou et al., 2024).

3.4.2. Phase 2 - design

In this phase, the core team went through iterations of design and refinement (i.e., running intra-team micro-evaluations). The process included the creation of the following design-informing models (Hartson & Pyla, 2012):

1. *Personas*: denoting user behaviour, use scenarios, and learning contexts, all of which help shape the tool's interaction.
2. *Hierarchical task flows*: plotting the user tasks, decisions and actions to achieve various goals, combined with low-fidelity prototypes.
3. *Learner's journey*: envisioning the interactive learning experience through progressive tasks, learning challenges, and rewards.
4. *Learner's journey scripts*: drafting the overall content of the learning challenges and the respective interaction scripts.

3.4.3. Phase 3 - prototype

This phase included the design of mid to high-fidelity prototypes and the engagement of the core team in gathering and integrating feedback into these (micro-evaluations). These prototypes presented the common interface elements used across the entire tool and the specific GUI elements employed in specific tool sections, using the task flows and challenges from the learner's journey. The core team refined the prototypes and the learner's journey scripts, through several micro-iterations. These evolved into high-fidelity interactive prototypes that were visually and behaviourally close to the final product.

3.4.4. Phase 4 - evaluation

This phase focused on (macro) evaluation, inviting input from all members of the design team via interviews (cycle 2) and asynchronous feedback. Specifically:

1. The core design team conducted group and one-to-one semi-structured interviews with educators and facilitators from the entire team, to review and gather suggestions on the high-fidelity prototypes. Following a short presentation of Assessmake21, the interviewees were prompted about their perceptions of the tool, its underpinning concepts and features, and how they envisioned integrating it into their classrooms. These revealed the features that were/weren't beneficial or easy/difficult to comprehend and follow, and provided helpful propositions for the educator's dashboard, the learning management and administration system for educators, which was undergoing development at the time.

2. The core design team also requested asynchronous reviews and feedback from the entire team. Educators and facilitators were requested to send their reviews of the *learner's journey* and *scripts*, while summarized feedback on the tool's design (high-fidelity/interactive prototypes) was gathered through MIRO and Adobe XD.

4. Results: Tool overview, design requirements and UI features

The design process in this work was both theoretically grounded and human centric, combining *theory-driven* and *data-driven* approaches. In this section we briefly outline the *pedagogical* decisions for the design and focus on the contextually informed *requirements specification* and *UI features* of the tool. A comprehensive analysis of the pedagogical framework underpinning Assessmake21's design, including decisions on *what* and *how* 21st-century skills were selected, as well as the learning concepts that were operationalized into activities, will be presented in forthcoming work by the authors.

4.1. Pedagogical design

4.1.1. 21st-century skills

Building on the interviews, workshops and related literature from Phase 1 (section 3.4.1), Assessmake21 focuses on five key skills linked to maker education, namely, collaboration, creativity, communication, life/social skills, and problem-solving (Adler-Beléndez et al., 2020; Ioannou et al., 2024; Iwata et al., 2020; Martin, 2015; Timotheou & Ioannou, 2021; Weiner et al., 2018). The tool enables users to identify these through a simplified and uniform process. For instance, when a learner identifies using/developing creativity, they "tap" the creativity button. This generates a challenge within a specific level. Tapping (or tagging) another skill within the same level, such as problem solving for instance, prompts the same or similar challenge, focussing on the new skill. In this way, skill-identification and tool learnability are achieved through the different skills.

The design of Assessmake21 faced two main challenges regarding 21st-century skills: the lack of clear definitions of these skills for both teachers and students, and the multimodal nature of makerspace activities and self-reflection, which complicated their identification, practice and assessment during learning (Carey & Stefaniak, 2018; Schad & Jones, 2020). To overcome these challenges, the tool incorporates a) a "Definitions" section, accessible throughout the entire tool, which offered explicit skill descriptions and related learning expectations, acting as a consistent vocabulary and resource for students, and b) an "Examples" section, showcasing sample reflections and pictures of artefacts created during making, to help students with documenting their own reflections.

4.1.2. Bloom's taxonomy

Assessmake21 integrates the revised Bloom's taxonomy (Anderson & Krathwohl, 2001) to categorize challenges based on six ascending (by complexity) educational objectives: *Remember*, *Understand*, *Apply*, *Analyse*, *Evaluate*, and *Create*. The challenges were designed to begin with simple tasks, providing a sense of achievement first, and gradually progressing to more complex ones, requiring higher-order thinking later, following the principle of moving "from simple to complex and concrete to abstract" (Anderson & Krathwohl, 2001). For example, Level 1 challenges focus on Remember, Understand, and Evaluate, while Levels 3 and 4 incorporate objectives like Analyse and Create, in response to the increased metacognitive awareness that students develop through using the tool.

We also followed a flexible - rather than a strict - adoption of the taxonomy. For instance, despite its higher degree of complexity, Evaluate was included across all task levels due to its critical role in self-reflection from the early stages of interacting with the tool.

4.1.3. Self-reflection

Students must self-regulate their emotional and motivational factors to achieve their learning goals in makerspaces, which often require higher-order thinking and the simultaneous activation of different skills (i.e., creativity, collaboration, and problem solving) simultaneously (Marsh et al., 2018). Recognizing this, Assessmake21 places emphasis on the affective factors of self-regulation, with particular focus on the Performance and Reflection stages of self-regulation (Zimmerman, 1989). Specifically, the tool offers three approaches for reflection to flexibly accommodate the learners' needs: a) *during* the making activities, b) *after* completing the making session, and c) a *combination* of both (Figure 8). This design allows reflective activity both in micro (during) and macro (post-session) modes. By addressing these emotional and motivational factors (gaining confidence, trusting the tool, minimal disruption) and through personalized learning, the tool ensures alignment with individual learning styles and sustained engagement.

4.1.4. Gamification

Makerspaces, are cognitively and creatively demanding environments (Bowler & Champagne, 2016). To safeguard these processes, self-reflection should remain unobtrusive, time-efficient and engaging (Marsh et al., 2018). Additionally, maker leaners are often reluctant to think about their activities (Godhe et al., 2019), highlighting the need for special approaches, like gamification, to induce interest in self-reflection. Assessmake21 integrates gamification techniques to create an enjoyable and sustained flow of tasks with escalated complexity, content unlocking, and reward mechanisms (Csikszentmihalyi, 2013; Groening & Binnewies, 2019).

4.2. Design requirements and user interface features

In this study we employed human-centred and learning experience design methodologies to enhance the design process and collected empirical data to inform our design decisions. In the following tables we present how the core team arrived at a design requirements specification. Following Hartson and Pyla (2012), we classified each requirement under the three proposed genres, *interaction*, *functional*, and *phenomenological* (Stephanidis et al., 2019). Some of these share overlap and are interdependent with others. The requirements were translated to respective tool features, which aim to enable learners to self-reflect on five 21st-century skill(s) - Collaboration, Creativity, Communication, Life/Social skills, and Problem-solving, with explanations and examples provided through 'information points' to help clarify their meaning. During or after their making activities, students can select the skills they used through 'tapping' which prompts challenges, such as answering questions, documenting artefacts through picture-taking, or typing open-ended reflections related to the 'tapped' skill. To enhance engagement, the tool integrates gamification through level progression, content unlocking, and educator-approved badges. Educators can manage their classrooms and/or individual students, customize the learning design based on approach (during/after/both activities) and duration (short/medium/long) through the Educator's dashboard. These features are presented in Tables 3–5.

4.2.1. Interaction requirements and tool features

Interaction requirements reflect the main features supporting the user's progressive activities across the tool. These are detailed in Table 3 below.

Table 3. Assessmake21 interaction requirements, tool features and prototypes.

Interaction requirements and tool features	
Design requirement	User interface feature - Assessmake21
1) Easy input of skill(s) used The tool should allow students to a) understand the meaning or definition of a skill through basic terminology and tangible examples, and b) detect the skill(s) they (perceive to) use and develop in their making through easy selection, i.e., "tapping" the respective button or using a slider to set their proficiency level. The tool should include 5 skills: *Collaboration, Creativity, Communication, Life/Social skills, and Problem-solving.*	*Skill-tapping*. Identification of and self-reflection on a skill is done through "tapping". Tapping triggers level-specific challenges (out of five levels) associated with the "tapped" skill. Each dot on the progress bar represents a challenge, providing learners with visual feedback on their progress (Figure 2)

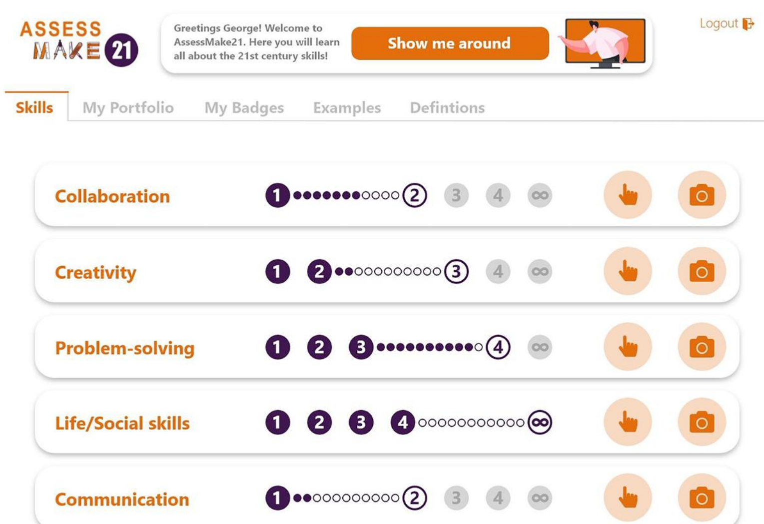

Figure 2. Student's dashboard page—overview of skill-tapping progress.

2) Record of skills' development process The tool should allow for both formative and summative ways of recording the students' skills progress. It should provide: a. an actionable *track bar* to present the steps needed to attain a goal (i.e., a badge) to sustain engagement with the tool b. a *visual pool* of their pictured artifacts as evidence c. the overall *student progress* through an "accumulated" portfolio of achievements	*Challenges.* Questions, activities, and picture-taking/uploading artifacts. • *Question* challenges prompt students to verbally reflect on their skills' use/development through scaled and open-ended questions. • *Picture-taking* challenges prompt students to document their skills' use/development through visual examples (i.e., produced artifacts and other making outcomes) (Figure 3). *Levels*. Completing challenges allows students to progress through *four* levels of increasing complexity and reach the infinite (final) level. The infinite level recycles the challenges from all previous levels, allowing students to continuously reflect on their skills. *Portfolio*. Access to an accumulated set of skills and artifacts (visuals) and related reflections (text), sorted by *skill* and *level* (Figure 4).

(*continued*)

Table 3. Continued.

Interaction requirements and tool features

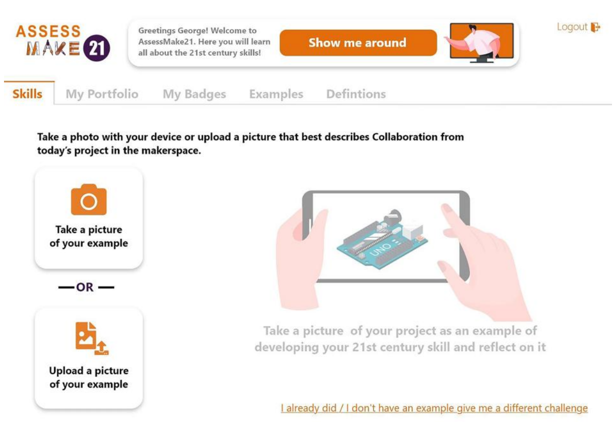

Figure 3. Student's picture-taking/uploading page.

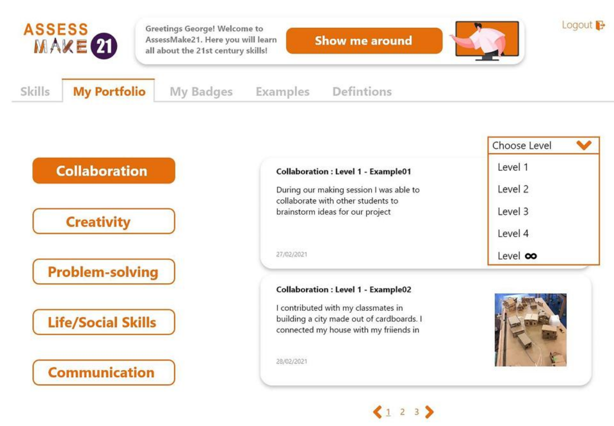

Figure 4. Overview (portfolio) of student's (tapped) skills.

Badges. Learners can request digital badges (pending educator's approval) upon level completion. Learners can receive a total of 20 badges on completing all four skill levels (Figure 5).

Information points. Various "show-me-around", "skill(s) definitions", and "examples from other players" sections clarify the tool's use in simple language (Figure 6).

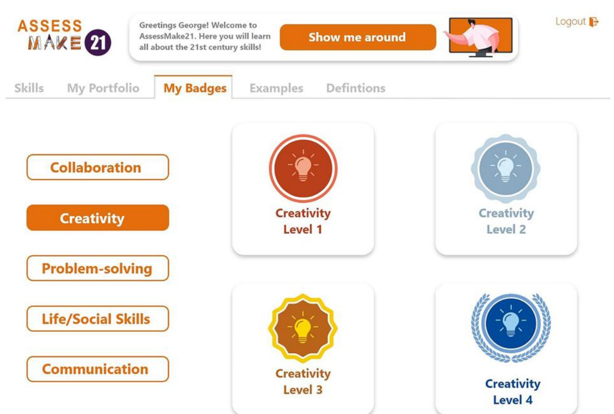

Figure 5. Overview of student's attained badges.

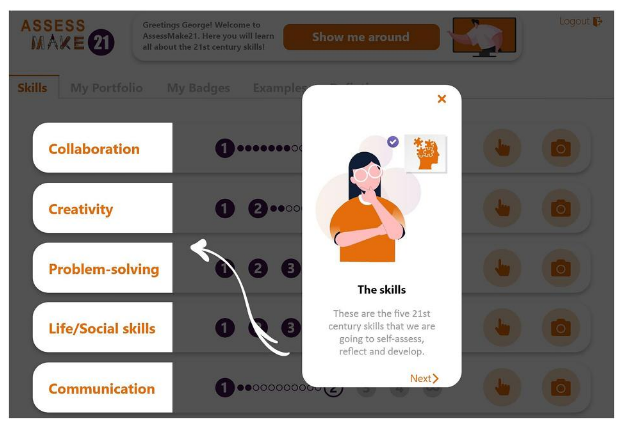

Figure 6. Information point: 'show-me-around' page.

3) Choice of different learning design approaches (Educator's dashboard)
The tool should allow teachers to select a learning design plan to appropriate their maker contexts and instructional/ facilitation practices (e.g., some follow a pre-planned set and order of activities, leaving no room for self-reflection during these, while others follow more unstructured and spontaneous approaches to their instruction).

Learning design customization. Allows teachers to choose their settings for a specific approach by choosing between:

- *Approach*: a) parallel, b) parallel with challenges at-the-end, or c) all at-the-end
- *Duration*: short, medium, or long
- *Technology*: types of devices available

Approach. Teachers/facilitators should be able to easily switch between the following approaches (Figure 7, Figure 8):

- *Parallel Approach.* Allows students to identify the skill(s) they use/develop and complete the respective challenges during their making activities in class.
- *Parallel input approach with challenges at-the-end.* Allows students to identify the skill(s) they use/develop during their making activities but complete the respective challenges at the end of the class/session. Challenges are constructed based on the student's session performance.
- *At-the-end approach.* Allows students to identify the skill(s) they use/ develop and complete respective tool challenges only at the end of their making activities in the class/session.

4) Choice of duration and number of sessions and activities (Educator's dashboard)
The tool should allow the selection of *duration* for the maker session, bearing in mind that these may also be affected by the number of maker sessions. The long duration could, for instance, appropriate a three-month series of two-hour weekly sessions, whereas a medium duration could match 50-minute daily sessions for a week. The overall purpose is to keep students engaged while enabling them to ascend through the tool's levels, neither too fast and effortlessly, nor too slow and laboriously.

Duration. Allows educators to choose duration and number of sessions and activities. Depending on the duration of a session (short, medium, long), each level will require the learner to perform a preset number of tasks (Figure 9).

- *Short:* 5 Activities (4 challenges & 1 Picture-taking example) in each level.
- *Medium:* 8 Activities (6 challenges & 2 Picture-taking examples) in each level.
- *Long:* 12 Activities (8 challenges & 4 Picture-taking examples) in each level.

(*continued*)

Table 3. Continued.

Interaction requirements and tool features

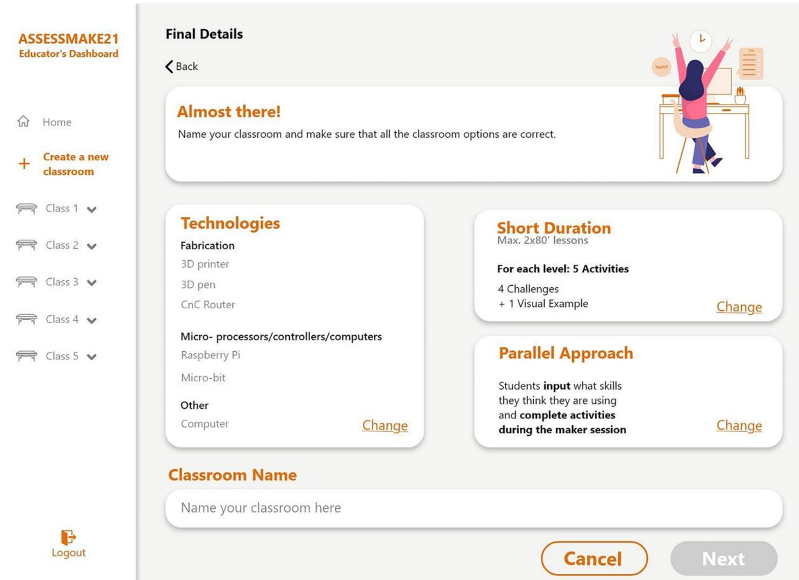

Figure 7. Educator's platform learning design customization based on choice of *duration*, *technologies* and *approach*.

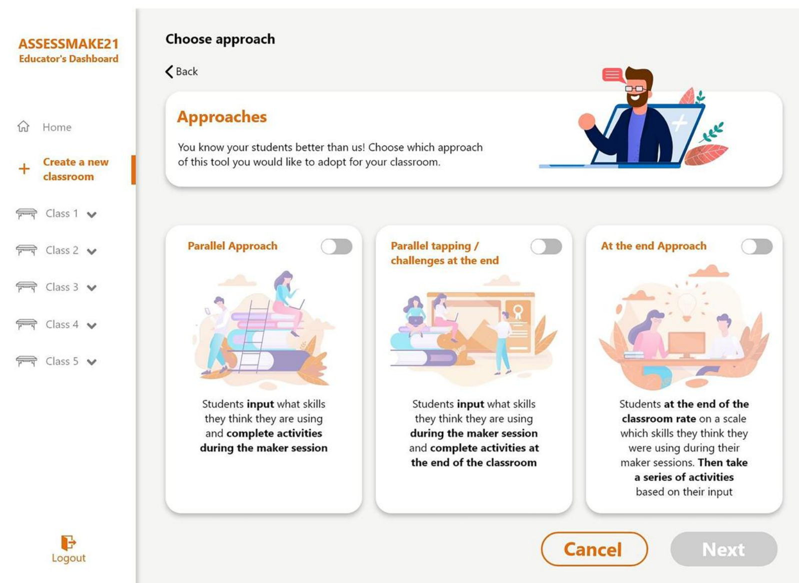

Figure 8. Educator's platform learning design customization based on choice of *approach*.

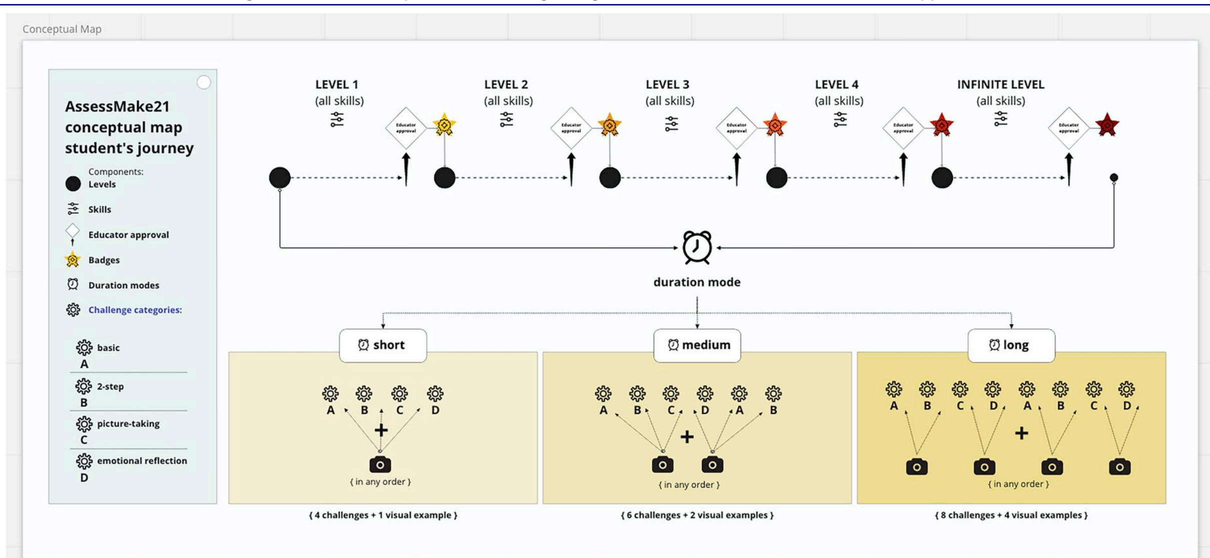

Figure 9. Conceptual map of learner's journey involving various challenge categories in different duration modes.

(*continued*)

Table 3. Continued.

Interaction requirements and tool features	
5) Visibility and monitoring of student badge requests and progress (Educator's dashboard) The tool should facilitate real-time overviews of: a. the students' progress, based on their individual responses and produced artifacts, informing teachers/facilitators about their overall tool engagement (inactive/active/super-active). b. students' completed levels and badge requests awaiting educator authorization. c. statistical data, graphs, and visuals reflecting individual, group, or entire class progress.	*Progress overview.* Allows teachers to form a synopsis for each student (Figure 10), group, or classroom progress (Figure 11) including the skills used/developed, activities, visual examples, and written self-reflections. *Badge requests & status*. Overview of students' badge requests, activity status, skills progress, and technologies used (Figure 10).

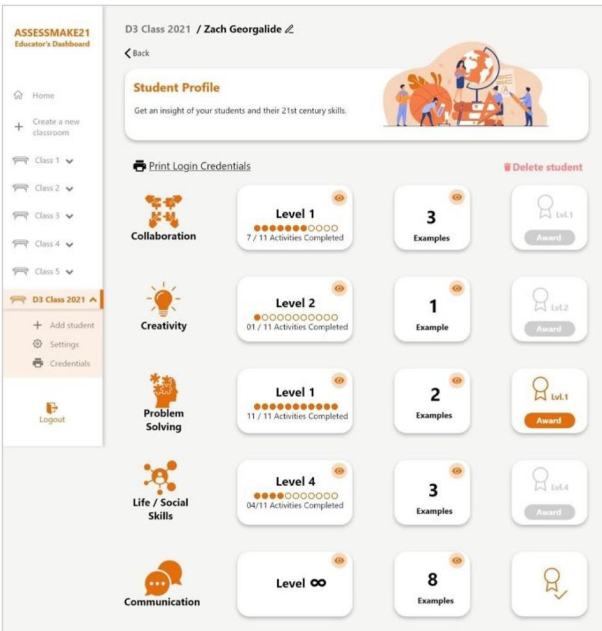

Figure 10. Individual student progress & badges overview in the educator's platform.

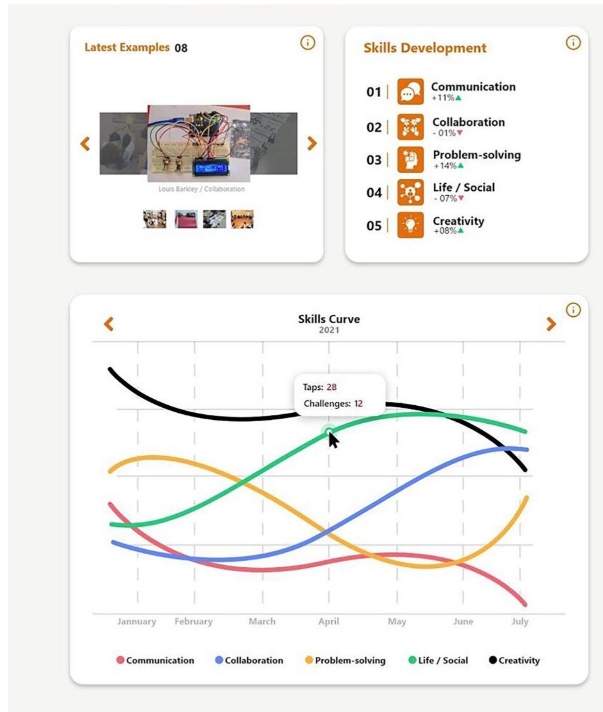

Figure 11. Class progress overview in the educator's platform.

4.2.2. Functional requirements and tool features

Functional requirements reflect the underlying functionality that supports the *Interaction design* requirements and features in Assessmake21. These are detailed in Table 4 below.

Table 4. Assessmake21 functional requirements, tool features and prototypes.

Functional requirements & tool features	
Design requirement	User interface feature - Assessmake21
1) Various devices and operating systems The tool should run smoothly on multiple devices. To avoid native app development (i.e., versions for specific OS), it should be implemented as a browser-based web app. While tablets and smartphones have built-in cameras, required for certain tool activities, students working on desktop computers should be able to use their own (or peers') smartphones for picture-taking and uploading to the tool.	*Browser-based tool.* The tool is web-based, runs smoothly on any browser and multiple devices.
2) Manual or automatic creation of class lists (Educator's dashboard) The tool needs to facilitate basic administrative processes by allowing: a. the *import* of spreadsheets and automatic creation of class lists and login codes/accounts for students b. the *manual* registration of students if needed c. common class *list editing features* (add/delete/edit) for the educator	*Setup & administration.* Allows teachers to create classrooms by importing class list files (*.csv) and generating automatic login codes for students. It also facilitates the creation of student sub-groups through drag-and-drop functionality to help review collective performances and skill development (Figure 12).
3) Multiple classrooms and groups (Educator's dashboard) The tool needs to allow the setup and management of multiple types of classrooms, as well as teams/groups through a single educator account.	See *Setup & administration* above

(*continued*)

Table 4. Continued.

Functional requirements & tool features

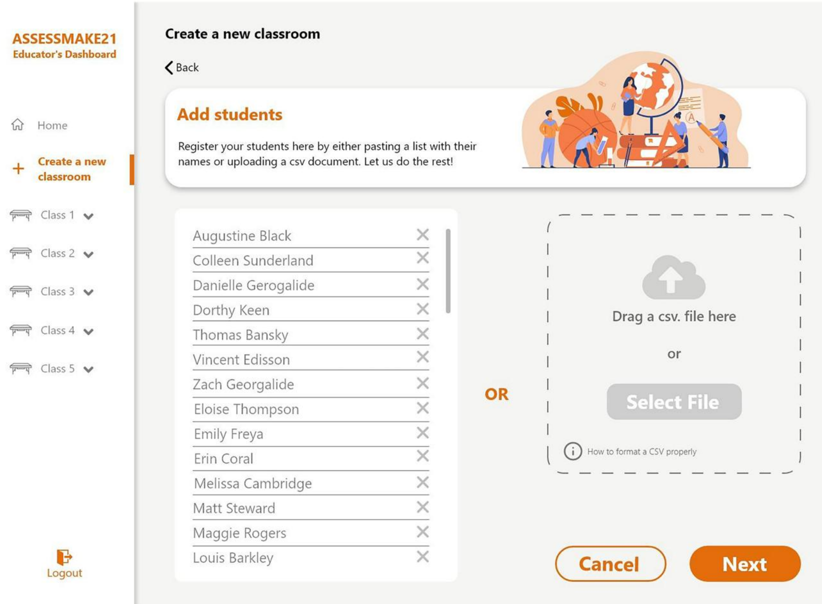

Figure 12. Multiple classes, class list file import, and automatic creation of login codes in the educator's platform.

4.2.3. Phenomenological requirements and tool features

Phenomenological requirements address the socio-emotional needs and impact that Assessmake21 is expected to have on users. These are detailed in Table 5 below.

Table 5. Assessmake21 phenomenological requirements, tool features and prototypes.

Phenomenological requirements & tool features

Design requirement	User interface feature - Assessmake21
1) Create confidence in tool usage The tool should provide a thorough, yet simple, explanation of its purpose, and demonstrate the "ways it can be used". This should be lightweight and entertaining, e.g., as a "*show me around*" video that takes users on a brief tour of the tool.	See Table 3, *Information points* (Figure 13, Figure 14)

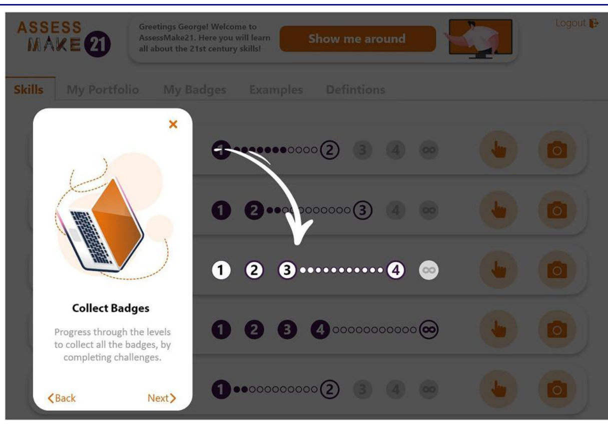

Figure 13. 'Show me around' badge feature demonstration.

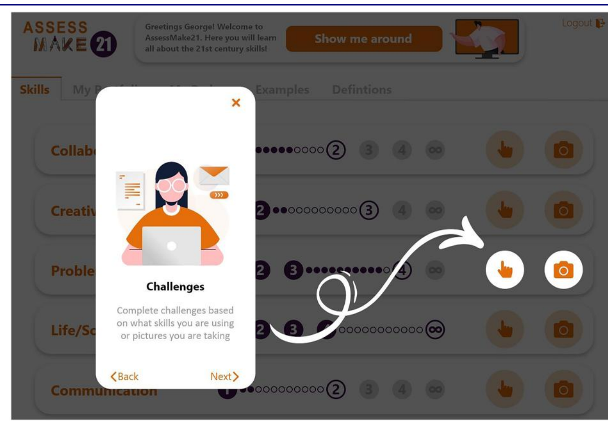

Figure 14. 'Show me around' challenges feature demonstration.

Design requirement	User interface feature - Assessmake21
2) Create confidence in skills identification The tool should provide clear definitions of each skill, its characteristics, and associated examples through pictured artifacts representing specific skill(s) and explanatory text.	See Table 3, *Information points* (Figure 15, Figure 16)

(*continued*)

Table 5. Continued.

Phenomenological requirements & tool features

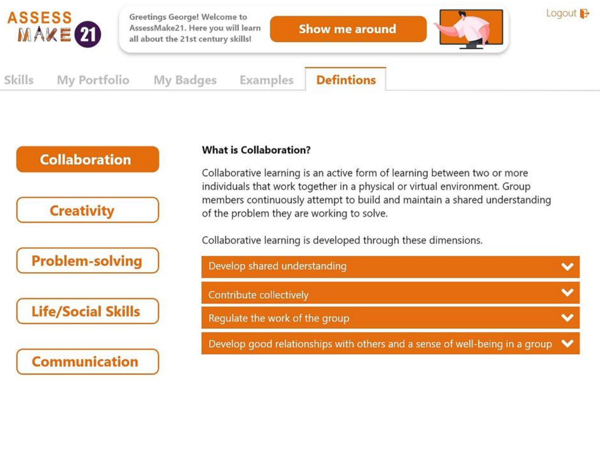

Figure 15. Information point: skill definition explanatory text.

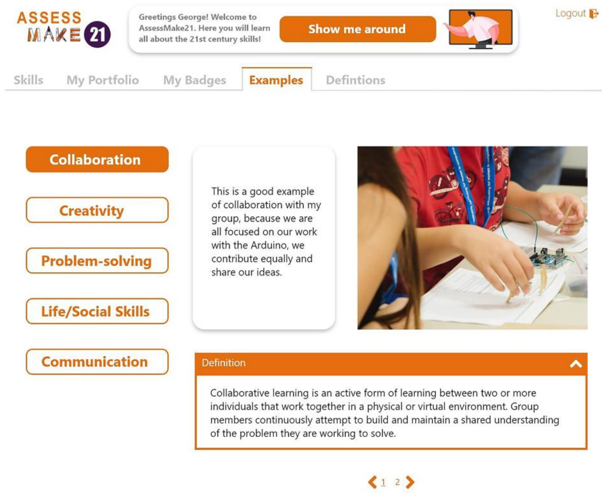

Figure 16. Information point: skill visual artifact examples.

Phenomenological requirements	Tool features
3) Encourage student engagement (rewards) The tool should present a gamified course of actions through levels that "unlock" rewards upon completion. Students may request a digital badge from their educator(s), who can approve or reject these using the Educator's platform. Level-completion badges should feature explicit visual properties (*Level: Bronze, Level 2: Silver, Level 3: Gold, Level 4: Platinum*) to steer excitement and ensure continuation. Educators can convert these badges into real-life prizes at the end of their session(s) to promote tool engagement, if they wish.	See Table 3, *Badges* (Figure 17)

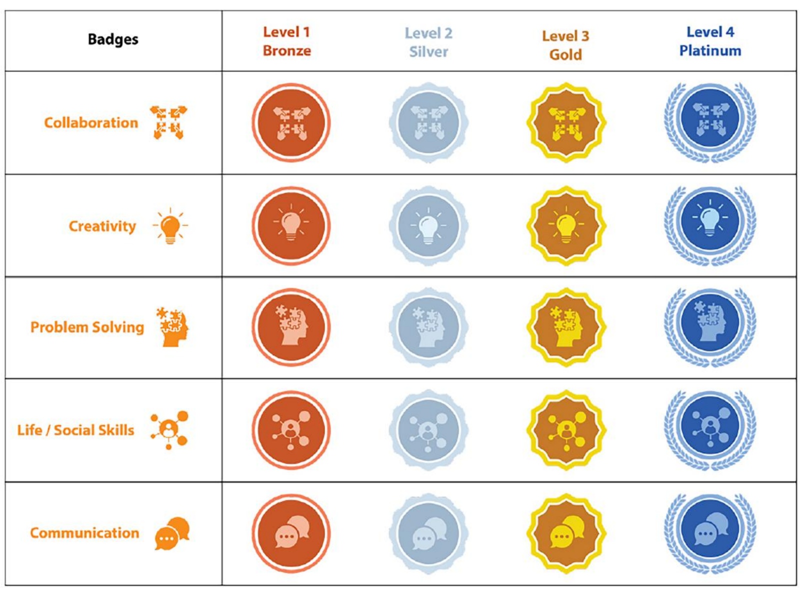

Figure 17. 4-level completion digital badges for all skills.

Phenomenological requirements	Tool features
4) Provide native language support The tool should facilitate native language support for better communication and interaction.	Language. The tool is currently available in three languages and affords easy integration of new languages.

5. Discussion

Few studies report on the design of educational technology tools from start-to-end, serving as a blueprint for digital learning products. This design case reports on the creation of a digital self-assessment tool to drive learners to develop and self-reflect on their 21st-century skills development in maker learning contexts. The work captures and documents the critical design decisions, discussed within the scope of the study's overarching research objectives.

Addressing research objective RQ1 (*What are the activities involved in the Assessmake21 design process?*), we provide a comprehensive account of the design activities performed for Assessmake21. Our design case demonstrates how the core team, considered theoretical and pedagogical perspectives and drew on the team's experience with maker education, user-centred, and learning experience design methodologies, to create a digital tool that respects the needs of all end users. While it does come as a limitation of this study, as well as the objective of parallel work, that "the learner" was not directly involved in the design team, we posit that the design activities incorporated learner input represented through the perceptions and feedback of their maker educators/facilitators. Our objectives align with those of Turakhia et al. (2024) who stress the importance of drawing on the educators' perspectives, not only the learners', to unpack critical insights of makerspace learning. This represents a holistic approach to design, acknowledging that the user is not merely the learner, since educators are often "ignored as both facilitators and end-users" (McCarthy et al., 2020). It is also worth noting that Assessmake21 was empirically tested with learners in real- life settings, as part of parallel work (Miliou et al., 2024). Despite some challenges related to conceptual and language comprehension, findings from this work showed that it effectively increased students' awareness of their skills, while gamification features helped maintain sustained engagement in self-reflection.

To structure the activities in this design case, we employed Hartson's and Pyla's (2012) methodological UX process model, through four distinct phases, emphasizing iterated collaboration within each one to improve the design. Our choice, informed through comparisons with similar models, like Lean UX (Gothelf & Lean, 2013) and the "Five Planes of UX" (Garrett, n.d.) models (section 2.4), was grounded in various factors. First, Lean UX's focus on the rapid development and testing of MVPs within the consumer market did not align with our objectives. Assessmake21 builds on a pre-existing MVP, SkillTrack! (Kipp et al., 2018) whose value and effectiveness in fostering reflection had already been validated. We remind the reader that Assessmake21 is intended for makerspace settings and SkillTrack! for general K-12 school contexts. Second, we found Lean UX to oversimplify the complexities of the UX design process, with less emphasis on detailed documentation, which was a critical requirement for our multi-stakeholder, long-term funded initiative (Tonkin et al., 2018). Third, we identified the importance of well-structured *analytical* and *evaluative* activities for feedback gathering from a diverse set of participants throughout our project. In this context, we initially considered the "Five Planes of UX" (Garrett, n.d.) due to its flexibility and adaptability (Sexton, n.d.). However, based on its limited focus on iterative feedback (through distinct analysis and evaluation phases) and the absence of clear implementation recommendations, we ultimately decided against this option. In contrast, the methodological UX process model (Hartson & Pyla, 2012) presented core phases for Analysis and Evaluation and supported micro-evaluative activities (i.e., contextual inquiry), methods (i.e., interviews) and techniques (i.e., semi-structured) within all phases (Figure 1). This offered the required direction and level of detail to meet the needs of our project. Fourth, the employed model's systematic, yet flexible nature allowed for the integration of other/complementary methodologies and components (i.e., codesign) in response to specific project needs, thereby enhancing its effectiveness in alternative research perspectives. The freedom granted for the loose or strict adaptation of the UX process model in this case, echoes its authors' assertion, that design experts can take shortcuts or make creative modifications to it depending on their objectives (Hartson & Pyla, 2012). Overall, the design team perceived the chosen model as "a highly structured framework that orchestrates the many different design and evaluative stages of system or product completion" (Franklin, 2013). A critical component offered by this model is its integrated 'requirements taxonomy', discussed next.

Addressing research objective RQ2 (*What are the design requirements and respective tool features resulting from this process?*) like Iwata et al. (2020), we adopted both a *theory-driven* and *data-driven* approach for the design of Assessmake21. We used Hartson's and Pyla's (2012) proposed interaction design requirements (IDR) taxonomy to translate theoretical and contextual evidence into design requirements, classifying them into *interaction design*, *functional*, and *phenomenological* requirements. The *interaction design* and *functional* requirements sought to ensure the tool's adaptability across diverse practical and learning contexts. The *phenomenological* requirements prioritized the learner's emotional and reflective needs (Stephanidis et al., 2019). The combined requirements resulted in key features like a) *skills tapping*, enabling a personalized experience based on the learner's understanding, pace, and aptitude, b) *information points*, clarifying the skills' dimensions and offering practical ways to measure them, and c) *real-time feedback*, supporting reflection through visual progress tracking, artifact portfolios, and earned badges. These features aimed to progressively support self-reflection and metacognitive knowledge-building for learners (Vann & Tawfik, 2020), while providing educators with reviewing and monitoring aids.

It was crucial for us to follow a systematic approach to requirements engineering, facilitated through the IDR taxonomy, to account for both *usability* (pragmatic) and *phenomenological* (emotional) perspectives in the learning experience. While usability-oriented approaches typically prioritize *effectiveness*, *efficiency*, and *user-satisfaction* (ISO, 2018; Nielsen, 1994; Pellas et al., 2021; Vredenburg et al., 2002), they often overlook value-sensitive perspectives of LXD which seek to "reflect users' core values and needs" (Roschelle et al., 2006). Addressing this limitation, the IDR taxonomy helped integrate the rich phenomenological evidence from various makerspace locations and contexts (different countries, formal/non-formal) into Assessmake21's design, drawing on the team's diverse multicultural backgrounds (Petrie & Bevan, 2009; Tosi, 2019).

Our approach aligns with Turakhia et al.'s (2024), who underscored the importance of incorporating a) the educators' perspectives, alongside those of learners to capture critical maker learning dynamics, and b) multi-location evidence to ensure meaningful and ecologically valid insights. Similar to our study, they also conducted interviews with makerspace instructors to inform the design of learning technologies for makerspaces, aiming to foster *reflection* (Turakhia et al., 2022; 2024). However, their focus pertained to *reflection* on general *maker skills* rather than *21st-century* skills. For older groups, such as university students (their study's target group), distinguishing between maker skills and 21st-century skills may be unnecessary, as the two are inherently connected, according to relevant bibliography (Iwata et al., 2020; Rayna & Striukova, 2021). Nonetheless, further research suggests that younger students require more structured support to engage in self-reflection. This aligns with findings from SkillTrack!'s evaluation, which highlighted language comprehension challenges among lower-grade learners (Bowler & Champagne, 2016; Kipp et al., 2018). This is perhaps due to the fact that while SkillTrack! was designed for the entire K-12 context, its design guidelines were primarily informed by relevant literature rather than (or combined to) contextual inquiry (SkillTrack! employed summative evaluation after its development). To address these challenges Assessmake21's requirements prioritize the explicit differentiation of complex 21st-century skills and terminology through clear explanations, simplified vocabulary, and practical examples. Additionally, while existing bibliography served as a strong theoretical foundation, Assessmake21's design requirements were continuously shaped by real-world evidence, from project initiation and throughout its entire lifecycle, to ensure a deeper understanding of maker learning reflection.

Finally, ad-hoc design planning may serve simple or short-term projects well. However, comprehensive frameworks, such as the UX process model and the IDR taxonomy, can provide systematic guidance for designing and analysing complex, longitudinal, and multistakeholder projects. In this design case we highlighted the value of structuring and documenting the entire design process using such a framework. Overall this approach enabled us to design a tool that a) supports an engaging and sustained process of skills identification and self-reflection for learners, and b) enables educators and facilitators to customise and manage the learning design and evaluate the learners' efforts through a flexible interface that adapts to various educational settings and constraints (Chang & Kuwata, 2020; Georgiou & Ioannou, 2021; Ioannou et al., 2024).

5.1. Contributions

This design case provides a detailed account of the end-to-end design process for a tailored self-reflection tool for makerspace learning. The study documents the integration of *theory-driven* and *data-driven* insights within a rigorous and well-structured design process. From a practical standpoint, addressing the needs of a large educational technology project, it serves as a *blueprint* for longitudinal, multi-stakeholder, and multicultural projects with similar objectives. From a theoretical standpoint, the study's grounding in key pedagogical theories, as well as the conceptual and methodological support from the user experience and learning design disciplines, helps enrich the learning experience design scholarship. Additionally, the study makes significant contributions to a new wave of technology research that places emphasis on *affective* factors in human computer interaction and learning experience design (Schmidt & Huang, 2022; Stephanidis et al., 2019). Future directions for this work include the integration and evaluation of the tool with a more diverse user base, the investigation of its long-term impact on learners' 21st-century skills development, and the integration of artificial intelligence (AI) to enhance and evaluate the design practice, the outcomes, and their impact on learners.

5.2. Limitations

This study is limited due to a few factors. First, as part of a larger body of a five-part DBR work, it requires interlinking with parallel studies to provide the reader with a more comprehensive understanding of its findings. It also represents a design case, by adopting a horizontal (process-oriented) approach to its reporting, rather than delving deeper into the pedagogical and conceptual underpinnings of the design or discussing the outcomes from strongly held theoretical perspectives.

Second, the limited involvement of learners in the initial phases of the project (*Assessment and Tool Design* intellectual output), caused by the COVID-19 restrictions, is an additional limitation. During this stage, the learners' perspectives were represented through their educators and makerspace facilitators. Later stages, like the "*Pilots and Evaluation*" intellectual outputs of the project invited learners to provide feedback after using the tool in their maker classrooms, which in turn, informed Assessmake21's development.

5.3. Conclusion

In this study we integrate pedagogical grounding with human-centred and socio-culturally sensitive evidence to guide the design of a digital tool that promotes self-reflection in makerspaces. Through our design case, we highlight the importance of systematic design models in analysing and organising the diverse information that is characteristic of complex longitudinal and multi-stakeholder projects. Using a structured model-based design process and an interaction design requirements taxonomy, we aimed to balance the *pragmatic* and *emotional* aspects of the tool's learning experience. Our approach provides a foundation for technologists and designers to expand upon in their own initiatives. This work adds to the growing conversation in the areas of learning experience design, as research which integrates multiple disciplines, methodological directions, and theoretical perspectives (Schmidt & Huang, 2022). Meanwhile this field is rapidly expanding with the use of Artificial Intelligence (AI) which requires openness to future *design practices* (i.e., automated prototypes and synthetic user-testing) as well as the *design outcomes*, informed by the possibilities of this new technology. This study is part of a broader design-based research that aims to make an empirical contribution to maker education and assessment concerning 21st-century learning.

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Author contributions

CRediT: **Aekaterini Mavri**: Conceptualization, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing; **Andri Ioannou**: Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – review & editing; **Andreas Kitsis**: Conceptualization, Investigation, Resources, Software, Visualization.

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ORCID

Aekaterini Mavri http://orcid.org/0000-0002-5076-5891
Andri Ioannou http://orcid.org/0000-0002-3570-6578

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About the authors

Aekaterini Mavri is an Assistant Professor at the Department of Multimedia & Graphic Arts, Cyprus University of Technology, co-director of Cyprus Interaction Lab, and researcher at CYENS. With extensive industry experience, her research focuses on UX/UI and Learning Experience Design, emphasizing university-industry learning models and future-ready skills in STEAM education.

Andri Ioannou is a Professor of Learning Design and Technology at the Cyprus University of Technology and the CYENS Centre of Excellence. Via the Cyprus Interaction Lab (https://www.cyprusinteractionlab.com/), Andri's research contributes to key areas of educational technology, technology enhanced learning, learning (experience) design, and digital transformation.

Andreas Kitsi holds an MSc in Interaction Design from Cyprus University of Technology and Tallinn University and a BA in Multimedia and Graphic Design from Cyprus University of Technology. As a UI/UX designer, his practice and research include UX design, UI design, usability, and user testing in product development.