Durall Gazulla, Eva; Bauters, Merja; Hietala, Iida; Leinonen, Teemu; Kapros, Evangelos

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Co-creation and co-design in technology-enhanced learning: Innovating science learning outside the classroom

Eva Durall[1], Merja Bauters[1], Iida Hietala[1], Teemu Leinonen[1], Evangelos Kapros[2]

[1] School of Arts, Design and Architecture, Aalto University, Otaniementie 14, 02150 Espoo, Finland
[2] Science Gallery, Trinity College Dublin, the University of Dublin, Pearse Street, D02 Ireland
{eva.durall, merja.bauters, iida.hietala, teemu.leinonen}@aalto.fi
ekapros@tcd.ie

Abstract. Innovation in technology-enhanced learning (TEL) is a complex process that requires the active involvement of diverse actors. This paper elaborates on two design innovation approaches that call for the active involvement of stakeholders: co-creation and co-design. While co-creation and co-design are well aligned, they are rooted in different traditions. We argue that co-creation and co-design can contribute to TEL innovation, and we present a design research case based on a research and innovation project that uses co-creation and co-design to innovate in science learning outside the classroom. Based on a qualitative analysis of the project co-creation and co-design outputs, we elaborate on the key differences between co-creation and co-design and highlight the main implications these differences have for TEL innovation.

Keywords: TEL innovation, co-creation, co-design, science learning

1 Introduction

Innovation in learning and education is a complex phenomenon. A common challenge in designing solutions is that they often work well at a local level in a specific context but are difficult to scale and make sustainable given a diversity of settings [1], [2], [3], [4], [5]. In order to respond to these challenges, scholars have advocated for the involvement of education stakeholders in the innovation process [6], [7], [8].

Co-creation and co-design are two approaches to innovation that build on such active involvement [9], [10]. While co-creation and co-design have gained popularity within design and innovation processes, the terms have also been used in other settings. For instance, practices based on co-creation can be found in marketing, healthcare, urban planning, engineering, design, and knowledge building. Although the emphasis is placed on joint creation, co-creation has been used with different aims depending on the context in which it has been adopted. In particular, co-creation has been used to create value and enhance engagement, collective intelligence, and creativity. [10], [11], [12]. Also, as [13] suggests, co-creation can help leverage open, social, and network resources. Unfortunately, quite often, the different understandings of co-creation are left implicit and accepted without further problematization. Therefore, the discussion hinders relevant debates on the opportunities and challenges offered by co-creation.

In technology-enhanced learning (TEL), co-creation has been understood as the co-production of knowledge, which is often achieved through artifacts such as wikis, as well as collaborative files and media creation [14], [15], [16]. Although this approach has shown promising results in terms of leveraging collective creativity, little attention has been paid to co-creation as a part of the innovation process in the design of learning environments and tools [17]. In contrast, other approaches based on collaboration, such as co-design and participatory design, have been adopted to support TEL innovation processes [18], [19], [20], [21].

Co-design is influenced by the user-centered design (UCD) tradition, which advocates for centering each phase of the design process on the users and their needs. Similar way as UCD, co-design aims to respond to the users need to ensure that the tools and services designed are useful and usable for those people who are expected to benefit from the design outcomes [22]. Thus, co-design aligns well with learner-centered design [23] as the focus is on designing usable and useful solutions that respond to users' needs.

In co-design, scholars have also argued for involving other people who may be directly or indirectly affected by the outcome of a project. Usually, these people are referred to as stakeholders. In TEL, co-design has proven useful in fostering stakeholders' engagement, collaboration, and empowerment [24], [25], [26]. In innovation processes, co-design has also been considered valuable because it can support the faster and more effective adoption of solutions [21], [27].

In this paper, we focus on co-creation and co-design as ways of structuring TEL innovation. We elaborate on the differences and similarities between co-creation and co-design based on a case that uses co-creation and co-design in designing tools and services that support innovation in science learning outside the classroom. We discuss the implications that co-creation and co-design have for TEL and highlight several opportunities and challenges.

2 Theoretical Background

2.1 Co-Creation and Co-Design Approaches

In technology and service design, the terms "co-creation" and "co-design" have frequently been used as synonyms. While, in both cases, there is a strong emphasis on the active involvement and collaboration of the people to whom the design products and services are addressed, it is important to note that co-creation and co-design are rooted in different disciplines and therefore, their vocabularies and focuses vary [28]. Whereas co-design originates in the design field and builds on existing traditions such as participatory design, cooperative design, and user-centered design, the term "co-creation" was originally developed within business studies and marketing. In this section, we elaborate on the differences between co-creation and co-design based on their aims, assumptions, and adoption times (see Table 1).

The different traditions from which co-creation and co-design stem have strong repercussions on their aims. Thus, while the production and retention of value is a central aspect of co-creation, the relations between the designers and those who would benefit from the design are at the center of co-design [28].

Table 1. Summary of differences between co-creation and co-design.

	Co-creation	Co-design
Origin	Business and marketing.	Design practice and theory.
Actors	Firms and consumers.	Designers, end-users, and stakeholders.
Aim	Joint production of value.	Developing shared understanding, making sense, producing design ideas, and solutions.
Assumptions	Consumers are creators of value.	People are creative and experts of their own experiences.
Adoption time	Throughout the interaction cycle, especially during use.	As part of design-related processes, typically at early stages.

Co-creation is based on the marketing and management scholarship, and it primarily refers to companies interacting and collaborating with their consumers in order to create reciprocal value. This challenges traditional views in business disciplines, which understand the market as a space for exchange: companies offer their products and services to passive consumers, without involving them in the process of designing and manufacturing these offerings. Today, however, the consumer is considered to be an active, informed, and connected actor who negotiates and co-creates value together with the company [11], [29], [30]. According to [29] and [31], this interaction enables co-creation, which could bring value to consumers, essentially in the form of personalized and meaningful experiences, as well as in a wider range of choice and suitable prices.

In business and marketing, the concept of value is crucial. Although scholars have distinguished between value-in-exchange and value-in-use, from a general perspective, the term “value” refers to the consumer’s experience of feeling good, accepted, or better than they did before [32], [33]. Naturally, in the context of business, this interaction could benefit the company and lead to competitive advantage [34]. Another formulation of value co-creation in the field of marketing is service-dominant logic (S-D or SDL), in which value is seen to be continuously co-created by a network of actors, especially in the context of services [35], [36].

In co-design, the focus of interest lies in the collaboration between designers, end-users, and stakeholders because this is considered crucial in building a shared understanding and making sense of a given situation, as well as creating design ideas that may produce a positive change in the current situation [37]. It is indeed possible to identify different approaches to co-design. While the active involvement of the design beneficiaries is a central element in all of them, some perspectives stress democratic participation and user empowerment (see [38] and [39]) because they are influenced by the UCD and participatory design traditions.

The democratization of design processes has also been raised as an issue in end-user innovation. In this context, scholars have called for supporting high levels of end-user participation from the early stages [40], [41], [42]. To this purpose, specific tools such as toolkits have been suggested in order to help end-users design products according to their needs and wishes [43]. In business innovation, tools such as the Business Model Canvas are commonly used in co-creation sessions, in which businesses and other stakeholders model the value proposition of an enterprise [44].

From another perspective, co-design has been understood as a collaborative creation process between designers and end-users [12], [23]. Within this approach, special attention is paid to methods and tools because they are key in supporting the designers' and end-users' active participation and sharing [45]. In order to ensure that design outcomes respond to people's needs and connect to their experiences, some voices have advocated for including a diversity of stakeholders, in addition to the people who are expected to be directly affected by the design solutions [12].

In co-design processes, designers dedicate a great effort to structuring collaboration. The underlying assumption that justifies such efforts is that people are experts regarding their own experiences. Therefore, to develop successful designs, it is critical to recognize and build on people's expertise [12].

Co-creation processes build on the assumption that consumers play an active part in creating value [29], [32], [33], [35], [46]. To understand how value is co-created, it is necessary to consider consumers' previous experiences with resources, processes, outcomes, and contexts [47], [48]. The role of companies in co-creation processes is to focus on building and facilitating environments in which consumers can co-create their own experiences. For instance, by following the DART model of value co-creation, consisting of dialogue (D), access (A), risk assessment (R), and transparency (T), companies can create a suitable context that allows consumers to become collaborators [29], [30].

Taking time to develop shared experiences is a critical part of co-design and co-creation processes [22]. To co-create value and co-shape consumers' expectations, firms must engage in a continuous dialogue with their customers. From this perspective, co-creation experiences should occur at diverse points in the interaction cycle between the company and its customers. [29]. Other views on co-creation have claimed that it "is through use and during usage that value emerges or is created" [33].

Co-creation can occur throughout the interaction cycle and especially at later stages; co-design workshops tend to occur throughout the design process in order to engage designers and non-designers in creative work around complex challenges [49]. A popular format used in co-design consists of workshops in which designers and stakeholders engage in joint exploration to identify the opportunities and challenges related to the issues involved in a particular situation.

Despite their differences, co-creation and co-design share an interest in shifting the attention from the final product to the process [33], [50], [51]. Supporting collaboration is another common element of both co-creation and co-design. In this regard, both approaches recognize that in order to support authentic collaboration, it is necessary to build horizontal relations that enable various parties share information and learn from one another on equal terms.

2.2 Co-Creation and Co-Design in Technology-Enhanced Learning Innovation

In education and learning, innovation has been described as the transformation of social practices in knowledge work. From this viewpoint, technology has the potential to enhance learning impacting the social practices surrounding knowledge creation, as well as strengthening communities of practice. [52].

Since the 1990s, the use of digital technology in learning has been referred to as TEL [53]. In this context, scholars have also highlighted the need to understand TEL as a complex socio-technical system [54]. Thus, innovation in TEL should be regarded as an ecology of practices that go beyond technical issues and requires an interdisciplinary research approach [7], [53], [54]. As [7] suggests, TEL innovations should take into consideration the relationships between pedagogy and technology, existing practices, and the communities involved, as well as the local learning ecology and the wider context, which are affected by policy, funding models, and revenue mechanisms.

In TEL innovation and research, bringing diverse stakeholders into the process has been advocated (see, for instance, the STELLAR project described in [55]). As discussed in the previous sections of this paper, this is similar to co-creation in which various stakeholders' needs and expectations regarding teaching, learning, and the role of technology should be taken into consideration [20], [56]. Simultaneously, funding bodies such as the European Union are increasingly urging that research and innovation initiatives include societal actors throughout the research and innovation cycle[1].

In the innovation literature, co-creation has been defined as a systemic process that builds upon stakeholders' involvement [57], [58]. As [57] claims, co-creation requires wide participation, new forms of generating qualitative knowledge, and a design-driven approach to innovation. In TEL innovation, co-design has also been adopted because it creates opportunities to actively involve education stakeholders and draw on their expertise [22], [59], [60]. While recognizing the value and importance of stakeholder involvement, some voices have warned that co-design and co-creation processes in TEL innovation should go beyond appropriate stakeholder selection and strongly highlight content or knowledge by focusing on the "Iron Triangle" of educative relationships (learners-instructors-knowledge) [61].

While acknowledging the need to develop learning designs that are pedagogically inclusive and appropriate, in this paper, we argue that co-creation and co-design can be used in TEL innovation because both approaches build on people's active involvement to ensure the effectiveness and sustainability of the design solutions.

3 Design Case

3.1 Context

The fast pace of scientific and technological development poses several challenges for science education. On the one hand, there is an urgent need to prepare young people for emerging careers in science and technology. On the other hand, people need to develop scientific and technological literacy in order to make informed decisions and participate in democratic debates about the role of science and technology in society. To ensure people have opportunities to participate in societal debates about technology and access scientific careers, science education must go beyond traditional contexts, such as schools and other formal institutions, and consider other contexts outside the classroom that are based on non-formal and informal learning and can significantly contribute to people's learning about science.

The design case presented in this paper is part of a research and innovation project for supporting science learning outside the classroom, SySTEM 2020. The SySTEM 2020 project aims to increase understanding of science learning outside the classroom among children and teenagers aged from nine to 20 in Europe. The project seeks to map science learning initiatives and examine learners' journeys in order to design solutions that contribute to making science learning outside the classroom more inclusive and equitable. SySTEM 2020 includes partners from 19 countries and

[1] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation

involves a diversity of organizations focused on research and science education in non-formal and informal learning contexts.

In this section, we present the SySTEM 2020 project approach to co-creation and co-design in order to design innovative solutions that will improve science learning outside the classroom. We introduce the rationale for using co-creation and co-design to structure the project innovation process, and we devote special attention to the first co-design workshop organized with the project stakeholders.

3.2 Co-Creation in the Science Learning Network

Learning networks are created through the interactions between different actors. In attempting to discuss co-creation in the science learning network, it is useful to first consider the variety of contexts in which science learning is being delivered and the interactions between these contexts. The context in which science learning may happen can be described as formal, non-formal, and informal. As presented in [62], the key aspects that distinguish these contexts deal with the level of structure and organization of the learning activities, the explicit intent to learn, and the obtention of validation and certification (see table 2).

Table 2. Comparison between the key traits of formal, non-formal and informal learning.

	Structure	Explicit intent	Certification
Formal learning	Yes	Yes	Yes
Non-formal learning	Yes	Yes	No
Informal learning	No	No	No

The interactions between the formal, non-formal, and informal science learning environments are diverse and fluid [63], [64]. While schools and other educational institutions are considered parts of the formal education system, non-formal and informal learning refer to out-of-school or outside-the-classroom learning; however, defining out-of-school learning is not straightforward [65]. In this regard, it has been argued that the various learning domains (formal, non-formal, and informal) should be considered networked relations that extend beyond location boundaries [66]. Although the case reported herein focuses on the outside-the-classroom contexts, the multiple connections to diverse environments and actors make it challenging to define clear limits. The adoption of a network perspective was considered useful in acknowledging the complexity of science learning.

The dynamic exchanges that occur between the various environments and actors connected to science learning make us consider them a value network. As [67] indicates, actors in a value-network system must collaborate and learn together to be adaptive in the face of change. This collaboration becomes especially critical because the network is continuously changing due to aspects related to interest growth, as well as knowledge creation and dissemination [68]. Within this perspective, the science learning network might be regarded as a value network in which actors co-create learning in order to develop meaningful learning environments. By actively participating in these science learning environments people are able to gain scientific thinking skills and sustain their own scientific interests over time.

In a value network, co-creation requires involving people with different levels of expertise and interest [68]. A central aspect of the SySTEM 2020 project deals with supporting close work between the design researchers and the stakeholders. As [56] highlights, “empathy between co-creators is essential.” Thus, to design TEL innovations that support science learning in a variety of contexts outside formal education, it has been considered necessary to build on people's experiences, as well as to involve the key stakeholders throughout the process. In this case, the stakeholders are the organizations and groups connected to science learning, such as science museums, makerspaces, science centers, etc., as well as learners and their families (whether they are currently involved in science learning or not), educators, and facilitators.

The increasing rejection of passive roles and preference for more active roles, in which people have the freedom to create, has motivated a change in how the design space has been approached [69]. Some authors have pointed toward people's collective creativity as a new paradigm for solving complex and interdisciplinary problems [70], as well as for designing tools and services [69], [71]. In this project, co-creation is understood as a creative atmosphere in which designers, researchers, and stakeholders engage in co-design workshops where they collaboratively explore, develop a shared understanding, and generate solutions and design concepts for jointly identified challenges. Because of the strong focus on learning, the researchers, as well as many of the stakeholders, have a strong expertise in learning and science in non-formal and informal contexts. The activities framed as part of the project seek to leverage this expertise in order to filter the co-designed solutions.

To identify the diversity of actors involved in science education outside the classroom, one of the SySTEM 2020 project endeavors to support co-creation consisted of the design and development of an online map. The map has been created to collect information about non-formal science education organizations and the activities they offer in the field of Science, Technology, Engineering, Arts, and Mathematics (STEAM) (see Figure 1). In particular, special attention is paid to identify the collaborations between diverse types of organizations, and thus, visualize the non-formal science education network in 19 countries in Europe and the Middle East[2].

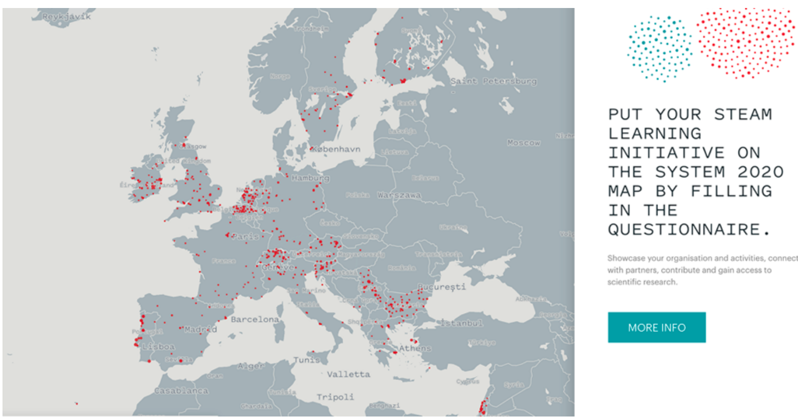

Fig. 1. Screen capture of the co-creation map on STEAM organizations and activities outside the classroom.

From certain points of view, the value of co-creation lies in that it allows the exploration of open-ended questions [56]. According to [56], this type of co-creation requires direct personal involvement through real-time, face-to-face interactions. In the following section, we describe the project's first co-design workshop, which

[2] All countries are European Union Member States, except for two. These two are Associated Countries, namely Israel and Serbia.

brought together researchers, designers, and stakeholders involved in the project. This co-design workshop was a key milestone of the ideation process, and it had a special focus on supporting participants in sharing experiences, developing collaborative sensemaking, and creating design solutions to improve some specific situation. The workshop was particularly relevant because it helped to move from the fuzzy front end to the definition of the design concepts. The term "fuzzy front end" was coined by Sanders and Stappers [12] to refer to the very early stage of a design process. This stage is characterized by high levels of ambiguity and uncertainty as the design problem and the opportunities have not been defined yet.

3.3 Co-design Workshop Goals and Participants

The first SySTEM 2020 co-design workshop with stakeholders such as project partners, learners, and other people involved in science learning outside the classroom was organized to find innovative solutions regarding science learning outside the classroom that support inclusion and engagement, as well as the assessment and recognition of learning in these contexts. In total, 51 people from 19 countries from Europe and the Middle East participated in the co-design sessions (see Figure 2).

Fig. 2. The project's first co-design workshop session.

The participants had diverse backgrounds and expertise, and this was reflected in the roles they undertook during the co-design sessions. Among the 51 participants, there were 29 people representing the project partner organizations, 12 young people (aged from 18 to 21 years old) who had been previously engaged in science learning activities at the project partner organizations, and eight external stakeholders. The external stakeholders were professionals involved in science learning (as coordinators, educators, or facilitators), but who were not engaged in the project.

The purpose of the co-design workshop was to create design concepts and solutions firmly based on the participants' collective understanding of the opportunities and challenges involved in non-formal and informal science learning. To achieve these objectives, participants shared their own experiences with others and elaborated on the perceived challenges together. The workshop set out to cultivate collective creativity by encouraging participants to ideate design solutions based on the opportunities they had previously identified.

The facilitation of the co-design workshop was arranged to support the participants' active participation and contribution. In total, six facilitators worked to guarantee that the participants felt comfortable expressing themselves and contributing to the co-design activities in a meaningful way. The participants were divided into groups based on the activities to be performed, and each group was designated a facilitator. Depending on the specific tasks to be accomplished, participants were assigned to specific subgroups.

The participants were asked to choose one of the workshop's themes based on their personal interests. The themes were (1) inclusion, (2) engagement, and (3) assessment and recognition. Although the participants had freedom to decide which group to join, they were instructed to avoid joining the same group as their fellows from their own organization. During the group formation, the facilitators checked that the groups were diverse in terms of age, gender, and roles.

3.4 Methods and Materials

Design thinking methods [72] (see Table 3) were applied to help the participants establish a shared understanding of a particular situation, then define, and finally, ideate solutions. For instance, methods such as mapping concepts, finding new opportunities and challenges, card sorting, clustering, and prioritization were used in defining and understanding the workshop themes of inclusion, engagement, and the assessment and recognition of science learning outside the classroom. After defining the themes and selecting one opportunity, the participants used techniques such as brainstorming and sketching to ideate solutions and thus improve science learning outside the classroom.

Table 3. Description of the methods used in the co-design workshop.

Method	Objective	Task
Mapping concepts	Defining, understanding	Each group of participants built a concept map for one specific theme. They started brainstorming the relevant concepts and elaborated their maps by clustering and filtering their contributions. This task was expected to help participants build a shared understanding of inclusion, engagement, and the assessment and recognition of science learning outside the classroom.
Finding new opportunities and challenges	Defining, understanding	Participants built on the concept maps developed in the previous task to identify opportunities and challenges connected to a specific theme. First, they started brainstorming, and then, they consolidated their lists by grouping and selecting the key opportunities and challenges.
Ranking and averaging the shared opportunities for prioritizing	Defining, understanding	Participants were asked to estimate the priority level for each opportunity based on the impact and difficulty of implementation. At first, this task was conducted individually. Then, the final ranking was defined by averaging the individual scores.
Ideating design solutions	Ideation	Several working groups were formed based on the opportunities ranked with the highest priority. Participants were guided to ideate solutions in light of a specific opportunity. Later, the solutions were peer-assessed and iterated before sharing them with the entire group.

Prior to the organization of the co-design workshop, the researchers conducted a contextual inquiry [19], [73] on science learning outside the classroom. During this contextual research, the researchers adopted a rapid ethnography approach [74] to understand the contexts, as well as the main actors, involved in science learning outside the classroom. The data collected through the field observations and interviews were analyzed and combined with previous research on science learning. This information helped to design the materials used during the co-design workshop. The materials[3] were used to inspire and scaffold participant discussions while triggering reflection on certain issues (see Table 4). To avoid an overly restrictive view of the issues, participants were encouraged to be critical and bring up the important matters they felt were missing from the discussion.

Table 4. Description of the materials used during the workshop.

Materials	Method	Description
A looping slideshow of the co-design workshop themes	Mapping concepts	Inspirational material that combined images and texts about the co-design workshop themes (inclusion, engagement, and the assessment and recognition of learning).
Proto-persona cards	Finding new opportunities and challenges	Six visual and textual portraits of fictional characters related to science learning in informal and non-formal learning environments.
'How Might We' cards	Finding new opportunities and challenges	Three decks of cards with open questions regarding challenges in science learning outside the classroom. Each deck contained 18 cards and was focused on a specific theme.
Ranking the opportunities I (individual scores table)	Ranking and averaging the shared opportunities in order of priority	A value matrix to assess the opportunities based on their impact and their difficulty of implementation. Participants assessed the consolidated opportunities individually.
Ranking the opportunities II (group averages table)	Ranking and averaging the shared opportunities in order of priority	Table to document the average of the prioritization of opportunities performed by participants individually.
Canvas for design solutions	Ideating design solutions	Template to document the design solutions. To support the systematic reporting of the solutions, participants were asked to provide information about different aspects of these solutions.
Directions for evaluating design solutions.	Ideating design solutions	Assessment criteria for analyzing the design solutions ideated. Participants were asked to use the guidelines to evaluate the utility, viability, and feasibility of the design solutions.

This research followed the Finnish National Board on Research Integrity TENK guidelines 2019. The research participants have been provided information about the SySTEM 2020 research well in advance and they were asked to give consent before taking part in the co-design workshop.

[3] The materials used during the co-design workshop are available in the project SySTEM 2020 website (https://system2020.education/resources/system-2020-helsinki-co-design-workshop-materials/)

4 Findings

The findings of this design case consist of the analysis of the co-creation and co-design outputs and their further elaboration into actions. In both cases, we have adopted a qualitative approach for assessing the outputs. First, we present and analyze the co-creation outputs which consist of the map on non-formal science education, and we indicate its potential impact for further co-creation actions based on our participant observations and the feedback provided by the stakeholders involved in the map campaign. Second, we present the solutions ideated during the co-design workshop around the themes of inclusion, engagement, and the assessment and recognition of science learning. We describe the themes identified during the analysis of the co-design workshop outputs, and we conclude by introducing the design principles generated based on the workshop results.

4.1 Co-creation Outputs

The SySTEM 2020 project's main co-creation output consists of an online platform in which organizations providing non-formal STEAM education can provide information about the activities they offer. To date, 2248 STEAM initiatives have been reported from 19 countries from Europe and the Middle East. These initiatives consist of 1063 organizations and 1185 activities offered to children and youngsters aged from nine to 20 (see Table 5).

Table 5. Number of organizations and activities by country that have been included in the SySTEM 2020 map to date of August 2019

Country	Number of organizations	Number of activities	Total number of entries
Austria	79	99	178
Belgium	55	45	100
Bulgaria	104	115	219
Finland	55	69	124
France	43	16	59
Germany	51	71	122
Greece	43	47	90
Ireland	76	61	137
Israel	63	54	117
Italy	41	24	65
Netherlands	84	68	152
Portugal	32	110	142
Serbia, Croatia, Montenegro, Macedonia, Albania	44	64	108
Slovenia	45	68	113
Spain	28	41	69
Sweden	73	54	127
Switzerland	59	94	153
United Kingdom	87	85	172
Total	1063	1185	2248

The SySTEM 2020 map offers different types of visualizations that enable science education stakeholders gain awareness of, for instance, the non-formal science education network, the collaborative relations among different organizations, as well as the range of topics and participation formats deployed. The map is a visualization tool that has the potential to strengthen the network and lead to further co-creation initiatives (see for instance, Figure 3 and Figure 4).

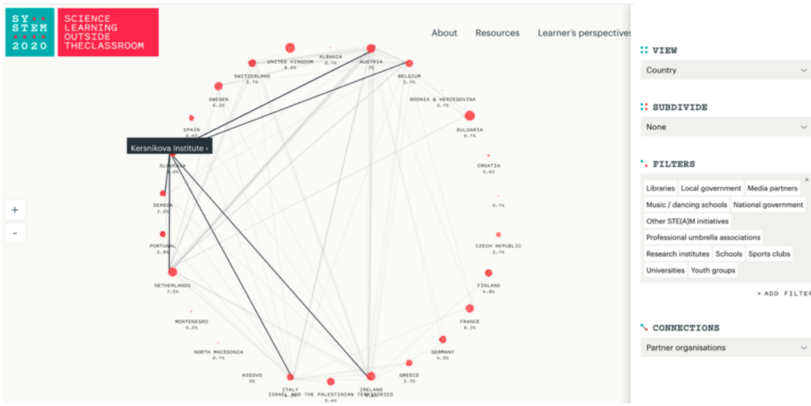

Fig. 3. Visualization of one of the non-formal science education organizations' European network through the SySTEM 2020 online map

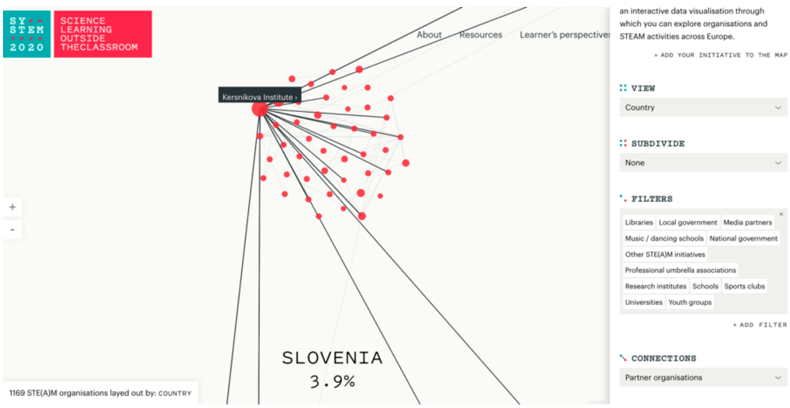

Fig. 4. Visualization of one of the non-formal science education organizations' national network through the SySTEM 2020 online map

While it is still early to assess the value that this co-creation output may bring to the science learning network, we can already report some seeds for new collaboration opportunities among the organizations listed in the SySTEM 2020 map. In particular, we consider that the following quote captures the potential impact of the map for enhancing co-creation in non-formal science education: "Some [of] Slovenian organizations have already contacted me saying they got many ideas from the map and find it extremely useful!".

4.2 Co-design Workshop Outputs

As outputs of the SySTEM 2020 co-design workshop, the participants ideated several design solutions (n=12). These solutions were either products or services related to the challenges and opportunities in science learning outside the classroom (see Table 6). During the ideation session, the participants assessed their solutions' levels of impact and potential for implementation to determine whether these solutions would be viable.

Table 6. List of the design solutions ideated for each of the co-design workshop themes.

Theme	Design Solution	Goals
Inclusion	"Improve your life" workshop network	- Make science approachable and relevant. - Include diverse communities and learners.
Inclusion	Implementation of diverse distribution channels through connections	- Make science approachable and relevant. - Include diverse communities and learners. - Demonstrate the value of building networks that connect diversity of actors.
Inclusion	Local Engagement Committee	- Promote and support STEAM learning among local communities and social minorities. - Support educators' training through knowledge sharing and reflection. - Include diverse communities and learners.
Inclusion	Guardians of Inclusion	- Foster guardians' active involvement in science learning activities. - Increase participation of minority groups in science learning. - Create awareness on the benefits of science learning for people's lives.
Engagement	LocalLearnLink	- Build networks of collaboration among researchers. technology developers and innovators. -Introduce diverse methods and skills to innovate in science learning. - Support the assessment of science learning in informal and non-formal learning environments.
Engagement	Failsafe: A festival celebrating failure	- Promote and support co-creation in science learning projects. - Encourage experimentation and risk-taking in science learning.
Engagement	Inquiry-based Learning	- Use inquiry to trigger science learning. - Advance learners' soft skills and creative thinking.
Engagement	Kitchen as a Lab	- Foster guardians' involvement in science learning activities. - Encourage a Do It Yourself (DIY) approach to science learning. - Trigger curiosity and open mindsets towards science.
Assessment and recognition	Free Day! Your Way!	- Promote a playful approach to science learning. - Help science learners develop autonomous learning skills. - Involve diverse communities and learners.
Assessment and recognition	MILA: My Informal Learning Accomplishments	- Enable diverse ways to assess and recognize learning. - Help learners gain awareness on their learning experiences.

Assessment and recognition	3 Step Method	- Encourage formative and participatory assessment. - Engage learners in critical thinking.
Assessment and recognition	License to Fail	- Promote positive learning experiences that build on failure. - Create tools and methods to support learning from failure.

The opportunities and solutions ideated during the workshop elaborated on some of the open questions presented in the workshop materials like in the "How might we" cards. Although it is possible to find links between the triggering materials and the workshop outputs, it is difficult to establish a direct relation as the range of issues and topics raised through the materials was broad and diverse. It is worth noting that the participants found the workshop materials useful for starting discussions and narrowing the topics down. After the workshop, the materials have been used by some of the project organizations to facilitate their own co-design sessions at their institutions and with their national networks of collaboration, even outside the scope of this project.

4.3 Design Principles for Supporting Science Learning Outside the Classroom

After the co-design workshop, the design researchers conducted a thematic analysis [75] of the design solutions ideated during the workshop. The examination of the ideated solutions presented at the end of the workshop, as well as the artefacts generated by the participants, enabled the identification of patterns of meaning — themes — that were transversal to the design solutions around inclusion, engagement, and the assessment and recognition of science learning outside the classroom. It is worth noting that although the participants focused on different issues and opportunities, the outputs had certain similarities. A good example of the high level of interconnection between the solutions (regardless of the theme they were focused on) can be found in the summary of the solutions around engagement in science learning outside the classroom made by one of the workshop participants: "I think we have identified three similarities in all four solutions. The first is that we want our solutions to be participatory, we want to have learners, beneficiaries actively be engaged in our programs. We want low barriers to our initiatives or incentives, so that they can enable easy access, and we would like to see that our processes are open-ended" (participant 1).

The definition of the themes followed an inductive, or bottom-up, approach [75]. Thus, special attention was paid to ensuring that the higher-level categorizations had a strong grounding in the data generated by participants in the workshop. The themes that emerged from the examination of the co-design outputs referred to diversity, collaboration, knowledge sharing and teacher training, outreach, learning strategies, and assessment methods and recognition. Participants shared a desire to make science approachable and relevant, and there were many references to the use of participatory approaches based on co-creation and co-design. For instance, in the final presentation of the solutions ideated around the theme of engagement, participants agreed that "a great deal of opportunities lie in the bottom-up approach" (participant 1).

Also, relying on local networks and locally available resources was strongly encouraged. While many of the solutions were built on the local resources, this was particularly clear in the case of the solutions ideated around the theme of inclusion. As one of the learners involved in the working groups summarized: "All the solutions involved local communities and the engagement of these local organizations" (participant 2).

Many of the solutions sought to support community building by fostering ownership and self-organization. Just as one of the learners ideating solutions around inclusion claimed, building on the members of the community expertise was a strength: “My group came up with a learning committee in the local council, they had like a subdivision to try and promote STEAM activities or like to try and put people from diverse backgrounds in the community because no one knows the community as good as the community itself” (participant 3).

Participants also emphasized the need to foster learners' self-confidence because this was considered key to their empowerment. Moreover, they stressed the importance of encouraging learners to have fun, to explore, and face the unexpected when engaging in science learning outside the classroom. For instance, one of the learners expressed the value of science learning in these contexts relating to “the freedom to explore, freedom that is capability to learn something new, capability to go outside of your background, outside of your field of study, not feel restricted and in that sense broaden your general knowledge of STEM and STEAM and engage with others” (participant 4).

Table 7. Design principles identified from the analysis of the co-design outputs.

Design Principle	Description
Celebrate diversity	Diversity exists at many levels, including the people involved in science, the contexts, the definition of science, and how one takes part in it. To benefit from diversity, one must create opportunities and facilitate environments that support various ways of being and relating to science.
Employ participatory methods	Learners and communities know what is relevant to them. Involve them from the beginning and make them a part of the process. Listen, adapt, and join the community.
Use existing resources	Start small, start local, and take advantage of what is easily accessible in the community. Do-It-Yourself and low-cost approaches can motivate people get started and engage in science learning based on their own knowledge levels and possibilities.
Bridge formal and informal science learning	Build networks of actors and environments connected to science learning. Take advantage of the possibilities of connecting formal, non-formal, and informal learning environments. Build on learners’ interests and support fun, free activities. Help learners pay attention to the process and avoid traditional school evaluation methods.
Encourage risk-taking and learning from failure	Foster exploration and experimentation. People learn from experience, and failure can teach great lessons if appropriately structured. Do not leave learners alone when facing the unexpected, and use those experiences to trigger their curiosity and creativity.
Sustain diverse competences	Science learning is not only about acquiring hard Science, Technology Engineering, and Mathematics (STEM) skills. Transverse competences such as creativity, collaboration, and communication are also important and enable diverse ways of engaging in science learning. Fostering these through transdisciplinary approaches such as STEAM will nourish the roots of a diverse, autonomous learning community.
Recognize learners’ accomplishments	Recognizing that learning is important because it creates opportunities for advancing education and accessing jobs and also fosters learners’ motivation and self-confidence. Support learners in gaining an awareness of their achievements and choosing an appropriately ambitious challenge to set for themselves.

Based on the themes identified in the co-design outputs, seven design principles (see Table 5) were formulated to guide further innovative TEL designs in science learning outside the classroom. The principles highlight intersecting ideas across the various opportunities and challenges connected to science learning outside the classroom that the participants explored during the workshop. The design principles capture participants' emphasis on supporting diversity and participation when designing activities in non-formal science education contexts. Other key ideas that influenced the definition of the principles are related to the use of available resources, connecting formal and informal learning environments, supporting risk-taking and learning from failure, helping learners develop diverse competences, and acknowledging learners' achievements (see Table 7).

In the project, the design principles function as concepts for prototypes (consisting of tools and services) and support further co-creation opportunities for innovating in science learning outside the classroom. In order to refine the concepts and improve the prototypes, additional co-design sessions (indicated as red dots in Figure 5) will be scheduled with stakeholders throughout the project (see Figure 5).

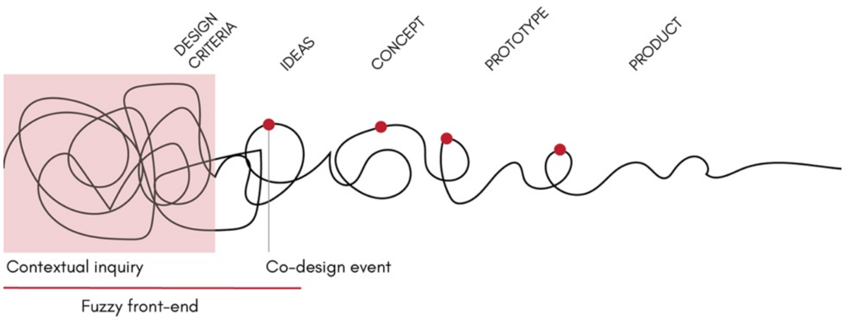

Fig. 5. The innovation design process deployed in the SySTEM 2020 project[4].

5 Discussion

In this section, we elaborate on the similarities and differences between co-creation and co-design, as well as their implications for TEL innovation. We build on our experiences from the SySTEM 2020 project's non-formal science education map and the first co-design workshop because it enables reflection regarding the opportunities and challenges that both approaches create in terms of developing innovative solutions.

5.1 Similarities between co-Creation and co-Design

Co-creation and co-design rely on the active involvement of stakeholders [23], [37], [76]. The active participation of end-users and stakeholders has been linked to a sense

[4] Figure 6 is an adaptation of Sanders and Stappers' visual representation of the design process [12].

of ownership over the problem and the solutions [37], [58], [77], which is key to the adoption and integration of such solutions in people's practices [20], [78]. Specifically, the stress placed on participation was one of the aspects that reached a higher level of consensus among the workshop participants. It is worth noting that after the workshop, some of the project stakeholders showed interest in using the co-design materials and knowing more about the facilitation process in order to conduct co-design sessions in their own practices. Despite it being too early to assess the impact and adoption of co-creation and co-design by science learning organizations, we may say that participatory approaches are considered key in supporting meaningful and sustainable actions.

Although participation does not guarantee stakeholders' ownership and appropriation of the design solutions, co-creation and co-design have been successful in shifting the attention from the outcomes to the process [9], [79]. That is why both approaches have gained popularity in innovation studies, in which the emphasis is placed on how to support change and the transformation processes that can improve such a situation [58], [80].

The similar mindset involved in co-creation and co-design makes both approaches suitable for structuring innovation processes in TEL. In particular, co-creation has been used as a strategy to create partnerships between students and academic staff [81], [82]. As [81] notes, co-creation in learning brings opportunities for high levels of engagement and shared responsibility among staff and students. In addition, co-creation helps students and staff gain a meta-cognitive awareness of learning and teaching processes [83]. In informal learning, FabLabs have been considered valuable for enabling citizens to engage in co-creation [84]. Co-design and participatory design have also been used to guide innovation in informal learning contexts [60] and in curriculum designs that embeds technology [85], [86], as well as to design assessment tools [22], [87] and collaborative mobile tools [88], [89]).

5.2 Differences between co-Creation and co-Design

While we believe that co-creation and co-design align well, we want to highlight several differences based on our experiences from the design case we have presented in this paper (see Table 8).

Table 8. Differences between co-creation and co-design in design-driven innovation.

	Co-creation	Co-design
Stakeholders' role	Creators.	Information providers, creative thinkers, evaluators of new ideas.
Designers' role	Coordinators, developers and providers of co-creation tools.	Facilitators, mediators.
Opportunities	Collective creativity, knowledge exchange, and social capital.	Design creativity, engagement, reflection and reflexivity, collective dialogue and negotiation.
Challenges	Risk of non-reciprocal relations in which stakeholders feel instrumentalized.	Balancing tensions and creating relationships of trust.

Co-creation and co-design challenge designers' and stakeholders' traditional roles, moving from expert-based, top-down decision-making to bottom-up processes in which stakeholders' active participation becomes crucial. In co-creation, the emphasis is on generating a creative and open atmosphere in which stakeholders are acknowledged as creators [12]. [58] identifies different types of stakeholder involvement in the co-creation process: involvement as co-implementers, co-designers, and initiators. In this project, stakeholders were considered co-designers and co-implementers of the design solutions generated to improve science learning outside the classroom.

In co-design, stakeholders become co-designers, who can act as information providers, creative thinkers, and evaluators of new ideas [37]. Certain co-design approaches also stress the importance of involving stakeholders in open-ended processes because this supports long-term collaboration [38]. Considering that science learning outside the classroom is an open-ended process, stakeholders' active involvement is a cornerstone of any innovation in this area. Thus, the project stakeholders play a key role because they will determine the scalability and sustainability of the project outcomes.

Simultaneously, co-creation and co-design also imply a reconsideration of the designers' roles. In co-creation, the designers are expected to focus on coordinating and orchestrating the process, as well as developing and providing tools for co-creation [12], [91]. In turn, in co-design processes, the designers' role involves facilitating and contributing to the specific workshops in which they engage with stakeholders in collaborative inquiry and creative thinking processes [37]. At the co-design workshops, the designers contribute and facilitate and also mediate the conflicts that may arise between stakeholders due to their different interests and goals [80]. In the SySTEM 2020 project, the design researchers planned the co-creation process and scheduled diverse co-design workshops and actions that required the stakeholders' active participation. The timing, objectives, and stakeholders involved in each action varied depending on the project phase in which a specific task took place. During the preparation of the project's first co-design workshop, special attention was paid to the facilitation process. To this purpose, a facilitation guide was created, and a preparatory meeting was held with the facilitators' team before the workshop.

In co-design, the designers are accountable for the quality of the resulting products and services [92]. For this reason, the user-generated data and models produced during the co-design workshops are considered work-in-process that require further analysis and interpretation to become actionable solutions ready for implementation. Thus, co-design processes rely on the designers' expertise to make decisions that are grounded in the analysis of the co-design outputs. A critical part of co-design processes is ensuring transparency in decision making and providing stakeholders with opportunities to further contribute throughout the process. In this case, the SySTEM 2020 project partners and stakeholders were expected to influence the process by providing feedback regarding the design concepts that were elaborated upon after the co-design workshop.

Though similar, the opportunities that co-creation and co-design are expected to bring to the innovation process are slightly different. Co-creation draws on the notion of collective creativity, which can be transformed into an exchange flow of knowledge and ideas, as well as social capital [58]. In social innovation, co-creation has become a well-known approach because it brings with it a specific culture, one based on experimentation and learning [93]. In turn, co-design supports stakeholders' and designers' design creativity [12], high levels of engagement [37], as well as collective dialogue and negotiation [76]. As [76] highlights, the type of participation formats used in co-design are useful in fostering reflection and reflexivity among designers and stakeholders regarding the design purpose and the process.

In the SySTEM 2020 project, co-creation is understood as an overarching concept that advocates for the adoption of an open and creative mindset by all agents involved in design and innovation processes. In this case, co-design works as a "specific instance of co-creation" [12], one that can materialize in workshops that bring together designers and stakeholders to collaboratively explore, plan, and learn about a specific issue [37]. We consider that this approach overcomes the challenges identified in previous work around the designers' and stakeholders' roles, as well as the opportunities of co-creation and co-design, and helps aligning the outputs of each phase of the project.

Previous studies on co-creation and co-design have also noted a number of challenges connected with their implementation. For instance, regarding co-creation, some voices have expressed concern about non-reciprocal relationships in which stakeholders are exploited [94], [95]. Regarding co-design, the main challenges are related to balancing tensions and creating relationships of trust between design researchers and stakeholders [22]. Regarding co-design workshops, authors have also noted challenges involved in finding a common understanding among participants with different levels of expertise [96], [97], encouraging efficient collaboration in teams [98], handling expectations (see [99]), and ensuring that everyone has a chance to take part and contribute meaningfully [100]. In order to meet such challenges, during the SySTEM 2020 project, special attention was dedicated to supporting transparency and close communication with stakeholders.

In the design literature, authors have stressed the need for designers to develop an empathic understanding of end-users [101], [102]. When designing for learning, researchers have also advocated for empathy between designers and design beneficiaries [103], [104]. Fostering an empathic understanding between designers and stakeholders was a central concern in the SySTEM 2020 first co-design workshop. Empathy was considered key to ensuring smooth and direct communication in future stages of the project and thus meeting the challenges involved in successful co-creation and co-design in innovation processes.

5.3 Implications of co-Creation and co-Design for Innovation in TEL

The implications of co-creation and co-design for TEL innovations are strongly related to the definition of value that is adopted. In the co-creation literature, it is possible to identify various perspectives on value (see [95]). For [56], social value surpasses monetary and experiential types of value creation because it affords an actual possibility of influencing the quality of life. From this perspective, co-creation processes that are intended to create social value should include both experts and everyday people working, interacting, and talking together in an empathetic way to reinforce their collective creativity [56].

In the SySTEM 2020 project, co-creation is expected to create social value because the focus is on supporting sustainability, transformation, ownership, and learning. This human-centric and ecological view of value co-creation emphasizes the long-term changes in the quality of people's lives. In order to reach these social value goals, the process of co-creation should involve a range of individuals, from experts to the people using the innovative solutions, and these people all should be able to empathetically interact, talk with, and listen to one another to amplify their collective creativity [56]. The active involvement of diverse stakeholders throughout the project process is intended to co-create social value. Despite the diversity of needs and wishes among the co-design workshop participants, the solutions created at the workshop were all intended to be sustainable and generate social value.

Along with the social value, the outputs of the SySTEM 2020 project's first co-design workshop could also be seen as creating experience value in the form of experience environments for science learners outside the classroom. Following [29] and [105]'s stance on the importance of experiences and the superior innovation potential of experience environments as compared to clear-cut products or services, these environments could support learners in creating their own meaningful learning experiences. For instance, the outputs of the co-design workshop that encourage risk-taking, failure, and the celebration of achievements, recognize the value of personal experiences for learning and innovation processes in science learning outside the classroom.

6 Conclusion

In this paper, we have presented a case in which co-creation and co-design have been adopted to structure innovation in science learning outside the classroom. As described above, the SySTEM 2020 project presented uses co-creation as a high-level approach, whereas co-design refers to specific events that bring together design researchers and stakeholders to develop a shared understanding and ideate solutions.

First, we argue that co-creation and co-design share a similar mindset in which the active involvement of stakeholders is a central part of the process. If managed appropriately, stakeholders' active participation creates opportunities to develop collaborative relationships in which the stakeholders develop a sense of ownership over the design solutions created during the process. We consider that this is an important element to stress in TEL innovation because it has substantial repercussions for the adoption and sustainability of innovative solutions and tools.

Second, we elaborate on some of the key differences between co-creation and co-design that we consider essential to take into account when structuring innovation processes that build on these approaches. In particular, we highlight co-creation and co-design differences regarding the stakeholders' and designers' roles, as well as the opportunities and challenges they pose for innovation processes in TEL.

Third, we reflect on the type of value that co-creation and co-design processes bring to innovation. Based on our experiences with co-creation and co-design, we advocate for a focus on social value as a way to bring together co-creation and co-design for the sake of TEL innovation.

Finally, although co-creation and co-design offer promising opportunities for structuring TEL innovation, the results reported in this project must be interpreted with caution, as they are specific to the context of this project. In addition, further studies that examine the sustainability of the solutions generated in TEL innovation using co-creation and co-design processes should be undertaken.

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