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Co-Designing for Equity in Informal Science Learning: A Proof-of-Concept Study of Design Principles

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Informal science learning has great potential to engage diverse learners, but faces issues of persistent inequities. While systemic change is needed to address these issues at a structural level, there is also a need for practical tools to support the organisations and the educators who are working to engage audiences in informal science that is authentic, culturally responsive, interest driven and learner centered. This article presents a collection of design principles, generated through a design approach which actively involved informal science learners, practitioners and researchers from nineteen countries as contributors. We present the design approach adopted, and suggest that participatory design methods could play a role in supporting equity efforts in informal science learning since several of the educators involved in the process decided to adopt participatory methods in their own practice. We also present an overview of the design principles generated through this process, and discuss the application of an early draft of these in an authentic informal science education programme. By adopting and adapting these principles and approaches in their practices, educators can work towards creating equitable and transformative informal science learning environments and experiences.

Keywords: informal science learning, equity, science communication and dissemination, co-design, design principles

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INTRODUCTION

Digital and physical spaces beyond the boundaries of formal education hold myriad opportunities for creative engagement with various combinations of science, technology, engineering, mathematics and the arts (Falk, 2001; Sacco et al., 2014; Bicer et al., 2017). As such, science learning in these out-of-school settings is extremely diverse (O'Donnell et al., 2006; Falk and Dierking, 2012). Such activity is referred to as free-choice (Falk, 2005), non-formal (Garner et al., 2014) and informal (Bell et al., 2009) learning. Drawing from the literature situated across this broad field, we will refer to the educational context of these experiences as informal science learning. Informal settings that offer such learning opportunities can promote curiosity, inquiry and exploration, and embrace learning that includes learner interest, engagement, and identity-building (Allen and Peterman, 2019). Despite the great potential for informal science learning to engage a broad range of learners (Sacco et al., 2014; Dawson, 2018), particularly those underserved by formal science education, there is persistent evidence that these spaces do not engage effectively with a diversity of communities; rather, they reinforce the dominance of particular societal groups and the culture of science (Dawson, 2014a; DeWitt and Archer, 2017; Dawson, 2018; Godec et al., 2021). Archer and colleagues assert that within informal science learning activities, equity is determined not only by underlying norms and values, but also by the extent to which it does or does not reproduce pre-existing social structures and power relations. Greater support for organisations and educators in the informal science learning sector can change the field fundamentally and realise equitable impacts on youth. (Archer et al., 2021).

The perspective presented in this paper emerges from a European Commission funded project SySTEM 2020 (2018–2021) which examined science learning outside the classroom through a number of lenses across 19 countries in Europe and the Middle East[1], covering learners between 9–20 years from various backgrounds. The research presented here incorporates design traditions to support informal science educators' work towards equitable science learning. This project uses co-design to foster diverse stakeholders' active involvement to develop tools that support equity in informal science education.

Co-design builds on the user-centered design tradition and is strongly aligned with approaches that advocate for the active participation of the design beneficiaries to ensure relevant and usable design solutions (Sanders and Stappers, 2008; Durall et al., 2020a). The design beneficiaries are referred to as stakeholders and include all those who would be directly and indirectly affected by the design solutions. The call for actively involving a diversity of stakeholders in the design process is based on the recognition that people are creative and experts of their own experience (Sanders, 2002). Co-design has been considered a valuable approach to support stakeholders' collaboration, ownership of design solutions and ultimately, empowerment (Tissenbaum et al., 2012; Kwon et al., 2014; Matuk et al., 2016; Durall et al., 2020b). In the mid and long term, participatory approaches like co-design are claimed to lead to more sustainable solutions with high levels of adoption (David et al., 2013; Treasure-Jones, 2018).

This paper offers a perspective on the development of a design-based solution to support equity in the informal science learning sector. In the following sections, we present results obtained from testing a proof-of-concept of the emergent solution in one setting, and provide a discussion of the potential value of co-design approaches to support science learning beyond classroom settings.

DESIGN PROCESS

This project followed a design approach to generate solutions to some of the most common challenges facing science educators in informal science learning settings. The design process included several rounds of iteration to ensure the stakeholders had the opportunity to influence the outcomes.

To gain a broad understanding of the research problem, the initial phase of the design process consisted of an inquiry into the context (Penuel et al., 2007; Leinonen et al., 2008). During this stage, the design researchers conducted a rapid ethnography (Millen, 2000) to identify main challenges and opportunities for learners and educators in informal science education. Activities in various settings, including museums, science centres, maker and hacker spaces, science fair and summer camps were observed and the participants were interviewed (see **Table 1**). The results of the contextual inquiry highlighted learners' socio-cultural barriers to access and actively participate in science learning—for instance, challenges to develop science identities and sustain interest over time. These findings informed the themes and methods used in co-design sessions with learners, educators and science education stakeholders in a two-day event in Helsinki in March 2019.

The co-design sessions gathered 51 people from 19 countries across Europe and the Middle East (**Table 1**). During the sessions, design-thinking methods were used to support participants to develop a shared understanding of issues and challenges for informal science educators and learners in terms of a) inclusion; b) engagement; and c) assessment and recognition of learning. Once a shared vision on these issues was established, the participants started to define key challenges and opportunities, and to ideate solutions to these challenges. To ensure diversity of viewpoints, each of the co-design session teams included learners, educators and other stakeholders. The methods used included concept mapping, identification of opportunities and challenges, card sorting, clustering and prioritisation. During the ideation phase, the participants brainstormed and sketched their ideas.

The outputs of the co-design sessions were analyzed and interpreted using design synthesis methods by the research designers. Design synthesis is an inference-based sense-making process through which designers look at the data from multiple perspectives, make relations and generate new ideas (Kolko, 2007). This process was iterated until a set of design principles could be formulated.

A first draft of the principles was shared with the SySTEM 2020 partners and external stakeholders, who were all asked for feedback through questionnaires and in workshop sessions (see **Table 1**). The feedback provided in each of the sharing sessions informed further refinement. The design principles underwent three iterations before a final version was released, this process is summarised in **Table 1**

RESULTS

Design Principles

A design principle is a proposition that works as the foundation for designing systems, services or products (Fu et al., 2015). In this instance, the design principles[2] were developed as a resource that provides inspiration for the design, facilitation and assessment of informal science learning activities and programmes.

A set of principles for designing science learning activities and programmes that cultivate involvement in an equitable way was considered valuable in order to meet the varied challenges that educators experience—the difficulties for broadening access and diversity to programmes, the struggle to support regular and continued engagement, as well as the need to master multiple skills. However, as the co-design participants acknowledged, the

[1]SySTEM 2020: https://cordis.europa.eu/project/id/788317

[2]The final version of the design principles is available at: https://system2020.education/resources/design-principles-and-methods-toolkit-for-supporting-science-learning-outside-the-classroom/

TABLE 1 | Summary of actions conducted during the SySTEM 2020 design inquiry.

phase	Action	Participants/actors
Contextual inquiry	Rapid ethnography of science learning in informal learning settings in Finland.	*n* ~ 200 (learners; parents /guardians; educators; makers; civic/ professional organisations)
Co-design	Helsinki co-design sessions.	*n* = 51 (learners aged 18–21; learning sciences researchers; educators/ pedagogical coordinators from informal science learning organisations, civic/professional organisations)
Studio work	Synthesis of the Helsinki co-design sessions key ideas. Formulation of the design principles.	Design researchers
Feedback and evaluation	Workshop session.	*n* = 15 (learning sciences researchers; educators/pedagogical coordinators from informal science learning organisations)
Studio work	Revision of the design principles.	Design researchers
Feedback and evaluation	Assessment questionnaire.	*n* = 15 (as Feedback and evaluation workshop)
Studio work	Revision of design principles.	Design researchers
Feedback and evaluation	Co-design workshop on making in Finnish public libraries	*n* = 14 (library staff workers)
Feedback and evaluation	Assessment questionnaire.	*n* = 20 (as Feedback and evaluation workshop)
Studio work	Iteration and final version release of the Design Principles.	Design researchers

needs, expectations and contexts in which informal science educators work are so diverse that a one size fits all solution is extremely challenging. As one of the educators expressed, the same methods might work very differently depending on the context: "Different approaches can produce the same outcome in different setting, or the same approach can produce opposite results depending on specific features of different context: understanding and respecting the subtle diversities of contexts and learning environments is a cross-cutting aspect that one should never forget". In recognition of these varied needs, the design principles have been proposed as a starting point for educators, requiring adaptation based on the specific context and needs.

The different expectations of educators, practitioners, researchers and designers translated into conflicting views regarding the approach and level of detail of the design principles. While there was consensus in moving away from prescriptive approaches, there were tensions regarding the level of openness of the principles. The adoption of an iterative approach with several rounds of assessment and feedback helped to reduce the tensions by progressively addressing some of the key demands.

The design principles are categorised in three areas based on their main design focus: *Design for Everyone*, *Design for Experience and Design for Growth* (see **Table 2**). *Design for Everyone* highlights the need to consider aspects connected to access, diversity and inclusion in order to develop equitable practices in informal science education. In a way, the principles included in this area are foundational for all the others.

Design for Experience elaborates on aspects that contribute to creating learning experiences that are meaningful, engaging, inspiring and that foster learning, in which facilitation and the design of social learning environments are central.

Design for Growth seeks to encourage thinking in the longer term. This area calls attention to supporting autonomous learning, identity-building, and lifelong learning.

Each area features three or four design principles, each further supported by several methods (see **Table 2**). The methods are intended to support practitioners to apply the principles in practice and they are accompanied by quotes from the contributors, who are educators and pedagogical coordinators in informal science learning organisations. The quotes provide indications about how to frame practice, as well as specific and practical advice based on the educators' first-hand experiences. For instance, the quote "You can't expect people disengaged with science to visit you. You need to take your education work out to where your audience is" is a call for taking a proactive attitude when seeking to increase access and participation. This supposes a change from strategies based on increasing dissemination efforts without reconsidering the channels and venues through which people are expected to access the information. On a more concrete level, the quote "Use your participants' local cultural knowledge, such as well known stories or myths as starting points for informal science learning activities and experiences. It is surprising how relevant topics can be co-opted to make rich learning opportunities" works as a strategy example for developing culturally responsive practices. To illustrate how the design principles can be applied, real-world cases are included alongside the methods.

In the next section we present the design principles proof-of-concept in the context of an informal science learning programme in Ireland.

Proof-of-Concept

In order to test the helpfulness of the design principles in a realistic context, they were used to aid the internal review of a digital learning curriculum offered by Science Gallery at Trinity College Dublin, a cultural space focused on engaging young adults in conversations about science and art (Gorman, 2020). The learning programme aimed to engage and support 14–16 year olds to use science to generate solutions to a locally relevant societal problem, and consisted of a collection of workshop guides and resources.

The design principles were shared with relevant staff in summer 2020 to guide the review of a digital learning programme, together with a checklist of questions which adapted the principles into self-review prompts. For instance, the principle *Make it accessible* was translated into: "*Does the workshop span a variety of senses and ways of exploring?*".

TABLE 2 | Design principles for supporting science education in out-of-school settings.

Area	Design Principle	Methods
Design for Everyone	Make it accessible	•Being approachable. •Accommodating diverse needs.
	Embrace diversity	•Showing the diversity of people who engage in science. •Fostering diversity among participants.
	Be inclusive	•Developing empathic understanding. •Becoming culturally responsive.
Design for Experience	Make it matter	•Showing the relevance of science. •Building on personal interests.
	Keep it engaging	•Triggering positive emotions. •Making concepts tangible. •Encouraging open-ended exploration.
	Inspire and motivate	•Guiding learning. •Fostering learners' self-confidence.
	Build social learning environments	•Encouraging sharing and collaboration. •Cultivating a community feeling.
Design for Growth	Create pathways	•Creating continuity and multiple entry points. •Bridging different disciplines.
	Support identity building	•Recognizing learners' achievements. •Raising awareness of possible futures.
	Promote learner autonomy	•Supporting learning to learn. •Boosting transversal competencies.
	Assess your practice	•Setting goals and monitoring progress. •Reflecting on your practice.

The two educators who reviewed the workshop guides using the prompts and the design principles were interviewed in order to explore their experiences using the prompts, and the usefulness of the principles in reviewing the programme curriculum. The interviewees were experienced science educators, who had ten and two years experience in informal science education and communication respectively. During the interview, they explained that they worked together to apply the checklist to the workshop guides that made up the programme curriculum. They reported that they used the questions for "refining workshop guides with design principles in mind" in a structured manner. In particular, they created "a spreadsheet with a column for each concept" to help them to lead "a discussion about each workshop session that we've been reviewing".

They found the reframing of the design principles into a checklist useful, since this format seemed to easily facilitate a reflective discussion about the workshop guides. As one of the educators highlighted, "the open self-reflection questions got us in the right frame of mind". Together, they checked for at least one example of each prompt being satisfied within the curriculum, though frequently multiple were found or aimed for. If no examples were found, they worked to integrate the principle into the activity through tweaking or expanding the existing content or approaches.

During the interview, the educators described the design principles as providing a "different lens on the activities that we are doing", demonstrating the value of a detached framework that can be used to highlight strengths as well as areas for improvement in curricula before they are implemented. They described the design principles as a self-checking mechanism which offered a new perspective on planned activity. For instance, as one of the educators acknowledged, the checklist helped them to consider the diverse needs of participants: "One thing I remember taking note of (from the design principles), was . . . some of the workshops use digital tools . . . Some students with special educational needs might find new digital tools a bit overwhelming, and that is something which we didn't consider".

Though the interviewees appreciated the checklist as a helpful and reflective tool to aid their work, they also found it somewhat challenging to apply. As one of them phrased it, "We struggled sometimes . . . we used it as a way to check everything we did and it was hard to make a statement that one specific way was the right way". Moving from the general (the design principle) to the specific (decision-making and practice in a learning environment) was perceived as a challenging, yet rewarding task. The feedback provided during the proof-of-concept testing and interviews was taken into consideration for the final version of the design principles.

DISCUSSION AND CONCLUSION

The preceding sections have introduced the design approach, the resulting design principles for informal science educators, as well as the implementation of the principles in an authentic setting as proof-of-concept. This section reflects on the approach and results to suggest some implications for research and practice.

First, collaborative design helps to include a diversity of voices and perspectives and cultivates equitable practices. While the participation of diverse science learning stakeholders helped to build a shared understanding of the challenges and opportunities that learners and educators face in informal science learning settings, the process was not exempt from tensions due to the stakeholders' different needs. During the development of the design principles, the adoption of a co-design approach helped to acknowledge these gaps and negotiate the solutions (Bønnelycke et al., 2018). The proof-of-concept testing of the design principles was part of this process of progressive refinement through iterations. Based on the SySTEM 2020 experience, we may say that the co-design process also provided learning opportunities for stakeholders by showcasing tools and methods for collaborative[3] design. As one of the participants expressed after the co-design event in Helsinki: "I have the impression that the co-design session has been a great chance, for a variety of people, to experiment (*sic*) a deep moment of debate and reflection. Such … moments are particular for several reasons: the international breadth, the importance and the quality of the content presented and debated, the experience of the structured facilitation of such big groups". Following the process, several practitioners have started using co-design with their teams and communities to foster diversity and inclusion. We consider this is an important impact that aligns with findings from other studies in which co-design processes have been used to support equitable teaching and learning (Penuel, 2019).

Secondly, we reflect on the challenges for developing tools that move from the general (the principles) to the particular (the context of a specific informal science learning setting and its learners). As presented in the proof-of-concept, the design principles provide general guidance to inspire practice in a broad range of science in out-of-school settings; the intention is to be independent of learner demographics, pedagogical framework or learning design methodology. The checklist created by the educators at the proof-of-concept testing phase acted as an intermediate tool to translate the design principles and make them usable for educators with diverse backgrounds and levels of experience. While the principles were highly appreciated, the process of translation—in this case in the form of a questions checklist—is an important step that would benefit from further iterations and requires the active involvement of the educators who are expected to use the tool. Based on the proof-of-concept, we consider that the translation work benefits from following a collaborative approach. Further work involves developing specific actions with learners for translating the principles into practice.

Third, making meaningful progress towards equity in informal science education requires awareness of the complexity of the issue. Inequity in science is reinforced when those designing experiences lack the tools to think critically about who they are trying to engage, and who they are (perhaps unintentionally) excluding (Dawson, 2014a; Dawson, 2014b; DeWitt and Archer, 2017). While fostering awareness amongst science educators in informal learning settings is important, the responsibility to advance equity work should not fall to or rely upon specific individuals. The efforts supporting equity should be framed as part of a collective endeavour that involves the whole science learning community. The design principles should be understood as part of this collective effort.

Finally, to understand the complexity of considering inequity in informal science education we suggest looking at it as a "wicked problem". In particular, wicked problems are complex and challenging because they are ill-defined, with multiple interconnections and conflicting interests that change over time (Dillon, 2017). Finding solutions to wicked problems is difficult because quite often solving one part of the issue creates other problems (Rittel and Webber, 1973). The educators who reviewed the science educational programmes using the checklist of questions struggled because it was challenging to know if "one specific way was the right way". This observation aligns with the claim that answers to equity problems cannot be assessed from a "right or wrong" perspective, since solutions are always incomplete and need to be constantly reviewed (Rittel and Webber, 1973). We consider that the adoption of co-design processes, as well as the use of tools like the design principles presented in this paper can help to cultivate equity-oriented practices. While modest, such a tool can contribute to a necessarily systemic change that is required to address inequity in science.

[3]More information about the co-design sessions can be found in Durall et al. (2020a).

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because it is not possible to guarantee the anonymity of the research participants. Requests to access the datasets should be directed to, mairead.hurley@tcd.ie.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ED led the conceptual design of this manuscript. ED, SP, MH, EK, and TL wrote the initial drafts collaboratively. ED led the design research intervention in the field, SP actively contributed to the proof-of-concept study. MH and ED designed the research project within which this work was realised, and MH coordinated this project. All authors reviewed the manuscript and provided comments and feedback.

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REFERENCES

Allen, S., and Peterman, K. (2019). Evaluating Informal STEM Education: Issues and Challenges in Context. *Evaluation* 2019 (161), 17–33. doi:10.1002/ev.20354

Archer, L., Godec, S., Calabrese Barton, A., Dawson, E., Mau, A., and Patel, U. (2021). Changing the Field: A Bourdieusian Analysis of Educational Practices that Support Equitable Outcomes Among Minoritized Youth on Two Informal Science Learning Programs. *Sci. Educ.* 105 (1), 166–203. doi:10.1002/sce.21602

Bell, P., Lewenstein, B., Shouse, A. W., and Feder, M. A. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits*, 140. Washington, DC: National Academies Press.

Bicer, A., Nite, S. B., Capraro, R. M., Barroso, L. R., Capraro, M. M., and Lee, Y. (2017). "Moving from STEM to STEAM: The Effects of Informal STEM Learning on Students' Creativity and Problem Solving Skills with 3D Printing," in IEEE Frontiers in Education Conference (FIE), Indianapolis, IN, USA, Oct 18–21, 2017, 1–6. doi:10.1109/FIE.2017.8190545

Bønnelycke, J., Thiel Sandholdt, C., and Pernille Jespersen, A. (2018). Co-designing Health Promotion at a Science centre: Distributing Expertise and Granting Modes of Participation. *CoDesign* 15, 128–141. doi:10.1080/15710882.2018.1434547

David, S., Sabiescu, A. G., and Cantoni, L. (2013). Co-design with Communities. A Reflection on the Literature. Proceedings of the 7th International Development Informatics Association Conference. Pretoria, South Africa, Nov 1, 2013 (IDIA, 152–166).

Dawson, E. (2014a). "Not Designed for Us": How Science Museums and Science Centers Socially Exclude Low-Income, Minority Ethnic Groups. *Sci. Ed.* 98 (6), 981–1008. doi:10.1002/sce.21133

Dawson, E. (2014b). Equity in Informal Science Education: Developing an Access and Equity Framework for Science Museums and Science Centres. *Stud. Sci. Educ.* 50 (2), 209–247. doi:10.1080/03057267.2014.957558

Dawson, E. (2018). Reimagining Publics and (Non) Participation: Exploring Exclusion from Science Communication through the Experiences of Low-Income, Minority Ethnic Groups. *Public Underst Sci.* 27 (7), 772–786. doi:10.1177/0963662517750072

DeWitt, J., and Archer, L. (2017). Participation in Informal Science Learning Experiences: The Rich Get Richer?. *Int. J. Sci. Educ. B* 7 (4), 356–373. doi:10.1080/21548455.2017.1360531

Dillon, J. (2017). Wicked Problems and the Need for Civic Science. *Spokes* 29 (April). Available at: https://www.ecsite.eu/activities-and-services/news-and-publications/digital-spokes/issue-29# (Accessed May, 28).

Durall, E., Bauters, M., Hietala, I., Leinonen, T., and Kapros, E. (2020a). Co-creation and Co-design in Technology-Enhanced Learning: Innovating Science Learning outside the Classroom. *Interaction Des. Architecture (S)* 42, 202–226.

Durall, E., Virnes, M., Leinonen, T., and Gros, B. (2020b). Ownership of Learning in Monitoring Technology: Design Case of Self-Monitoring Tech in Independent Study. *Interaction Des. Architecture(s) J.* 45, 133–154.

Falk, J. H., and Dierking, L. D. (2012). "Lifelong Science Learning for Adults: The Role of Free-Choice Experiences," in *Second International Handbook of Science Education*. *Springer International Handbooks of Education*. Editors B. Fraser, K. Tobin, and C. McRobbie (Dordrecht: Springer), 24, 1063–1079. doi:10.1007/978-1-4020-9041-7_70

Falk, J. H. (2001). *Free-Choice Science Education: How We Learn Science outside of School*. New York: Teachers College Press.

Falk, J. H. (2005). Free-choice Environmental Learning: Framing the Discussion. *Environ. Educ. Res.* 11 (3), 265–280. doi:10.1080/13504620500081129

Fu, K. K., Yang, M. C., and Wood, K. L. (2015). "Design Principles: The Foundation of Design," in International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Boston, MA, United States, Aug 2–5, 2015. (American Society of Mechanical Engineers), V007T06A034.57175.

Garner, N., Hayes, S. M., and Eilks, I. (2014). Linking Formal and Non-formal Learning in Science Education–A Reflection from Two Cases in Ireland and Germany. *Sisyphus. Journal Educ.* 2 (2), 10–31.

Godec, S., Archer, L., and Dawson, E. (2021). Interested but Not Being Served: Mapping Young People's Participation in Informal STEM Education through an Equity Lens. *Res. Pap. Educ.*, 1–28. doi:10.1080/02671522.2020.1849365

Gorman, M. J. (2020). *Idea Colliders: The Future of Science Museums*. MIT Press. doi:10.7551/mitpress/11019.001.0001

Kolko, J. (2007). Information Architecture and Design Strategy: The Importance of Synthesis during the Process of Design. Industrial Designers Society of America Conference, San Francisco, CA, United States, October 17–20, 2007.

Kwon, S. M., Wardrip, P. S., and Gomez, L. M. (2014). Co-design of Interdisciplinary Projects as a Mechanism for School Capacity Growth. *Improving Schools* 17 (1), 54–71. doi:10.1177/1365480213519517

Leinonen, T., Toikkanen, T., and Silfvast, K. (2008). "Software as Hypothesis: Research-Based Design Methodology," in Proceedings of the Tenth Anniversary Conference on Participatory Design, Indianapolis, IN, United States, October 61–70, 2008 (Indiana University), 61–70.

Matuk, C., Gerard, L., Lim-Breitbart, J., and Linn, M. (2016). Gathering Requirements for Teacher Tools: Strategies for Empowering Teachers through Co-design. *J. Sci. Teach. Educ.* 27 (1), 79–110. doi:10.1007/s10972-016-9459-2

Millen, D. R. (2000). "Rapid Ethnography: Time Deepening Strategies for HCI Field Research," in Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York, NY, United States, August, 280–286.

O'Donnell, L., Morris, M., and Wilson, R. (2006). *Education outside the Classroom: An Assessment of Activity and Practice in Schools and Local Authorities*. Nottingham: Department for Education and Skills.

Penuel, W. R. (2019). "Co-design as Infrastructuring with Attention to Power: Building Collective Capacity for Equitable Teaching and Learning through Design-Based Implementation Research," in *Collaborative Curriculum Design for Sustainable Innovation and Teacher Learning* (Cham: Springer), 387–401. doi:10.1007/978-3-030-20062-6_21

Penuel, W. R., Roschelle, J., and Shechtman, N. (2007). Designing Formative Assessment Software with Teachers: An Analysis of the Co-design Process. *Res. Pract. Tech. Enhanced Learn.* 02 (01), 51–74. doi:10.1142/s1793206807000300

Rittel, H. W. J., and Webber, M. M. (1973). Dilemmas in a General Theory of Planning. *Policy Sci.* 4, 155–169. doi:10.1007/bf01405730

Sacco, K., Falk, J. H., and Bell, J. (2014). Informal Science Education: Lifelong, Life-Wide, Life-Deep. *Plos Biol.* 12 (11), e1001986. doi:10.1371/journal.pbio.1001986

Sanders, E. B.-N., and Stappers, P. J. (2008). Co-creation and the New Landscapes of Design. *CoDesign* 4 (1), 5–18. doi:10.1080/15710880701875068

Sanders, E. B. (2002). From User-Centered to Participatory Design Approaches. *Des. Soc. Sci. Making connections* 1 (8), 1.

Tissenbaum, M., Lui, M., and Slotta, J. D. (2012). Co-Designing Collaborative Smart Classroom Curriculum for Secondary School Science. *J. UCS* 18 (3), 327–352.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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