



Parallel Design: Achieving both Researchers' and Practitioners' Goals in the Design of an Interactive Learning System

Tomohiro Nagashima
Saarland University, Saarland
Informatics Campus
nagashima@cs.uni-saarland.de

Katharina Bonaventura
Saarland University, Saarland
Informatics Campus
s8kabona@stud.uni-saarland.de

Man Su
Saarland University, Saarland
Informatics Campus
mansu@cs.uni-saarland.de

ABSTRACT

Co-design has been traditionally employed as an approach to design learning technologies with stakeholders, offering tangible benefits in practice. However, this approach may sometimes struggle to adequately fulfil the objectives of both researchers and practitioners, particularly when their goals are slightly different. To address this issue, we propose *Parallel Design*, a bottom-up participatory design process specifically formulated to meet the objectives of both parties without compromising one for the other. Our initial efforts involved collaboration with a middle-school mathematics teacher to create interactive algebra learning software that meets his instructional needs. Simultaneously, we also pursued our research goal that could be tested in parallel with the instructional goal. This paper introduces *Parallel Design* as an approach to designing technology with practitioners that can advance both research and practice.

CCS CONCEPTS

• Applied computing; • Education; • Interactive learning environments;

KEYWORDS

Co-design, Intelligent Tutoring System, Mathematics education, Algebra

ACM Reference Format:

Tomohiro Nagashima, Katharina Bonaventura, and Man Su. 2024. Parallel Design: Achieving both Researchers' and Practitioners' Goals in the Design of an Interactive Learning System. In *Symposium on Learning, Design and Technology (LDT '24)*, June 21, 2024, Delft, Netherlands. ACM, New York, NY, USA, 4 pages. <https://doi.org/10.1145/3663433.3663434>

1 INTRODUCTION

Recent years have witnessed an increased use of participatory approaches for designing technologies aimed at supporting teaching and learning, with a primary focus on aligning these technologies with stakeholders' goals, including school children and teachers [1, 4, 15]. For example, a growing body of research has used participatory, co-design approaches to develop awareness tools for educators, such as the design of a teacher-facing learning dashboard that provides insights into class performance [1, 8, 11]. By actively

engaging with educators (and students), these studies ensure that stakeholder feedback, needs, and preferences are incorporated into both the design process and the final product.

However, there remains a notable gap in employing participatory approaches for the design of learning technologies specifically tailored to enhance student learning within the classroom setting. For instance, Intelligent Tutoring Systems (ITSs), despite their extensive history of research and practical implementation in the classroom environments [10], typically do not undergo a participatory design process that leverages teachers' and students' preferences and needs. Although some user involvement is observed in the design of these systems [13], they are predominantly shaped through researcher-led design process such as Cognitive Task Analysis (i.e., conducting think-aloud sessions with learners and teachers to understand step-by-step instructional procedure, which are subsequently integrated into the system) [5] or through iterative feedback from teachers [13]. In these conventional design approaches, researchers usually steer the process, setting goals, and incorporating user feedback from teachers (and learners). However, they often fall short in empowering users to take a more central role in driving the design process with increased agency and participation.

Co-designing instructional technology (e.g., ITSs) with stakeholders poses a distinct challenge due to the technology's dual role of serving as both a learning platform for teaching domain knowledge and a research tool for testing instructional principles [3]. That is, these systems not only function as specific instructional tools for teaching domain-specific concepts but also serve as platforms for testing various instructional principles to contribute to learning science research [14]. Designing such systems in a participatory manner with stakeholders requires alignment among the diverse goals held by researchers and teachers (or learners). For instance, Alevén and Koedinger [2] investigated students' metacognitive learning processes within a geometry intelligent tutor, wherein the platform served dual purposes: an instructional goal of teaching geometry theorems and problem-solving skills, and a researcher's goal of examining and supporting students' metacognitive processes of learning through self-explanation [2]. In such a situation where stakeholders might possess different goals in using the designed product, it would be practically challenging to co-design instructional technology effectively. Although a number of studies on co-design and research-practice partnerships illustrate how co-design can be conducted effectively [6], no practical approach exists for addressing potential misalignment between researchers and practitioners in this specific context.

This paper presents an initial attempt of *Parallel Design* (defined below) in which the research team worked with a mathematics

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for third-party components of this work must be honored. For all other uses, contact the owner/author(s).

LDT '24, June 21, 2024, Delft, Netherlands

© 2024 Copyright held by the owner/author(s).

ACM ISBN 979-8-4007-1722-2/24/06

<https://doi.org/10.1145/3663433.3663434>

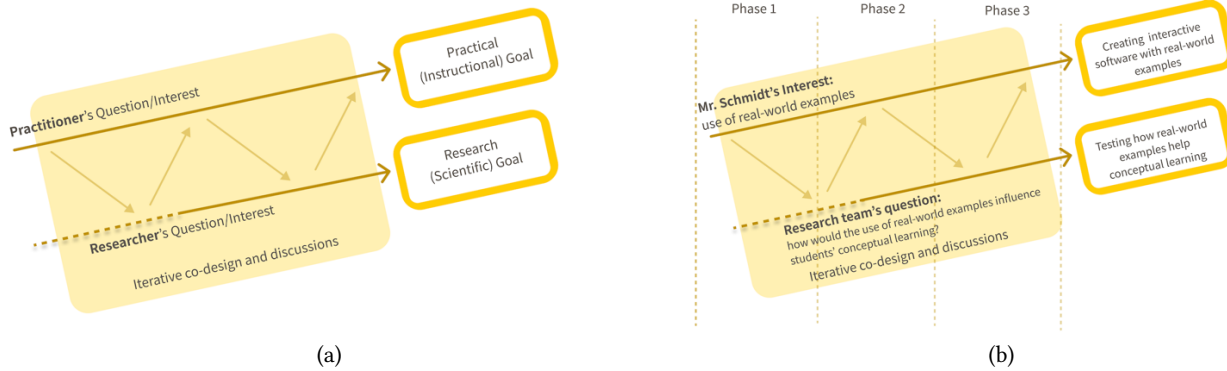


Figure 1: (a) The concept underlying *Parallel Design* entails aligning the goals of researchers' and teachers' in a direction that is shared but exhibits slight variations. The practitioners' inquiries/interests drive the design and research processes, while researchers formulate their own questions and goals, positioned in the middle. Through iterative co-design and discussions, both stakeholders would refine their inquiries, approaches, and prototypes to achieve mutual alignment and sustainable progress. (b) shows the specific goals/questions/interests shared in the work with Mr. Schmidt.

teacher for approximately 13 months to design interactive software aimed at facilitating learning in solving systems of equations. Initially, our focus was directed towards achieving the teacher's goal of creating interactive software for solving systems of equations. However, through iterative reflection on our practices, we decided to concurrently pursue the researchers' goal of testing specific instructional principles *in parallel* with fulfilling the teacher's goal. This paper introduces a practical approach that enables effective collaboration with education stakeholders in designing an instructional tool that not only supports practical instructional objectives but also aligns with scientific research goals.

2 PARALLEL DESIGN

Parallel Design is defined as a bottom-up, co-design approach in the design of learning technology where researchers (or designers) and practitioners aim to achieve the goals of both parties without unnecessarily compromising with each other. The term *parallel* is used because these goals typically align rather than conflict; they are oriented towards a similar direction but may exhibit slight variations. For example, when designing a tutoring system for learning math, teachers and researchers would both agree to design a system that benefits student learning. However, their interests may diverge slightly, with teachers focusing on helping students grasp a specific concept, while researchers prioritize understanding the learning processes students would undergo. As depicted in Figure 1(a), these goals can be pursued in parallel.

3 METHOD

3.1 Participant

A research team, consisting of a graduate student in Computer Science and a faculty member with expertise in the Learning Sciences and Human-Computer Interaction, conducted six co-design sessions with a mathematics teacher from a public high school in Germany. We recruited the teacher through a contact established

by another research lab. From now on, we call the teacher "Mr. Schmidt" (pseudonym) in this paper.

3.2 Procedure

We started to collaborate with Mr. Schmidt by first informally observing his teaching in the classroom (not for a data collection purpose but rather to build a relationship with the teacher). After the initial observation, we started co-design sessions by inviting him to the university lab (five times) and online (once). In the beginning, we asked his needs and issues in his math teaching without a clear targeted research question, which we (both Mr. Schmidt and the research team) turned into a practical instructional goal (Phase 1). Then, we (the research team) generated a research question that we were interested in asking using the technology we would create for Mr. Schmidt (Phase 2). Following this phase, we continued to prototype the tool while targeting both goals (Phase 3). Figure 1(b) visually shows the procedure. We describe a more detailed process of each phase below. Mr. Schmidt received compensation of 25 Euros per session for his participation.

3.3 Materials

Throughout the co-design sessions, we used several different types of materials, including low-fi and mid-fi prototypes (e.g., presentation slides in PowerPoint) as well as functional prototypes of the software. In the early stage of the design study, we also used mathematics textbooks used at Mr. Schmidt's school as a reference during the discussion.

4 DESIGN PROCESS AND PRELIMINARY FINDINGS

4.1 Phase 1: Understanding the Needs of Mr. Schmidt to Define a Practical Goal

Upon the initial observation of Mr. Schmidt's class and a follow-up interview with him, we started to discuss his needs and preferences

for teaching mathematics and how technology could be designed to help his teaching. As the goal of the Phase 1 was to identify his practical/instructional needs, we asked him several prompting questions such as “What are some topics or ideas that *you* have difficulty teaching students?” instead of us suggesting any topics to focus on. We recognized the importance of providing a space where he could freely express his ideas without being influenced by any topic preferences we may have had, as it was essential for fostering a sustainable partnership with him.

Through having unstructured conversations with Mr. Schmidt, we were able to gradually understand his teaching approach; in particular, we found that he frequently cited that using real-world examples makes math learning more relevant and interesting. Due to this benefit that he had realized, he tries to use analogies and examples from daily lives that could help connect abstract math concepts with everyday objects and situations.

The conversations then focused on the current math topic that he was teaching at the time of the study: linear systems of equations with two variables in algebra (e.g., solving for x and y when given $x + y = 3$ and $x - y = -1$). He shared that students could easily *get by*—through applying solution strategies (e.g., The *substitution* strategy: turning the second equation into $x = y - 1$ and then substitute $y - 1$ for the x in the first equation, making $(y - 1) + y = 3$) but often lack a deep understanding of how those strategies actually work (e.g., students get confused: e.g., “Why do I substitute one variable for another?”, “Why can I add one equation to another to eliminate one variable?”). He reported that, in his teaching, he would use analogies to make math more relevant to real-world situations. For instance, to illustrate the *equalization* strategy (where one would isolate x for the two equations above: $x = 3 - y$ and $x = y - 1$ and solve $3 - y = y - 1$ for y), he would explain, “My hair color is brown, and I have the same hair color as Sophie. Sophie has the same hair color as her brother. Therefore, Sophie’s brother’s hair color must be brown.” Although he said that such an example helps students, one challenge that he encountered was the lack of effective analogies in both the textbooks he used and other learning software recommended by the school, despite his preference for incorporating real-world examples.

In summary, in this phase, the research team and Mr. Schmidt discussed what kinds of approaches were used in his teaching, and what kinds of difficulties he had encountered during his teaching. In doing so, the research team did not bring in any pre-defined topic(s) or research question(s) to focus on; rather we provided an open space where the teacher could freely articulate his current needs and preferences. This process allowed us to identify his practical goal/need: *to have an interactive tool that teaches students how solution strategies work when solving linear systems using real-world examples.*

4.2 Phase 2: Gradual Formulation of a Scientific Goal in Parallel with the Practical Goal

After identifying Mr. Schmidt’s practical goal that targets the instructional aspect, the research team started prototyping ideas to achieve the goal. As Mr. Schmidt was interested in using real-world examples, we prototyped different ways in which real-world examples were used to illustrate how to solve linear systems of

equations and discussed with him to iteratively improve the ideas. For instance, for the *elimination* strategy (i.e., adding $x + y = 3$ and $x - y = -1$ to eliminate y), we came up with an analogy where learners would identify the unit price of two different items (where each represents x and y) using the information on the total cost when both are purchased in different quantities (e.g., buying one T-shirt and one mug equals 23 Euros while three T-shirts and five mugs would cost 75 Euros).

During this process, while keeping the practical goal as our main target, we (the research team) also started to formulate relevant research questions that could be pursued in parallel with the practical goal (by using the final product as a platform for learning research). Through literature search and reflection on earlier discussions with Mr. Schmidt with a focus on real-world examples, we became interested in exploring how interactive exercises with real-world examples could impact students’ conceptual understanding of how to solve linear systems with two variables [9]. This reflective thinking resulted in the following research question that we decided to target: *how will interactive exercises with real-world examples help students develop conceptual understanding of solving linear systems of equations with two variables?*

It is critical to reiterate that the research team did not have any concrete research question when we started collaborating with Mr. Schmidt. Rather, through reflecting on the conversations with the teacher and follow-up literature research, we formulated the above-mentioned research question. To be more specific, the following factors directly or indirectly influenced the formulation of the research question: First, through interacting with Mr. Schmidt, we realized that the explicit use of real-world examples may have a positive benefit on students’ understanding of concepts behind each strategy (by understanding the process of using solution strategies) [7, 9]. Also, both Mr. Schmidt and the research team were interested in making learning playful, and therefore aimed to create interactive, engaging user interactions. We thought that interactive features in a learning game could influence students’ better understanding of conceptual meanings behind strategies, coupled with targeted feedback [13]. Finally, it is also important to note that the research team’s background and expertise might have influenced this process; for instance, one of the team members previously had conducted a study testing the use of visual representations on students’ conceptual learning in algebra [12]. We recognize that such past experiences of the researchers may have influenced our perception of the design space and the idea generation process.

4.3 Phase 3: Targeting both Practical and Scientific Goals during Prototyping and Implementation

Keeping both goals as our target objectives, we continued to iteratively develop and implement prototypes. Figure 2 shows the implemented software, “AlgeSPACE,” in which students can engage in learning how to solve linear systems using the three solution strategies: equalization, substitution, and elimination (see <https://algespace.sic.saarland/>). In all these games, we focused on achieving both practical (Mr. Schmidt’s) and scientific (researcher’s) goals. For instance, the games emphasize step-by-step solution procedure for applying the strategies in a real-world story problem

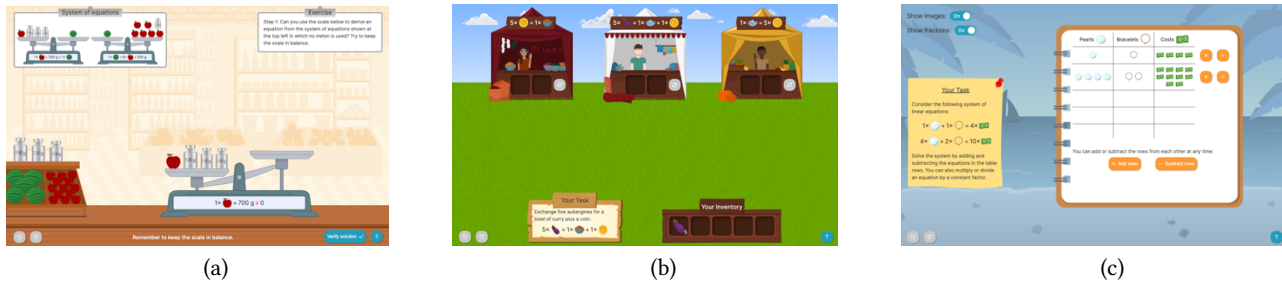


Figure 2: The implemented AlgeSPACE software has three games, each corresponding to each of the main solution strategies. Game (a) uses a balance scale to communicate the idea of the equalization strategy, Game (b) shows how the idea of exchanging objects can be used to explain the substitution strategy, and Game (c) uses a note pad where learners can calculate the unit price of items they purchase by using the elimination strategy. All games provide step-by-step problem-solving opportunities with targeted feedback.

context. This feature is designed to support the scientific goal of enhancing conceptual learning by providing fine-grained opportunities for students to understand how each strategy works step-by-step. Simultaneously, the feature was also meant to address the practical goal by allowing learners to experience the step-by-step solution procedure applied in the context of story problems without turning them into abstract terms. In other words, the tool is focused specifically on scaffolding students' initial understanding of how procedure works in context, with the expectation that teachers, including Mr. Schmidt, would supplement student understanding by giving instruction on how to perform the solution steps in abstract terms.

5 DISCUSSION AND CONCLUSION

In co-design efforts with practitioners, it is common to encounter multiple shared objectives that the practitioners and the research team aim to achieve. The interests, questions, and goals of practitioners may diverge slightly from those of the research team. It is not always necessary to consolidate these goals into one single goal; instead, they can be pursued in parallel. We propose *Parallel Design*, a design approach that facilitates targeting multiple goals explicitly during the design/research process. We share insights on how this approach was applied in our case study. However, it is not clear whether the strategy could be applied in other contexts. Moving forward, we plan to refine the *Parallel Design* technique into a more universally applicable framework, enabling its adoption and generalizability across various design situations.

ACKNOWLEDGMENTS

We want to thank Mr. Schmidt for the collaborative work.

REFERENCES

- [1] June Ahn, Fabio Campos, Maria Hays, and Daniela DiGiacomo. 2019. Designing in context: Reaching beyond usability in learning analytics dashboard design. *Journal of Learning Analytics* 6, 2 (2019), 70-85. <https://doi.org/10.18608/jla.2019.62.5>
- [2] Vincent Aleven and Kenneth R. Koedinger. 2002. An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science* 26, 2 (2002), 147-179. https://doi.org/10.1207/s15516709cog2602_1
- [3] Roger Azevedo, François Bouchet, Melissa Duffy, Jason Harley, Michelle Taub, Gregory Trevors, Elizabeth Cloude, Daryn Dever, Megan Wiedbusch, Franz Wortha, and Rebeca Cerezo. 2022. Lessons learned and future directions of MetaTutor: Leveraging multichannel data to scaffold self-regulated learning with an intelligent tutoring system. *Frontiers in Psychology* 13 (2022). <https://doi.org/10.3389/fpsyg.2022.813632>
- [4] Jenny Yun-Chen Chan, Tomohiro Nagashima, and Avery H. Closser. 2023. Participatory design for cognitive science: Examples from the learning sciences and human-computer interaction. *Cognitive Science* 47, 10 (2023). <https://doi.org/10.1111/cogs.13365>
- [5] Richard E. Clark, David F. Feldon, Jeroen J. G. van Merriënboer, Kenneth A. Yates, and Sean Early. 2007. *Cognitive task analysis. The handbook of research on educational communications and technology*, Routledge, 577-593.
- [6] Cynthia E. Coburn and William R. Penuel. 2016. Research-practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher* 45, 1 (2016), 48-54. <https://doi.org/10.3102/0013189x16631750>
- [7] Julie Gainsburg. 2008. Real-world connections in secondary mathematics teaching. *Journal of Mathematics Teacher Education* 11 (2008), 199-219. <https://doi.org/10.1007/s10857-007-9070-8>
- [8] Holstein, Kenneth, Bruce M. McLaren, and Vincent Aleven. 2019. Co-designing a real-time classroom orchestration tool to support teacher-AI complementarity. *Journal of Learning Analytics* 6, 2 (2019), 27-52. <https://doi.org/10.18608/jla.2019.62.3>
- [9] Martin Kindt, Mieke Abels, Truus Dekker, Margaret R. Meyer, Margaret A. Pligge, and Gail Burrill. 2010. Comparing quantities. In *Wisconsin Center for Education Research & Freudenthal Institute (Eds.), Mathematics in context*. Encyclopedia Britannica, Chicago.
- [10] James A. Kulik and John D. Fletcher. 2016. Effectiveness of Intelligent Tutoring Systems: A meta-analytic review. *Review of Educational Research* 86, 1 (2016), 42-78. <https://doi.org/10.3102/0034654315581420>
- [11] LuEttamae Lawrence, Vanessa Echeverria, Kexin Yang, Vincent Aleven, and Nikol Rummel. 2023. How teachers conceptualise shared control with an AI co-orchestration tool: A multiyear teacher-centred design process. *British Journal of Educational Technology* (2023), 823-844. <https://doi.org/10.1111/bjet.13372>
- [12] Tomohiro Nagashima, Anna N. Bartel, Elena M. Silla, Nicholas A. Vest, Martha W. Alibali, and Vincent Aleven. 2020. Enhancing conceptual knowledge in early algebra through scaffolding diagrammatic self-Explanation. In *Proceedings of the International Conference of the Learning Sciences, International Society of the Learning Sciences*, Nashville, TN, 35-42. <https://doi.org/10.31219/osf.io/bwfw>
- [13] Tomohiro Nagashima, John Britti, Xiran Wang, Bin Zheng, Violet Turri, Stephanie Tseng, and Vincent Aleven. 2022. Designing playful intelligent tutoring software to support engaging and effective algebra learning. In *European Conference on Technology Enhanced Learning*. Springer International Publishing (2022), 258-271. https://doi.org/10.1007/978-3-031-16290-9_19
- [14] Mitchell J. Nathan and Martha W. Alibali. 2010. Learning sciences. *Wiley Interdisciplinary Reviews: Cognitive Science* 1, 3 (2010), 329-345. <https://doi.org/10.1002/wcs.54>
- [15] Juan P. Sarmiento and Alyssa F. Wise. 2022. Participatory and co-design of learning analytics: An initial review of the literature. In *LAK22: 12th International Learning Analytics and Knowledge Conference (LAK22)*. ACM, New York, NY, USA, 535-541. <https://doi.org/10.1145/3506860.3506910>