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Abstract This research explored the implementation of a technology-enhanced instructional model for interdisciplinary learning. The model was developed in a previous phase of this research via DBR in the context of higher-education. Our aim in the current phase was to extend the applicability of the model and refine its underlying design principles based on their implementation in three secondary schools. For this purpose, a research-practice partnership was established, which included researchers, practitioners from an educational non-governmental organization, school principals, and teachers. Three practitioner-teams, facilitated by one of the researchers, collaboratively designed their own technology-enhanced interdisciplinary learning environments, in which they adapted the instructional model. This paper presents a new type of principled practical knowledge (PPK) —enhanced principled instructional model— which was obtained by comparison between the practitioners' designs and the original, higher-education context design. The PPK broadened the partnership's understanding of ways to promote interdisciplinary learning. Furthermore, it has raised new perspectives that were not considered during the development of the model, thereby allowing deeper understanding of the notion of interdisciplinary learning. Thus, this study illustrates how the establishment of productive research-practice partnerships can serve as a powerful strategy for implementing and scaling educational innovations beyond the original DBR context.

Keywords Enhanced principled instructional model
Design based research (DBR)
Interdisciplinary learning
Principled practical knowledge (PPK)
Research-practice partnerships (RPP)
Technology-enhanced learning environments

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Extending the applicability of design-based research through research-practice partnerships

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1.0 Introduction

One of the main reasons for the well-documented research-practice gap in educational research is the fact that many educational innovations are developed and explored in specific educational contexts (Goodyear & Dimitriadis, 2013). This enables researchers to focus on the exploration of fine-grained issues of learning and instruction, on innovative uses of new and emerging technologies (McKenney, 2013), and on the development of stable designs that have recognizable identities that lead to desired learning outcomes (Bielaczyc, 2013). However, not enough attention is given to the exploration of future adoption and adaptation of these innovations beyond the original research context (McKenney, 2013; Goodyear & Dimitriadis, 2013). Specifically, not enough is known about the broader factors that determine if, and how innovations are understood, adopted and used by practitioners, and especially teachers and schools, so that the ownership of the innovation can be shifted from the designers to the hands of those who would continue to use it (McKenney, 2013). As a result, implementation of innovations beyond the context of the research in which they are developed often raises design problems and new challenges that are typically not met in the context of the (design-based) research and development phases. At the same time, extending the research context is an opportunity to test the innovative designs in different conditions. In contrast to the more traditional custom, in which knowledge flows uni-directionally from researchers to practitioners (Ormel, Pareja-Robin, McKenney, Voogt, & Pieters, 2012), this opportunity allows for bi-directionality (enabling knowledge to flow back and forth between practitioners and researchers). Adding a research phase that examines the applicability of an innovation in an additional, different context, and involving practitioners as partners, opens up the possibility to learn from the practitioners' enactment of the instructional models and to use this knowledge to derive generalized understandings of how to support others in doing so.

The design-based research (DBR) genre of research has been developed to complement other educational research genres with the purpose of increasing the impact, transfer and translation of educational research into improved practice (Anderson and Shattuck, 2012), while contributing to educational theory building. DBR brings research and practice closer together since it potentially takes place in authentic complex settings and is therefore more ecologically valid, leading to more usable findings, while also involving practitioners' voices (Ormel et al., 2012). Accordingly, the outcomes of DBR studies are both theoretical and practical in their nature (Barab & Squire, 2004; Cobb, Confrey, DiSessa, Lehrer, & Schauble, 2003; Collins, Joseph, & Bielaczyc, 2004; McKenney & Reeves, 2012). Bereiter (2014), however, argues that DBR studies need to better connect between the theoretical and the practical, and have the potential of doing so by generating more generalizable knowledge, which he named Principled Practical Knowledge (PPK). PPK, he maintains, has some characteristics of scientific theory („know-why"), being explanatory in its nature, and based on coherence with other explanatory propositions in the field. However, PPK's main function is practical guidance („know-how"), which speaks directly to the types of problems that practitioners address in the course of their work. Bereiter explains that:

> „PPK grows out of efforts to solve practical problems, but it requires additional effort invested in producing knowledge that goes beyond what is required for the task at hand yet not so far beyond as to be unusable by practitioners". (p. 4)

In the theoretical and methodological section of this article, we elaborate on the notion of PPK, and current debates in the learning science community regarding the form it needs to take to make it useful. For the purpose of the current introduction, it is important to note that recently, a new line of research has emerged that has the potential to foster the development of PPK in DBR studies. It focuses on Research-Practice Partnerships (RPPs) (Kali, Eylon, McKenney & Kidron, forthcoming; Coburn & Penuel, 2016; McKenney, 2016) that can be established as part of DBR, and has been termed Design Based Implementation Research (DBIR) to highlight the collaboration with practitioners (Fishman, Penuel, Allen, Haugan Cheng, & Sabelli, 2013). Tabak, Nasser and Asher (2015) have suggested that RPPs in such research endeavors can raise the different concerns that are necessary for the production of PPK. The current study explores this notion empirically, while demonstrating the means and mechanisms for doing so. We[1] focus on the development of what we view as a type of PPK – *innovative enhanced principled instructional models* that lend themselves to implementation in various educational contexts. In ‚instructional model' we refer to a description of a set of (technology-enhanced) features that together, have been shown to advance a certain educational goal (e.g., interdisciplinary learning). In ‚principled' we mean that the model is augmented with design principles that enable people who wish to adopt (and potentially adapt) the model, to understand the rationale and theoretical background behind the design of the features (as illustrated in Table 1 below). In ‚enhanced', we seek to convey that the principled instructional model provides information for potential implementers regarding others' practical experience and considerations of implementation (as illustrated in the discussion below).

The enhanced principled instructional model we explored in this study – Boundary Breaking for Interdisciplinary Learning (BBIL) - was developed in a DBR methodological approach to promote interdisciplinary understanding among higher-education students (Kidron & Kali, 2015). We view this three-year DBR study (further described below), as Phase I of the research project.

[1] In the context of this article, ‚we' refers to the two authors only, whereas all other groupings with the RPP's participants are indicated specifically.

The rationale for developing this model was that the ability to integrate knowledge from different disciplines is one of the most important skills people need in today's information society. This skill is required for developing interdisciplinary understanding of complex and critical issues relevant to our society (e.g., climate change, migration, human rights, or terrorism). We assumed that this skill is relevant not only for higher-education students but for high school and even middle-school students as well.

Our aim in the current work, which we view as Phase II of the research, was to expand the applicability of the BBIL model by enhancing it with practical insights. Therefore, we extended the context for which it was developed in Phase I, and explored the way it was implemented in a very different context - school. To do so, we established in Phase II a RPP (Coburn & Penuel, 2016; McKenney, 2016) with Kadima Mada - World ORT, a non-governmental organization (NGO) that specializes in the implementation of educational innovation within school-contexts. This led to the formation of three practitioner-teams from three different schools who volunteered to be involved in co-design and enactment of technology-enhanced interdisciplinary learning environments, based on the BBIL model. Our goal in the current work (Phase II of the research) was to document the PPK (in the form of *enhanced principled instructional model*) that resulted from, and was developed through, the adoption and adaptation of the BBIL model by practitioner-teams as part of the RPP. By doing so, we address several calls:

- Sharing research that features practitioner co-creation of knowledge, and analysis of the reasoning and influences shaping instructional interventions (Ormel et al., 2012),
- Documenting how students and teachers change and adapt interventions in interactions with each other in relation to their dynamic local contexts (Gutierrez & Penuel, 2014),
- Explaining how to produce PPK that is both principled and practical (Bereiter, 2014).

2.0 Theoretical and methodological perspectives

2.1 Extending the applicability of designs beyond the research context

To extend the applicability of DBR projects, Goodyear and Dimitriadis (2013) claim that researchers should consider: (1) the complexities involved in enacting the design in new contexts; (2) the customization teachers might make to adjust the design to the new context; (3) supporting the work of teachers who will continue to enact the innovation outside the research-context; and (4) the need for periodic review and redesign of the innovation. Therefore, a design should, amongst other aspects, prepare for modifications and adaptations of the design to suit specific needs (*„design for configuration"*), and provide support for the teachers' work in real-time (*„design for orchestration"*) (Goodyear & Dimitriadis, 2013). We view the process of enhancing principled instructional models as a way to address these considerations. Bielaczyc (2013) too, referred to the issue of applicability noting the importance of „making the model transportable to settings outside the innovator‘s control“ (p.260). This means that designers of instructional models should consider issues of dissemination, and design ways to support teachers in implementing innovative models within a classroom context, which may be quite different from the DBR context, as in the case of the current study. Another relevant notion is the *zone of proximal implementation* (ZPI) (McKenney, 2013), which refers to what teachers and schools can implement with realistically sustainable amounts of guidance or collaboration. Designing for ZPI means, „explicitly tailoring products and processes to fit the needs of not only learners, but also of teachers and schools“. Expanding the design of educational innovation to address the different implementation needs, as described in the current endeavor, is important for the relevance and practical applicability of DBR, as well as for the successful implementation of innovation within educational systems. Nevertheless, it may lead to challenges that these new realities pose. Possible challenges were described by the Open University of the Netherland (Kirschner, Hendricks, Paas, Wopereis, & Cordewener, 2005) as the six „sure-fire causes of failure“ for the implementation of technology innovations. These include: (1) lack of balance between investments and output; (2) information politics that prevent the transmission of information; (3) lack of responsibility of the different participants; (4) culture gaps between planning and enacting teams of the innovation; (5) over-commitment that distracts managerial decision-making; and (6) all-in-one solutions that lead to too many goals per project. As described in the introduction above, in our case, we explored the shifting from a higher-education to a school context. At the same time, we shifted from a study in which we served as both designers and enactors in Phase I, into a situation that was to a large extent „outside the innovator‘s control“ (to put it in Bielaczyc‘s words), in Phase II of the research. Accordingly, the school context posed additional challenges, such as issues of alignment to the curriculum, insufficient infrastructure, and lack of teacher expertise, and sometime even interest.

An additional perspective that can inform the process of broadening DBR contexts is McKenney and Reeves‘ (2012) characterization of successfully implemented innovations. These include: (1) *value-added*, i.e., the innovation brings some kind of improvement; (2) *clearness*, i.e., the innovation‘s ideas, procedures and mechanisms are easy to understand; (3) *compatibility*, i.e., the innovation is congruent with characteristics of the target setting such as existing values, cultures, practices and beliefs; and (4) *tolerance*, i.e., the extent to which the design of the innovation can be changed during its adaptation without losing the original goals and turning into what Brown and Campione (1996) defined as „lethal mutations“. The process of co-designing the interdisciplinary learning environments for schools, and developing the PPK in the current study, enabled the RPP to consider all these issues, as elaborated in the discussion.

2.2 Principal practical knowledge

To clarify the value of PPK, Bereiter begins by illustrating limitations of practical knowledge that is not enough principled, as well as principled knowledge that lacks practicality. For instance, he notes that a typical food recipe includes non-principled practical knowledge, because „it tells us what to do, but it seldom tells us why“ (p. 5). The lack of explanation makes it difficult to improve the recipe because „without principled knowledge we have no way of evaluating these alternatives except through empirical trials“ (p. 5). On the other hand, principled knowledge may lack on the practicality dimension. DBR studies result in theoretical explanations regarding how people learn in particular contexts, and often produce innovations designed for that context. But, according to Bereiter (2014), most DBR studies are missing a substantial „know-how“ ingredient, which together with the „know why“, can enable further development of the innovation.

The notion of PPK and its roots in DBR is relatively new. As a result, very little has been reported regarding how PPK can be produced and what forms make its outputs useful. It is clear that there is a wide territory between the recipe and the theory models, and that there are many different ways to combine „know why“ and „know how“ in DBR outcomes. However, balancing the two is far from trivial. For example, Kali (2006) has developed a principled approach for synthesizing practical design knowledge from various DBR projects. As part of this endeavor, the Design Principles Database (DPD) was developed (currently archived at http://edu-design-principles.org). The DPD has been useful for dozens of design researchers around the world who participated in contributing, discussing and coalescing design knowledge, and for many others who used the ‚browse‘ mode to learn about the synthesized knowledge developed (Kali, 2008). However, the use of the DPD by teachers as designers of technology-enhanced activities has been quite limited. Despite the many examples of technology-enhanced features in learning environments, linked with specific, pragmatic and meta design principles in the DPD, teachers found the information too abstract for their independent use (Kali & Ronen-Fuhrmann, 2011).

Another example illustrating the challenge of balancing the „principled“ and „practical“ in DBR outcomes can be depicted from the debate published in the Journal of the Learning Sciences following Bereiter‘s introduction of the notion of PPK. Janssen, Westbroek and Doyle‘s response article (2015)—provocatively entitled „how to move from what works in principle to what works in practice—maintained that PPK, as portrayed by Bereiter „does not suffice to address the challenging issues of practicality teachers face“ (p. 176). In order for PPK to fulfill this goal, they suggested to complement it with „fast and frugal heuristics“. Stemming from decision making research, such heuristics are known to enable people to ignore some information in order to make quick (and generally more accurate) decisions in complex situations. The debate continued with a response article by Bereiter (2015), entitled „the practicality of principled practical knowledge“. Bereiter claimed there, that fast and frugal heuristics represent a promising way of getting PPK to actual classroom action, but since such heuristics are unprincipled, they cannot be considered as PPK. He maintained that fast and frugal heuristics fail to meet the criterion of explanatory coherence, and therefore provide „inadequate support for improving the heuristic or generating new ones based on the same idea“ (p. 191). The current study suggests that the notion of ‚enhanced principled instructional model has the potential to provide a balance between the principled and practical knowledge in a productive manner.

2.3 Developing principled practical knowledge in research practice partnerships

Developing PPK inherently involves collaboration between researchers and practitioners while drawing on both types of expertise (Kali et al., forthcoming; Coburn & Penuel, 2016; McKenney, 2013). From the researchers‘ point of view, practitioners‘ enactment of the innovation enables to examine how the realization of the designed artifact functions in practice. Such an understanding can serve to improve the design and make it easier for its reuse in other contexts (Goodyear & Dimitriadis, 2013). From the practitioners‘ point of view, working with researchers is an opportunity to develop expertise and ownership of the innovation as the designers gradually fade away. Such fading should be supported with scaffolds specifically designed for the gradual change in responsibilities and division of labor (McKenney, 2013).

RPPs are defined as long-term collaborations between practitioners and researchers that aim at investigating issues of practice in various contexts (Coburn & Penuel, 2016; McKenney, 2016). Rather than addressing gaps in existing theory, such partnerships are motivated by key dilemmas and challenges that practitioners face. They employ rules, roles, routines and protocols that are designed to structure the interactions within the RPP. Even before the term RPP was coined, studies have explored the nature of partnerships between researchers and practitioners and the mechanisms to support them in educational research (e.g., Wagner, 1997). Recently, such studies have begun to take place in the context of DBR (Ormel et al., 2012; Mckenney, 2016). These studies delineated common processes, values and roles in design research partnerships, led by either practitioners or researchers. Kali (2016) views these partnerships as ranging on a continuum between *cooperative* and collaborative. That is, the responsibilities within such partnerships can be divided between practitioners and researchers in various ways in different types of partnerships. In the cooperative type of partnership there is a clear division of labor between practitioners and researchers, with only very little overlap of responsibility. As the degree of collaboration increases, there is more and more overlap in the responsibilities taken by participants, until a situation where the researchers and practitioners are engaged in all practices. That said, it is important to note that in most K-12 DBR studies, the researchers serve as agents, who oversee the local adaptation into classroom practices (Bielaczyc, 2013). The current study, in contrast, can be characterized as residing at the collaborative side of Kali's (2016) continuum, as we demonstrate below.

3.0 Methods

3.1 Methodological approach

This work follows Bielaczyc's (2013) DBR approach exploring critical change processes that occur during the practical implementation of educational innovations by schoolteachers (e.g., adaptations made to adjust the innovation to local constraints and affordances). This knowledge, she argues, can be integrated into a „theory of trajectories of change", or *„implementation paths"*, that can inform future implementations in additional educational settings which are necessary for scaling the innovation. The data for the comparison are the design decisions teachers take. These refer to four dimensions: cultural beliefs, practices, socio-techno-spatial relations, and interactions with the outside world. Analysis of the comparison can take different perspectives, each indicating different issues of adaptation and implementation paths: (1) points of divergence from the original design – can indicate various implementation conditions that need to be considered or scaffolded; (2) variations across iterations of teachers designs – can indicate the possible affordances and constraints of particular implementation approaches; (3) increased detail of dimensions in teachers' designs – can indicate insufficient information needed for the enactment of the design within a classroom. Out of these three perspectives, Bielaczyc focused on examining *points of divergence* in order to understand how teacher designs can help construct implementation paths. This rationale is strengthen by the work of Sannino, Engestrom and Lemos (2016) who argued that the study of interventions should focus on ‚productive deviations', i.e., deviations from the researchers' instructional intentions, because of their potential to lead to significant outcomes, both practical and theoretical, which could not have been anticipated by the interventionists, nor by the participants. In the current study, we used these approaches to compare the designs of teachers who adopted and adapted the BBIL principled instructional model into a school context, with the design of the Phase I (higher-education) research context. This comparison enabled us to shed light on the negotiation teachers made between the BBIL models' goals and principles, and the reality of their local contexts.

3.2 The original research context of the BBIL model (Phase I)

The BBIL model refers to three perspectives – curricular, pedagogical, and organizational – each represented as a design principle that can be embodied by unique technology-enhanced features (table 1). The curricular perspective builds on notions of interdisciplinarity (Boix-Mansilla, 2010) as well the notions of knowledge integration (Linn, 2006; Linn & Eylon, 2011), and is represented as the „breaking boundaries between disciplines“ design principle. The technology-enhanced features that embody this design principle seek to assist learners to integrate knowledge, ideas and insights within and between disciplines. The pedagogical perspective builds mainly on the notion of learning communities (Bielaczyc & Collins, 1999; Bielaczyc, Kapur, & Collins, 2013), and the organizational perspective builds mainly on the notion of cognitive apprenticeship (Collins, 2006). These perspectives are respectively expressed as the „breaking boundaries between learners“ and „breaking boundaries between organizational hierarchies“ design principles.

Table 1: Design principles and features of the BBIL model (See detailed version in Authors, 2015)

The design principle	Technology-enhanced features
Design principle 1: Breaking boundaries between disciplines This curricular perspective builds on notions of interdisciplinarity (Boix-Mansilla, 2010) as well the notions of knowledge integration (Linn, 2006; Linn & Eylon, 2011).	1. Cross-cutting theme 2. Guidelines for integrative artifacts 3. Integrative lens 4. Disciplinary resources 5. Deepening and focusing script 6. Moderation for interdisciplinarity 7. Interdisciplinarity norm prompts
Design principle 2: Breaking boundaries between learners This pedagogical perspective, builds mainly on the notion of learning communities (Bielaczyc & Collins, 1999; Bielaczyc et al., 2013).	8. Collaborative knowledge-building activities 9. Reuse of student artifacts 10. Peer review activities 11. Social infrastructure activities 12. Learning community norm prompts
Design principle 3: Breaking boundaries between organizational hierarchies This organizational perspective builds mainly on the notion of cognitive apprenticeship (Collins, 2006).	13. Personal mentoring 14. Modeling artifacts 15. Structured feedback activities between communities 16. Coaching

To implement the BBIL model in the higher-education context of phase I, Kidron & Kali (2015) designed an interdisciplinary, technology-enhanced, semester-long course for undergraduate students. The course‘s title, as well as its cross-cutting theme, were derived from the LINKS I-CORE research center‘s scientific agenda. This work, conducted in phase I, which served as the theoretical and curricular basis for the current study, has demonstrated the potential of the BBIL model to promote interdisciplinary understanding. We hereby provide a brief summary of the main findings in the three iterations of the DBR study in Phase I (Kidron & Kali, 2015).

The first iteration of the study indicated that the students’ interdisciplinary understanding of the course contents significantly improved, as portrayed in 1000-word essays they wrote as ‚integrative artifacts‘ (feature 2 in Table 1) in the course. The essays produced at the end of the course indicated higher levels of knowledge integration (Linn & Eylon, 2011) between the various disciplinary perspectives of the course contents. Content analysis of students‘ answers to open-ended questions indicated that this outcome can mostly be attributed to the technology-enhanced features designed to promote breaking boundaries between disciplines (design principle 1 and features 1-7), and that the potential of the two other design principles was not fully exploited.

This potential, and especially the value of breaking boundaries between learners (design principle 2), and features designed to support the classroom to act as a learning community (features 8-12) was further studied in the second and third iterations. Based on observations conducted in the second iteration, in which the design of these features was refined, we devised the third iteration as an experimental study focusing on the added-value of the learning community approach to students' development of interdisciplinary learning. Findings indicated that integrative essays written by students who studied in an online learning community approach (implementing the refined version of the course design) showed higher levels of synthesis as compared with the essays written by students who studied the same course in which the learning community features (8-12) were omitted. Equipped with these understandings in this first phase of the DBR, we decided to partner with schools for the second phase of the study, in which we collaboratively examined the BBIL model's applicability with a younger audience, and a very different context - schools.

3.3 Participants of the RPP in the current research (Phase II)

By definition, RPPs involve different perspectives, expertise, and motivations that lead to various forms of engagement of the various participants. These are reflected in the types of issues facing the RPP (e.g., defining key processes of the RPP, common roles, agreeing on core values that serve the mission, and setting up common expectations) throughout the different phases of the work: analysis and exploration, design and construction, evaluation and reflection (McKenney, 2016).
The RPP in the current research comprised of the following participants:

- **Members of the Kadima Mada - World ORT organization (NGO) for the implementation of educational innovations.** The leading participant was the NGO's chief pedagogical officer who was experienced in building different types of partnerships in order to promote the NGO's goals. Though not always present, she was very involved in all phases of the implementation, enriching the discussions with various relevant insights from other parallel projects and partnerships. Her team, which included technological and pedagogical personnel, participated in different levels of involvement.
- **Researchers.** The two authors of this article, who were part of the RPP, were also part of the LINKS I-CORE research center - an interdisciplinary center for the research of co-creation of knowledge in technology-enhanced communities of learning. The first author participated as the facilitator and moderator of the RPP and the second author as the academic consultant and supervisor.
- **Schools.** Three middle-schools (grades 7th to 9th) were offered to participate in the RPP, to experience new ways of learning for both teachers and students, and receive the required technological infrastructure (e.g., laptop computers). The schools were part of broader comprehensive schools

(grades 7th to 12th), affiliated with the NGO. Eight 8th grade classes (two from School 1, four from School 2, and two from School 3), each consisting of about 35 students, participated in the partnership. In schools 2 and 3 this included all 8th graders and their teachers, and in school 1 this included half of the 8th grade classes.

- **School principals.** Three representatives from each school management participated in the RPP. Their level of involvement in the RPP differed according to their personal preferences and the school's organizational culture.
- **Teachers.** Twenty teachers from the three schools participated in the RPP. The teachers were chosen by the school principals out of the 8th grade teaching teams, who agreed to participate in the RPP. Most of them were senior teachers in their schools, who professionalized in different disciplines: biology, chemistry, physics, geography, history, art, and social studies. Some of the teachers were the homeroom-teachers, i.e., they were in charge of social and educational aspects of the class (rather than disciplinary-domain aspects). Their previous experience with educational technologies varied from no experience at all, to much experience in incorporating technology into the everyday teaching.
- **Ministry administrators.** Two district superintendents participated in the RPP retreats and occasionally visited the school sites.

3.4 Mechanisms to support the RPP

Since only little is known about the specific tasks and activities that enable RPPs to work productively (Ormel et al., 2012), we find it important to describe the mechanisms that were designed to support the RPP in the current study:

- **Kickoff meetings.** The first meetings in the establishment of the RPP in which only a small forum of representatives (school management, researchers, and NGO representatives) in each school decided on their unique ‚operation model' (table 3). In these meetings, participants defined the general framework for their implementation, such as the age of the students who will participate, the duration of the enactment, etc.
- **Co-design workshop.** In order to enable the teachers to get familiar with the BBIL model, and for us to learn about the characteristics, needs, affordances and constraints of each of the school contexts, we conducted three 30-hour workshops (at each of the schools) before the beginning of the year. The workshops included activities that supported teachers in: (1) getting familiar with the theoretical ideas regarding interdisciplinarity, learning communities, and technology-enhanced learning environments; (2) designing a technology-enhanced interdisciplinary learning environment based on the BBIL design principles and features (table 1); and (3) experiencing a learning community culture supported by technology. These activities triggered open discussions in which teachers reflected and shared insights about their own school culture.

Acquaintance with the specific school contexts enabled us to collaboratively consider different dilemmas that arose during the adaption of the BBIL model and the design of the technology-enhanced learning environments. These dilemmas involved various negotiations between the participants regarding different theoretical and practical perspectives. At the same time, it enabled all participants to reflect on the BBIL model and better understand its features. The artifacts developed during the workshop (e.g., design documents, learning materials) were documented in an online „RPP Website" we developed for this purpose. In order to receive external accreditation, the participants wrote a summative assignment in which they analyzed their designed technology-enhanced interdisciplinary learning environment, and reflected on the learning process.

- **Reflection in practice meetings.** Following the co-design workshop, each practitioner-team held ongoing meetings during the enactment of the interdisciplinary learning environments they have developed. The meetings, which were organized by the teachers, were supported by the researcher, who joined about a third of them. During the meetings, team members reflected on their experiences and shared emergent student insights. This was especially important due to the interdisciplinary nature of the programs. The teachers' understanding of the insights that were developed with the students in the separate lessons was crucial for supporting the students' interdisciplinary understanding. Additionally, meetings were used for addressing ongoing needs, such as discussing emerging implementation issues, refining the learning materials or activities for the students based on insights from the enactment, or solving unexpected problems (e.g., infrastructure fails, or unplanned school activities which interrupted the planned timeline).
- **RPP retreats.** Once a year all participants of the RPP (about 40 participants, including teachers, school managers, researchers, and administrators from the three schools) met in order to collaboratively develop the PPK. The researchers guided the process based on Bielaczyc's (2013) implementation paths approach. To do so, we (the researchers and the NGO representatives) planned the following activities: (1) Plenary sessions included presentations of each of the teachers' team work (the technology-enhanced interdisciplinary learning environments they designed, as well as their students' artifacts); (2) Small (mixed) group sessions included discussions regarding common challenges, and sharing of experiences specific perspectives from the three schools. The products of all these activities were documented as shared insights and recommendations in the online „RPP Website".
- **RPP leaders' meetings.** Periodic meetings between the researchers and the NGO representatives were conducted to reflect on the overall process, ensure that the overarching goals of the program are met, re-examine these goals in light of the occurrences, and make strategic decisions to lead the project.

- **The „RPP website".** An online working environment was developed to support the different mechanisms described above. The website was developed in Moodle with embedded Google Docs, and was available to all the RPP's participants throughout the year. It consisted of separate collaborative work areas (for each school) as well as general areas (for all the RPP's participants), and thus, served as a „growing portfolio" that documented the processes as well as products of the whole project.

3.5 Data sources

In order to compare the designs and the different decisions taken by the practitioner-teams in adapting the BBIL model to their local settings, data were collected from the following sources:

- **Co-design workshop artifacts.** These artifacts were saved in the RPP Website and included the documentation of the various dilemmas, considerations, specifications and decisions taken during the different stages of the design process (e.g., the stages of defining the cross cutting theme and disciplines, the disciplinary and interdisciplinary learning goals, learning scripts, or student evaluation rubric). Artifacts also included the learning resources that teachers developed for their students during the workshop.
- **Technology-enhanced interdisciplinary learning environments.** These environments were designed by the teachers for the use of their students and were developed as Google or Moodle environments with embedded Google docs. They typically reflected the decisions made in the design documentation, as well as several „on the fly" design decisions that took place during the enactment.
- **Teachers' summative assignments.** These were written by each teacher at the end of the co-design workshop, and included teachers' analyses of the technology-enhanced interdisciplinary learning environment design, and a reflection on his or her own learning process.
- **Participants' reflections on action.** Participants' reflections regarding the program were documented both by various participants of the RPP during the yearly retreats, and by the researcher during the summary meetings in each of the schools.
- **Researcher's reflective diary.** Following each co-design meeting, the participating researcher documented the events, and his interpretation of the events. This enabled the two researchers, sometimes with the NGO leaders, to discuss various implementation issues, and decide how to continue leading the project.
- **Monthly reports.** These internal reports were written by the participating researcher and sent to the NGO representatives. The reports included detailed status of the implementation process, different pedagogical, technological or organizational challenges, and future planning.

- **Interviews.** Four of the RPP‘s participants were interviewed at the end of the enactment to enable deeper understanding of the issues that were negotiated within each practitioner-team.

3.6 Data analysis

To compare the designs of teachers with the design of the original research context, we used the BBIL model‘s design principles as organizing dimensions (instead of the dimensions defined by Bielaczyc, 2013), since they comprise the essence of our innovation that we sought to refine within the RPP.

The analysis of the comparison included three steps:

(1) **Mapping.** Using the data sources mentioned above, we mapped the dilemmas that arose for each of the design features during the co-design workshop in all three schools.

(2) **Classifying.** Based on Bielaczyc‘s (2013) perspectives, each dilemma was classified in terms of its divergence from the BBIL model as one of three possible types (table 2). To achieve inter-rater reliability (IRR) the two authors of this paper independently classified each dilemma. Initial IRR was 82% (agreement on 18 of the 22 dilemmas mapped) and following discussion reached 100%.

(3) **Analyzing.** We decided to focus our analysis on the Existing Dilemma New Solution (EDNS) type of dilemmas. The rationale for this is inspired by the work of Sannino and her colleagues (2016), which emphasized the importance of deviations to both practical outcomes and theoretical understanding. Analysis of the EDNS dilemmas enabled us to identify both new considerations that were not raised during the original design, and new practical solutions that were designed to address the new needs, thereby deviating from our original solutions

Table 2: Type of dilemma in terms of divergence from the BBIL model

Type	Divergence scale
Existing Dilemma and Solution (ED&S)	Dilemmas that were considered in the original design of the BBIL model in the higher education context, in which adaptations in all three schools was quite similar to original solutions. This includes adaptation of only part of the original designed solutions.
Existing Dilemma New Solution (EDNS)	Dilemmas that were considered in the original design, in which adaptations in all three schools yielded new, and sometimes varied solutions (category based on Bielaczyc's (2013) notion of "points of divergence from the original design").
New Dilemma (ND)	The adaptation yielded new dilemmas that were not taken into account during the original design (category based on Bielaczyc's (2013) notion of "increased detail of dimensions in teacher's designs".

4.0 Findings

4.1 The three schools' implementation paths

Table 3 describes the different operation models implemented in each school. The operation model was defined mainly with the school management in the Kickoff meetings. It included the general framework of the implementation and therefore influenced many of the design decisions that were taken later on by the practitioner-teams. All practitioner-teams designed technology-enhanced interdisciplinary learning environments for their students (Figure 1) based on the BBIL design principles and features (Table 1). The learning environments differed in their themes, content domains, and integrative lens questions, as demonstrated in table 4. All learning environments comprised of technology-enhanced activities in which students learned disciplinary contents, explored interdisciplinary connections, and culminated with an integrative assignment.

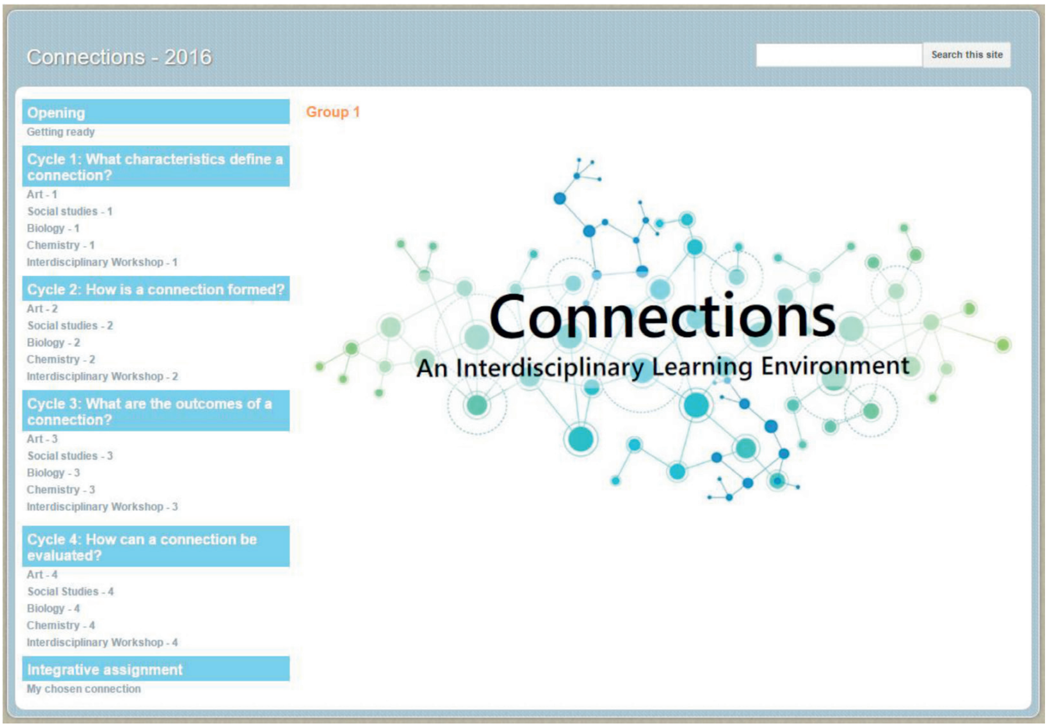

Figure 1: Homepage of the learning environment designed by School 1 practitioner-team

Table 3: Summary of the operation models defined by the school managements

	School 1	School 2	School 3
Grade	8th	8th	8th
Number of classes taught	2	4	2
Duration (weeks)	16	4	6
Incorporation into the weekly schedule	2 weekly hours: Disciplinary/ Interdisciplinary lesson	9 weekly hours: 4 disciplinary lessons (2h) 1 interdisciplinary lesson (1h)	8 weekly hours: 3 disciplinary lessons (2h) 1 interdisciplinary lesson (2h)
Duration of enactment (hours)	32	36	40
Duration of disciplinary activities (hours)	24 (half class)	32 (full class)	30 (full class)
Duration (and class size) of interdisciplinary activities (hours/classes)	8 (half class)	4 (full class)	10 (half class)
Identity of the interdisciplinary moderator	Disciplinary experts (development team)	The homeroom-teachers (some are disciplinary experts)	Disciplinary experts + homeroom-teachers

Table 4: The interdisciplinarity features of the BBIL model as designed in the three schools

	School 1	School 2	School 3
Cross cutting theme (feature 1)	Connections	Revolutions	Futurism
Disciplinary domains and topics (feature 4)	• Biology (animals' communication) • Chemistry (chemical bonds) • Social studies (social structures) • Art (relations and feelings)	• Biology (the discovery of microorganisms) • History (the French revolution) • Geography (continents discovery) • Art (the invention of the camera)	• Biology (genetic engineering) • Physics (alternative energy) • Geography (pollution)
Integrative lens questions (feature 3)	1. What characteristics define a connection? 2. How is a connection formed? 3. What are the outcomes of a connection? 4. How can its implications be valued?	1. What defines a revolution? 2. What enables a revolution? 3. What are the implications of a revolutions? 4. How can a revolution be evaluated?	1. What is considered as "change"? 2. What needs lead humankind to interfere in nature laws? 3. What are the consequences of these human interventions? 4. Where are we heading?
Guidelines for integrative artifact (feature 2)	"My chosen connection": choose any subject of interest and analyze the different connections within this subject, based on the integrative lens questions. Creatively integrate two disciplinary examples into the chosen subject.	"My revolution": present either a personal revolution, or one of the revolutions taught in the learning unit, or a revolution that was not explored in the learning unit, or a suggestion for the presentation of the whole learning unit to next year's students.	"A day in my next century life": describe your futuristic daily life while referring to the disciplinary domains.

4.2 Emergent dilemmas

The analysis of the data resources revealed 22 dilemmas that were raised by the three practitioner teams, regarding the implementation of different design features (table 5). Due to the intensive knowledge sharing between practitioners in the three schools, which was supported by the RPP mechanisms described above (e.g., the RPP website, the RPP retreats), there were many similarities in both the design dilemmas and the solutions designed by the three teams. Therefore, we present the list of dilemmas in table 5 as a whole (and do not focus on differences between schools). The analysis of the types of dilemmas indicates that 50% (11 dilemmas) represent new solutions to existing dilemmas (EDNS), 41% (9 dilemmas) represent new dilemmas (ND), and 9% (2 dilemmas) represent existing dilemmas where the original designed solutions were adopted as is (ED&S). We describe in detail and discuss five of the EDNS dilemmas in the ‚discussion' section below.

Table 5: Emergent dilemmas (organized by design principles and features of the BBIL model)

Design principle 1: Breaking boundaries between disciplines		
Design features	**Dilemmas**	**Type***
The cross cutting theme	1. What makes a good cross cutting theme?	EDNS
	2. Who should be involved in choosing the cross cutting theme?	ND
	3. What comes first – the cross cutting theme or the disciplinary domains?	ND
Integrative lens questions	4. How should the integrative lens questions be incorporated in the learning sequence?	EDNS
Integrative artifacts	5. What makes a good integrative artifact?	EDNS
	6. What are possible formats for integrative artifacts?	EDNS
	7. When should the integrative artifact be incorporated into the learning sequence?	EDNS
	8. What type of guidelines should be provided to students?	EDNS
Deepening and focusing script	9. How flexible can the deepening and focusing script be?	EDNS
Moderation for interdisciplinarity	10. To what extent should the interdisciplinary moderator understand the disciplinary domains?	EDNS
	11. How can students' insights be streamlined throughout the unit in order to support connections between them?	EDNS
Interdisciplinary norm prompts	12. How to provide personalized prompts for students in a large class?	EDNS
Design principle 2: Breaking boundaries between learners		
Design features	**Dilemmas**	**Type***
Collaborative knowledge building activities	13. How to support collaboration within large groups of learners?	ED&S
Reuse of students' artifacts	14. How to motivate learners to reuse their peers' artifacts?	ED&S
Peer-review activities	15. How can the age of learners be taken into account when designing peer-review activities?	ND
Social infrastructure activities	16. What type of social infrastructure activities are required for interdisciplinary learning when students already know each other?	EDNS
Design principle 3: Breaking boundaries between organizational structures		
Design features	**Dilemmas**	**Type***
Implementation model (this feature emerged during the school implementation)	17. How long should an implementation be?	ND
	18. How intense should the learning process be?	ND
	19. How can the model be adapted to different age groups?	ND
	20. When should schools combine online learning?	ND
	21. When should classes be divided into smaller groups?	ND
	22. When should the BBIL model be implemented as a whole?	ND

5.0 Discussion

All of the mapped dilemmas served as an invaluable resource for enriching our understanding of the BBIL model and its implementation. For the purpose of the current discussion, we decided to focus on EDNS-type dilemmas that represented ‚productive deviations' (Sannino et al., 2016) from the original designed solutions. These dilemmas led to significant practical and theoretical outcomes that enabled the partnership to enhance the BBIL principled instructional model, and thus, expand its applicability. As can be seen in table 5, most of the EDNS dilemmas referred to the curricular perspective of the model (design principle 1), which, overall, raised most of the dilemmas, compared to the pedagogical and organizational perspectives (design principles 2, 3).

To demonstrate their contribution to PPK, we elaborate on five of the EDNS dilemmas (dilemmas #4, 6, 7, 9, and 10 in table 5), which focus on the implementation of interdisciplinary features. For each of these dilemmas, we describe and compare between the challenges, considerations, and scope of solutions that emerged in the RPP in the school context, to those documented in Phase I in the higher-education context. We also provide preliminary evidence that illustrate consequences of some of the design decisions made by the practitioner-teams. By doing so, we adopt Collins (1996) cost-benefit approach to guide design decisions, or in his words:

> "From this perspective, the crucial issues are: What are the issues that must be addressed in designing learning environments? What are the cost-benefit tradeoffs associated with each design issue? How should the costs and benefits be weighed?" (p. 347)

5.1 How should the integrative lens questions be incorporated in the learning sequence? (Dilemma #4)

The integrative lens questions in the BBIL model are a set of generic questions derived from the cross-cutting theme and implemented into the disciplinary activities to promote the development of interdisciplinary connections (for instance, 'How is *learning* conceptualized in each of the disciplinary domains?') (Kidron & Kali, 2015)

In the context of the undergraduate course in Phase I, students learned the disciplinary domains sequentially. That is, all the integrative lens questions were discussed for each domain (see the top part of figure 2). Our original design decision to use the same set of generic questions for each of the domains was based on the assumption that this will support students' development of deep understanding in each disciplinary domain, while also creating the ground for connections to other disciplinary domains.

This issue became an important dilemma in the school context in Phase II, since organizational constraints prevented the flexibility of teaching a whole disciplinary domain in a sequence of successive lessons. This would have required students to meet all the domain experts (the teachers) every week. In order to adapt to this organizational constraint, all three practitioner-teams adopted a different approach for the learning sequence and the incorporation of the integrative lens questions. Their design decision was to follow the notion of „interdisciplinary teaching cycles", in which following a relatively short exposure to each of the content domains, students discussed only one of the integrative lens questions (see bottom part of figure 2). The number of „teaching cycles“ was equal to the number of integrative lens questions (four to five), and had to fit the pre-defined duration of the enactment.

This design decision demonstrates how organizational constraints can lead to creative solutions and how important it is to *design for configuration* (Goodyear & Dimitriadis, 2013) and prepare for modifications of the design to specific needs. However, a tradeoff of these „interdisciplinary teaching cycles“ is that they may cause fragmentation of the disciplinary learning processes in each domain. Theoretically, this may give students more opportunities to examine the connections between the disciplines. However, since the process of deepening into the disciplinary ideas is a crucial and basic phase for the development of interdisciplinary understanding, this may become a price too high to pay. This concern was expressed in the co-design workshop meetings, as voiced in one of the teachers‘ comments, just before the implementation: „My biggest fear is that the learning will be superficial and that students won‘t get a real chance for deep understanding“ (researcher diary, school 2). Eventually, some of these concerns decreased during, and following the implementation, but further research is required to better understand the consequences of the two different models of learning sequences. We believe that awareness to such options and to the considerations they involve may increase the applicability of the model.

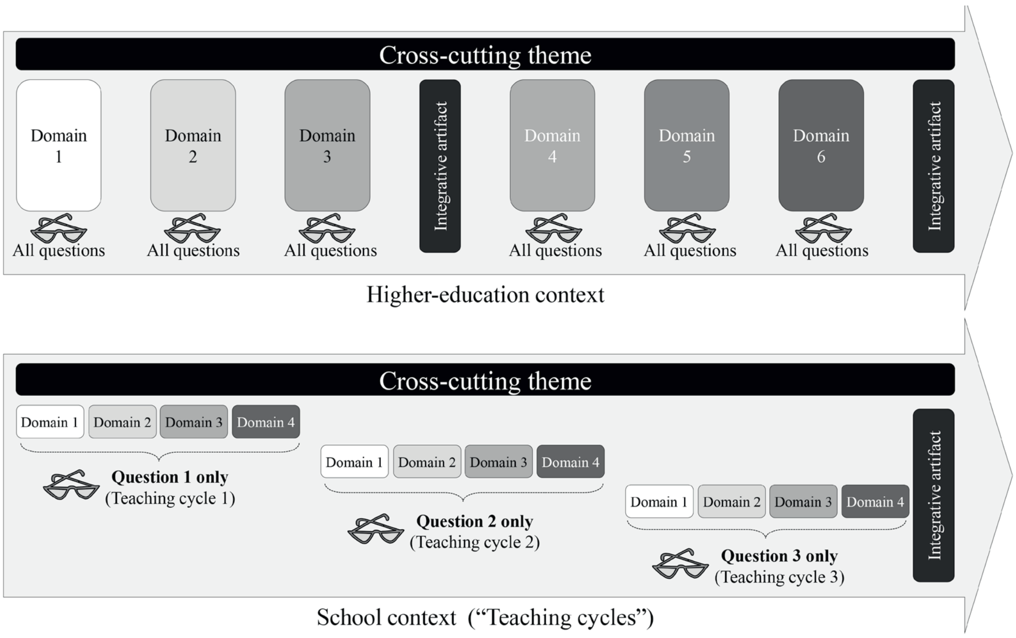

Figure 2: Options for incorporating integrative lens questions into the learning sequence

5.2 What are possible formats for integrative artifacts? (Diemma #6)

Integrative artifacts in the BBIL model are designed to help students build their interdisciplinary knowledge and to reflect on the integration of the disciplinary ideas (Kidron & Kali, 2015). The integrative artifacts designed for the undergraduate course, as mentioned above, were textual synthesis essays. This was a typical choice for an academic context, and it enabled us to systematically evaluate the essays and grade students. In addition, since the course was fully online it was easier, logistically, to work with textual artifacts.

When designing the integrative artifact for the school context, there was a consensus among most practitioners that the artifact students would be required to develop should be in a creative expressive format (songs, plays, drawings, movies, comics, etc.), with less emphasis on text, in order to enhance student engagement and to support different learning styles.

The general design consideration regarding this dilemma was that various expression formats are indeed engaging and support different learning styles. Nevertheless, an explicit verbal articulation of students' ideas or explanation of their creative artifact has its own benefits. First, it can support students' work and serve as a guiding rationale while immersing into the creative process. Second, it may ease the moderator to point out common ideas thereby promoting mutual learning and discussion. Third, it makes it easier to systematically evaluate the integrative artifacts in terms of their interdisciplinary value. Such considerations were well expressed in teachers' discussions, such as in the following saying: „The students were very enthusiastic and engaged when working on their artifacts; they even continued working during the lesson breaks. But it's hard to tell how much interdisciplinary understanding was there in these impressing and beautiful artifacts…" (Teacher's interview, school 2). Thus, future implementers of the BBIL model will need to weigh the costs and benefits of these two types of formats of the integrative artifact to adapt the BBIL model for their specific needs. Another possibility that will need further exploration may be a combination of a creative, expressive format that embeds meaningful textual information.

5.3 When should the integrative artifact be incorporated into the learning sequence? (Dilemma #7)

When designing the undergraduate course we decided to incorporate two integrative artifacts (the synthesis essays described in Dilemma #6) throughout the learning sequence – one at the middle and one at the end of the course. The essays were identical and differed only in the questions and contents to which they referred. The rationale for this design decision was both pedagogical and methodological. Pedagogically, this enabled meaningful formative feedback on the first essay, enabling students to develop the skills for the summative essay. Methodologically, this enabled the two comparable pre-post artifacts described above. We presented the essays assignment in detail to the students as part of the course introduction so that they will have the full picture of what is expected from them. However, we noticed that this created a significant cognitive load at this initial stage.

When moving to schools in Phase II of the research, placing the integrative artifact (the creative artifact described in Dilemma #6) within the learning sequence became an issue that was debated in each of the practitioner-teams, as well as during the three enactments. The teachers designed the integrative artifact assignments towards the end of their co-design workshop, after deciding on the disciplinary and interdisciplinary learning goals, and designing the different activities. In a similar manner, the teachers decided that the students would learn about, and start working on the integrative artifact only towards the end of the learning sequence. The reason was to avoid cognitive overload and enable students to understand the rationale of the learning environment before thinking about the integrative artifact. As one of the teachers said: „the students will probably be overwhelmed by all the new changes we‘re bringing. No chance they will understand this assignment, which is complicated and new by itself. They need time to adjust!" (Researcher diary, school 1).

The cost-benefit design consideration in this case is that the integrative artifact has a crucial role in the learning process as a scaffold for the development of interdisciplinary understanding. It can assist students to better understand the rationale and goal of the interdisciplinary endeavor in the learning environment. It can also serve as a concrete backbone through which knowledge from the different disciplinary perspectives is integrated, even more than the cross-cutting theme itself. On the other hand, understanding what is required in an integrative artifact assignment might be too complicated to achieve before experiencing some of the interdisciplinary learning (as indicated by the difficulty that the undergraduate students encountered in phase I of the research project). A possible solution for this dilemma is to design activities throughout the learning sequence in which students will gradually develop their integrative artifacts, thereby working on their interdisciplinary integration of ideas.

5.4 How flexible can the deepening and focusing script be? (Dilemma #9)

The deepening and focusing script is a sequence of technology-enhanced activities that is repeated for each disciplinary domain and designed to support deep learning within that domain. In the design of the undergraduate course in Phase I of the research, we followed a two-week sequence of activities (design script) that was repeated for each of the six domains. The script always started with a social infrastructure activity (feature 11 in table 1) in which students were exposed to the domain in an engaging manner and shared relevant personal perspectives. Then, the script continued with exposing students to the disciplinary resources (feature 4), which included video-recorded expert lectures and articles. This was followed by collaborative online discussions (feature 8) to which students received personal feedback (feature 7). The next step of the script was to provide students with a summary of the disciplinary ideas (feature 14) and finally with an activity in which they provided feedback on the summary (feature 15). This design script was repeated exactly the same way, using similar instructions, and a constant user interface. The rationale was that by using the same format of activities students would be able to focus on the contents (rather than on figuring out what they are required to do).

The practitioner-teams in all three schools initially adopted this feature as is, and designed their learning environments according to a common repeated script, which they developed in the co-design workshop. However, as they continued to design the specific activities for each disciplinary domain, many of them found the script they developed to be an obstacle. They were concerned that students would become bored or lose their interest in the project. Hence, they designed some variations between and within the different disciplinary domains in their learning environments.

Such ‚breaking' of the script of activities, in order to keep the students alert and surprised and to avoid boredom, may lead to two potential pitfalls. First, it may draw too much of the students' attention on understanding the assignments (rather than focusing on the content). Second, it may put much more weight on the disciplinary activities, and thereby disrupt the delicate balance between deepening into each disciplinary perspective and making connections between the different disciplines. Both of these potential pitfalls may harm the development of interdisciplinary understanding. Additionally, from a practical perspective, breaking the script required increased design work from the teachers who needed to design a larger variety of activities. As a result, too many hours of the co-design workshop were invested in the design and production of these activities, instead of focusing on other important aspects of the BBIL model, such as learning community features, which were only partially implemented in Phase II. In addition, the teams needed to continue their work beyond the workshop hours. This might undermine the balance between investment and output, which is one of the „sure-fire causes of failure" for the implementation of innovations (Kirschner et al., 2005). Such considerations need to be taken into account in future adaptations of the BBIL model.

5.5 To what extent should the interdisciplinary moderator understand the disciplinary domains? (#Dilemma #10)

The moderator plays a critical role in the BBIL model by assisting the community of learners in delving deeply into each disciplinary domain and in making the connections between domains to enhance students understanding of the cross cutting theme. The moderator's role, as defined it in the BBIL features (Kidron & Kali, 2015), does not necessarily require expertise in any of the disciplinary domains; however, interdisciplinary thinking, synthetic capabilities and moderating skills are needed.

This dilemma was not raised during the design of the undergraduate course in Phase I, in which the two authors of this article designed and moderated the course. The second author was a domain expert representing the first discipline explored in the course. The other five disciplinary domains in the course were presented through video-recorded lectures and online articles provided by disciplinary domain experts who did not actively participate in teaching the course. Therefore, the undergraduate course required the moderators to explore the online disciplinary domain resources together with the students, and to analyze, together with them, possible interdisciplinary connections.

The dilemma regarding the level of disciplinary domain expertise needed in order to moderate interdisciplinary learning became more complex when moving to schools in Phase II of the research, since there were several optional moderators. The teachers who participated in the enactment included professional teachers who were domain-experts. In addition to them were the homeroom-teachers who knew the students and had established a relationship with them based on educational and social activities. The design decisions taken by the practitioner-teams varied (table 3): School 1 practitioner-team decided that the moderators would be the professional teachers who had designed the technology-enhanced interdisciplinary learning environment. School 2 practitioners decided that the moderators would be the homeroom-teachers who had joined the co-design workshop toward the end of the program. In school 3, the moderators were both. In general, the homeroom-teachers felt that they were lacking disciplinary knowledge to support their work with the students on the interdisciplinary connections. On the other hand, some of the professional teachers complained they felt too „confined within their discipline and could not see the overall interdisciplinary picture that students were able to experience." (Teacher's interview, school 2).

Following the schools' implementations, we understood that the BBIL definitions regarding interdisciplinary and disciplinary domain expertise required further elaboration. The design consideration that should be taken into account is that interdisciplinary understanding is built from the synthesis of disciplinary domain ideas and hence, it is crucial that the moderator would have some level of understanding in all disciplinary domains. Participation of all moderators in the design process of the learning environment during the co-design workshop can address this issue. However, the question remains to what extent can the interdisciplinary insights be taken into account in advance so that all teachers can moderate the learning equally, or should such insights be left to emerge naturally during enactment. Here too, the weighing of costs and benefits would probably yield a range of solutions in future implementations of the BBIL model. But as Collins (1996) claims:

> "When designing a learning environment, computer based or not, there are a multitude of design decisions that must be made. Many of these design decisions are made unconsciously without any articulated view of the issues being addressed or the tradeoffs involved. It would be better if these design decisions were consciously considered, rather than unconsciously made." (p. 347).

6.0 Conclusions

This study has demonstrated the significance and effectiveness of RPPs for expanding the applicability of educational innovations beyond the DBR contexts in which they are developed. The RPP that was created as part of Phase II of the research was based on a shared goal: to bridge the gap between research and practice, and to enable teachers to implement educational innovation within their schools. Accordingly, there was much overlap in the responsibilities taken by the researchers and practitioners within the partnership (e.g., defining the RPP's mechanisms, designing the learning environments), which places this RPP at the collaborative side of Kali's (2016) continuum.

Working within a RPP enabled meaningful mutual learning for all participants – a better understanding of the BBIL model, on one hand, and of ways to successfully implement it in school-context, on the other. We argue that the work of the RPP contributed to a productive shifting from the higher-education to the school context, because it fulfilled several of McKenney & Reeves' (2012) characteristics of successful RPPs. Specifically, it brought added-value to the process, enabled congruency with the local characteristics, and maintained the model's original goals (as conveyed in the design principles) during the adaptation process.

Due to local culture, beliefs, practices and resources in each of the three schools, moving beyond the higher-education context led to the development of different implementation paths (Bielaczyc, 2103). These were reflected in the designs that each practitioner-team created, and especially in the dilemmas raised, and the considerations and decisions taken. We argue that these varied implementation paths demonstrate that the BBIL model is generative. Furthermore, it is flexible enough to support design for ZPI (McKenney, 2013), and address the needs of not only learners but also of teachers and schools.

Finally, through the different RPP's mechanisms (i.e., kickoff meetings, co-design workshop, reflection in practice meetings, and RPP retreats) we were able to synthesize the different perspectives and enhance the original BBIL model developed in Phase I of the research, with new design considerations and authentic examples implementations designed by teachers. We argue that such an enhanced model represents a new type of PPK – enhanced principled instructional models. This type of PPK can be developed via the two-phase approach illustrated in the current study, combining the benefits of a more controlled DBR to develop a principled instructional model in the first phase („know why" knowledge), and enhancing its applicability in through DBIR with the practical knowledge that practitioners bring with them („know how" knowledge). The enhanced principled instructional model derived in this two-phase approach attends to the design requirements defined by Goodyear and Dimitriadis (2013), namely – addressing the potential complexity of new contexts; the customization teachers might make; the different supports for teachers; and the option to redesign the innovation. That said, it is important to note that this study has focused on the process of developing PPK. Further research is required to explore the effectiveness of this type of PPK in future implementations, and to examine the implications of the different decisions taken for each of these dilemmas on students' development of interdisciplinary understanding. Yet, we argue that enhanced principled instructional models have the potential to serve as an invaluable resource for other practitioners who would want to use the model in additional contexts. In this way, the PPK developed in the current study does not merely connect theory with practice, but enables the continual improvement of practice, or to put it in Bereiter's (2014) words, it is „not a bridge but a ladder".

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