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# Teaching Expertise Reconsidered: The Technology, Pedagogy, Content, and Spaces (TPeCS) Knowledge Framework

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# Abstract

School-practitioners are increasingly expected to lead construction projects in their schools to create future learning spaces (FLSs) that support learning in today's networked society. This study examined the process by which practitioners of one school developed their readiness to incorporate an FLS into the school via a long-lasting research-practice-partnership that focused on co-designing learning materials for contemporary teaching. To conceptualize this process, we introduce the Technology, Pedagogy, Content and Space (TPeCS) knowledge framework, which expands current conceptualizations of teaching expertise by tying them into the emerging field of FLSs. We interpret practitioners' learning within a series of action-reaction progressive developments along a two-year timeline of the partnership. Visits to an FLS, where researchers modeled, coached, then faded their guidance along this timeline played a key role in practitioners' development of readiness to incorporate an FLS into their school. The pedagogical domain was most challenging among all the dimension of TPeCS. We conclude that school-practitioners' involvement leading FLS endeavors within their schools can serve as an unprecedented opportunity for practitioners to develop contemporary teaching skills, with FLSs serving as ideal spaces that make pedagogy visible.

**Keywords:** future learning spaces; making pedagogy visible; teaching expertise; learning communities; technology-enhanced learning; research-practice-partnerships

**Practitioner notes**

What is already known about this topic

- School-practitioners are increasingly expected to participate in construction/renovation projects of FLSs
- Teaching expertise is often conceptualized in terms of technological, pedagogical, and content knowledge (TPaCK)

What this paper adds

- A novel framework for conceptualizing teaching expertise as the competence to flexibly use knowledge that combines technological, pedagogical, content, and space (TPeCS) considerations
- The pedagogical component within TPeCS has a bottleneck quality. Reducing pedagogical gaps accelerates the development of other TPeCS components
- Visits to state-of-the-art FLSs, involving modeling, coaching and fading of expert guidance can foster practitioners' development of TPeCS knowledge and competencies, increasing their readiness to incorporate FLSs into their schools. FLSs, and specifically the use of large digital displays are ideal for making pedagogy visible

Implications for practice and/or policy

- School-practitioners can, and should, be key players in leading FLS endeavors within their schools. When appropriately guided, this can serve as an unprecedented opportunity for practitioners to develop contemporary teaching skills

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# Rationale

In an era of immense advancements in information and communication technologies that affect every aspect of our lives, and especially what we know and how we learn (Hoadley & Kali, 2019)—teaching has become more challenging than ever. Even the very notion of schooling is constantly reconceptualized (Collins & Halverson, 2018). School-practitioners find themselves in a difficult position of staying up-to-date with these advancements in their curriculum, pedagogies, and use of technology (Mishra & Koehler, 2006). In recent years this trend has also included rethinking the design of learning spaces. Increasingly, school-practitioners are expected to take part (e.g., van Merriënboer, McKenney, Cullinan, & Heuer, 2017) and even lead renovation or construction projects in their schools to create new technology-enhanced learning spaces to support the type of learning that is relevant for today's networked society. That is, a society in which daily interactions are increasingly engulfed in information and communication technologies, and learning is conceptualized as co-creation of knowledge in technology-enhanced communities (Kali, Baram-Tsabari, & Schejter, 2019). In Israel, for example, the Ministry of Education recently published a call for school-practitioners to propose building or renovating "21st century" learning spaces (entitled M21), with the intention of funding thousands of proposals over the next few years. One of the main funding criteria is the alignment of design considerations regarding space with curricular content, pedagogy, and technology (Israeli Ministry of Education, 2018).

In this vein, we expand the line of research that has evolved in recent decades around teaching expertise (e.g., Shulman,1986; 1987; Mishra & Koehler, 2006) by connecting it with current notions of learning in a networked society (Kali et al., 2019), and the emerging research trajectory on FLSs (e.g., Ellis & Goodyear, 2016; Hod, 2017; Hod et al., 2019). Specifically, we introduce the Technology, Pedagogy, Content and Space (TPeCS)[1] theoretical framework, which is an extension of TPaCK. In a nutshell, TPeCS contends that good teaching nowadays requires not only "an understanding of how technology relates to the pedagogy and content" (as in Mishra & Kohler's TPaCK, 2006, p.1026), but also an understanding and skill to adapt existing physical spaces, take advantage of alternative spaces, or design new ones. This may include the use of digital technologies such as mobile devices, augmented reality, maker-spaces, and—as a focal point for this study—large digital displays (Tissenbaum & Slotta, 2019).

One way to support such development is by fostering research-practice partnerships (RPPs) a specific form of partnership between researchers and educational practitioners in which (a) problems of practice are explored, (b) mutualism is sought via negotiation of goals and joint practices, (c) intentional strategies are employed to support and maintain the partnership, and (d) data is collected and analyzed to address the problems explored (Coburn & Penuel, 2016, McKenney, 2016). Such partnerships often provide productive grounds for teacher professional growth as they involve experiences outside the teachers' world (as afforded by the connection with researchers), increasing the likelihood of advancing the teachers' knowledge, beliefs and attitudes (Clarke & Hollingsworth, 2002).

Building on our TPeCS framework and in the context of an ongoing RPP, the current study examined the process by which practitioners of one school in the northern periphery of Israel developed their understandings, competencies, and agency to implement innovative teaching practices that included use of digital technologies within FLSs. Specifically, we aim to elucidate the ways in which technology-enhanced learning spaces come to be valued as part of school-practitioners' educational discourse.

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[1] TPeCS should be pronounced as Tipp-Ex resonating the correction liquid which we view as a way to blur the boundaries between technological, pedagogical, content and space design considerations.

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# Theoretical Background

## *FLSs: What are they, and what new opportunities and challenges do they pose for teaching?*

In the past decade, several frameworks have been developed to conceptualize innovative, technology-enhanced "future" learning spaces, which address current views of learning (e.g., Hod, 2017; Hod, Ya'ari, & Eberle, 2019; Ellis & Goodyear 2016; Radcliffe, 2009; Tissenbaum & Slotta, 2019). All of them view space as one of several interdependent components within a dynamic ecology. For instance, Radcliffe (2009), in his pedagogy–space–technology framework, explains:

> Each of the three elements, pedagogy, space and technology, influence each other in a reciprocal fashion. Thus achieving a desired pedagogy might suggest a preferred way to arrange the shape and use of space, equally a learning space irrespective of its intended use will tend to shape what people do in it and hence the patterns of teaching and learning. Similarly a particular space places constraints (or presents opportunities) for the introduction of certain types of technology while a given technology can impact how a space is used by teachers and students (p.14).

The emerging field of FLS research is concerned not only with ontologies (i.e., our knowledge of FLSs) but also with processes by which design decisions are made and their consequences for learning. For instance, Tissenbaum and Slotta (2019) indicate that large shared digital displays can serve as effective means for supporting collaboration among students, as well as teacher classroom orchestration. Another FLS research trajectory concerns the multiple perspectives that various stakeholders bring to the table in making design decisions. For instance, Rook and McDonald (2015) point to the critical role that learning experts play in this process, claiming that such expertise is often neglected while the architectural and environmental-behavior design knowledge is privileged.

Given that teachers are important stakeholders and are increasingly expected to take leading roles in the development of FLS projects within their schools, it is crucial to study how teachers develop the expertise to do so. In the following section, we build on existing conceptualizations of teacher expertise, specifically—Shulmans' (1986; 1987) pedagogical content knowledge (PCK), and Mishra and Koehler's (2006) technological pedagogical content knowledge (TPACK)—to introduce an expanded framework that integrates the notion of FLSs.

## *Brief historical account on teacher expertise: From pre PCK to post TPACK*

### PCK: Teacher expertise as blending pedagogy and content knowledge

In his seminal paper, "Those who understand: Knowledge growth in teaching" Shulman (1986; 1987) presented acute criticism of the way society, for hundreds of years, had referred to the profession of teaching. He illustrated that, paradoxically, reform movements that sought to formalize and improve teaching as a profession since the 19$^{th}$ century developed trivialized

conceptualizations of teacher expertise. While in ancient times, expertise was regarded as an art that tied knowing and teaching, in the 19th century it was regarded almost exclusively as mastery of subject-matter contents, ignoring questions such as how teachers make such content accessible and interesting to diverse learners. Shulman (1986) demonstrated how in the 20th century the pendulum reversed course and procedural demands replaced disciplinary content.

Building on a multitude of observations and interviews, Shulman (1986; 1987) characterized the process of gaining teaching expertise as pedagogical reasoning. Such reasoning enables teachers to transform their content knowledge into teaching—what he coined in the concept of Pedagogical Content Knowledge (PCK). PCK "goes beyond knowledge of subject matter per se to the dimension of subject matter knowledge for teaching... that embodies the aspects of content most germane to its teachability" (Shulman, 1986, p.9).

### TPACK: The addition of technology as a third component to PCK

Two decades later, an additional major advancement was made. Specifically, Mishra and Koehler (2006) pointed out that Shulman's PCK (1986; 1987) was missing a component that had become by then a substantial part of teaching proficiency—the ability to integrate technology into everyday teaching. They contended that technology should be considered as a third component in teachers' knowledge-base and coined their revised view of teacher expertise as technological pedagogical and content knowledge (TPACK).

An important feature in TPACK was the nuanced understanding it provided regarding the intersections between the knowledge domains:

> Technologies often come with their own imperatives that constrain the content that has to be covered and the nature of possible representations. These decisions have a ripple-effect by defining, or in other ways, constraining, instructional moves and other pedagogical decisions. So it may be inappropriate to see knowledge of technology as being isolated from knowledge of pedagogy and content (p.1025).

Interestingly, Mishra and Koehler (2006) explained the absence of the technology component in Shulman's notion of PCK as resulting from a certain 'transparency' of technologies (e.g., textbooks and overhead-projectors), that took for granted the knowledge required to use technologies competently. This complex set of skills has only become more profound as technologies have advanced. We find a similar transparency of the notion of space in the TPACK framework, which we contend undervalues the important material and spatial considerations when trying to create successful learning ecologies that integrate technologies, pedagogies, and content.

## TPeCS: Introducing space as a fourth dimension in TPACK

We hereby introduce the TPeCS framework (Figure1) positing that in the networked society—where learning is conceptualized as co-creation of knowledge in technology-enhanced learning communities—space plays an important role in both learning and teaching (Kali, et al., 2019).

Before the emerging trend of FLSs, as described in the theoretical background, space was often assumed to be a given. Classrooms had a particular arrangement of furniture and hardware, with

little flexibility for supporting co-creation and orchestration of knowledge-building. The current trend around FLSs trend and the (appropriate) expectation that teachers will lead FLS endeavors within their schools is the impetus for our extension of TPaCK (Mishra & Koehler, 2006) into TPeCS.

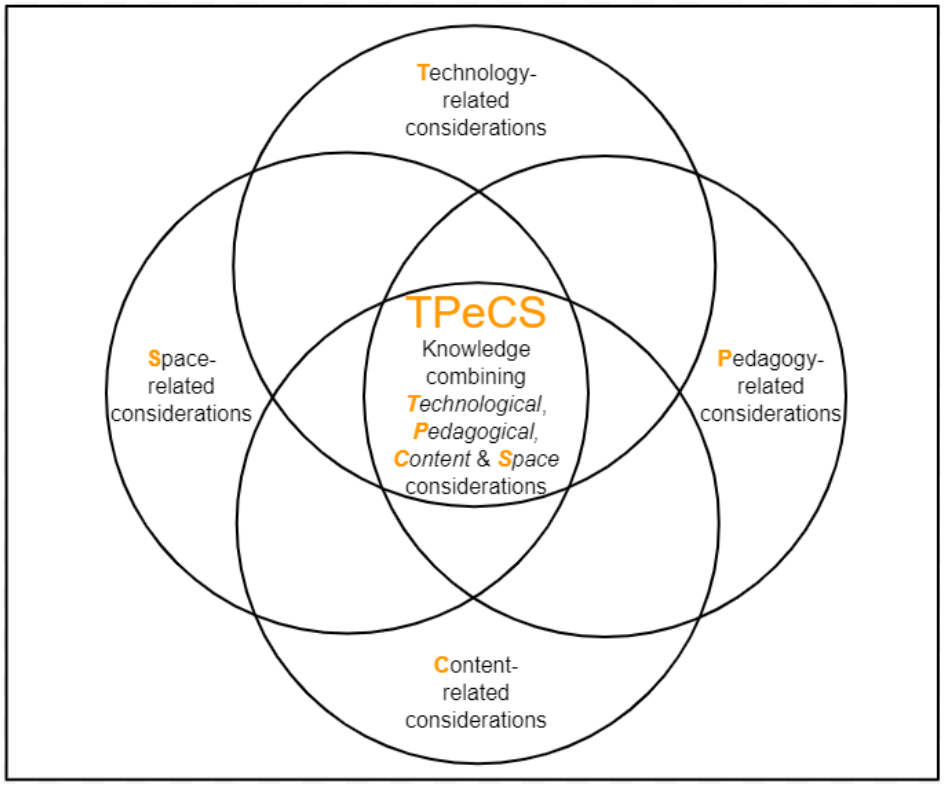


Figure1: the TPeCS framework

Accordingly, the TPeCS framework bridges between the field of teacher expertise and the emerging field of FLSs. The current study leverages this to study the role of technology-enhanced spaces in school-practitioners' development of teaching expertise. We explored the development of TPeCS knowledge and skills by asking how site visits to state-of-the-art FLSs, in the context of RPPs, support the readiness of school-practitioners to meaningfully incorporate FLSs into their schools.

# METHOD

To address our research question, we investigated a long-lasting RPP between our research team and the teaching-practitioners in the aforementioned school. We focused on an underserved school in a peripheral area to explore the development of TPeCS expertise and FLS readiness as a process that *all* schools can undergo as part of a long-lasting RPP, despite limited resources. We used an ethnographic approach to analyze teaching expertise. Using ethnographic approaches to study practitioners' design processes allows researchers to "focus on how it is that people participate in and make sense of their participation in design activities" (Severance et al., 2016, p.539).

## *Context and participants*

The RPP stemmed from an initiative of the school's principal. She was brought into a school climate that had high levels of parent distrust and faced a declining trend of enrollment. Likewise, it had suffered from a recent history of a revolving door of school principals and pedagogical visions, and only few opportunities for teacher professional development. The principal was brought in based on her established record of successful management, and was eager to raise the school's status. After one year in which she managed to bring the school-practitioners into what she defined as a "healing trajectory", the principal, together with a few leading teachers, approached the department of professional development of our university to arrange for an in-school teacher professional development program that would promote contemporary teaching and learning within the school. The partnership formed with our team at the center for learning in a networked society (LINKS, Kali et al., 2019).

The goals of the RPP and the means for achieving them were negotiated in a series of launching meetings between all participants, leading to the following agreements:

1. **Focus of project.** Incorporating a marine-biology citizen-science project on jellyfish in Israel's coastal area as a context around which contemporary teaching and learning will take place. The project was part of a LINKS endeavor to explore the affordances of citizen-science (projects involving citizens in advancing science in collaboration with scientists) to bridge school-based science with real ongoing research (Sagy et al., 2019). The specific project was chosen due to the proximity of the school to the beach, where data collection could be made by students using a designated online-platform[2].
2. **Learning in a networked society (LINKS) pedagogical principles.** Our team offered an approach guided by two main design-principles. These encapsulate our view of the pedagogical domain within TPeCS:
    a. fostering negotiation of ideas in (data-driven) inquiry-processes (e.g., Ben-Zvi, Gravemeijer, & Ainley, 2018; Marx et al., 2004);
    b. cultivating classrooms as learning communities (e.g., Bielaczyc, Kapur, & Collins, 2013; Hod, Bielaczyc, & Ben-Zvi, 2018).

    From the practitioners' side, the principal was interested in promoting her staff's competencies in carrying out project-based learning (PBL), which has been promoted by the Ministry of Education. Thus, it was decided to use the PBL approach as an instantiation of the pedagogical principles, and explore its affordance to promote teachers' TPeCS expertise.
3. **Enactment.** It was decided that the activities to be co-designed by the partnership would be enacted with about 70 students in 4$^{th}$ and 5$^{th}$ grade classes. Part of the program would involve teachers' and students' activities at the state-of-the-art facility at the university (LINKS-FLS[3]). This FLS (Figure 2) was designed for active learning for communities supported by large digital computer displays (Tissenbaum & Slotta, 2019), citizen science and other collaborative online learning platforms, and moveable furniture to support moving between multiple social activity structures (Bielaczyc, 2016).

[2] meduzot.co.il
[3] fls.haifa.ac.il

**Figure 2**: LINKS-FLS

4. **Means of collaboration.** Collaboration involved mutual exploration of the LINKS principles via co-designed technology-enhanced activities in the context of citizen science, their implementation, and evaluation. This took place as an in-school professional development program led by the researchers (total of 90 hours), and teachers' enactment of the co-designed activities with students (total of 40 teaching hours). The nature of the partnership enabled practitioners to take advantage of hours they were required to spend in school for the co-design work, and for researchers to have the flexibility to meet emerging needs rather than follow a pre-scripted schedule. The professional development program was supported with an online collaborative Google Apps website including a set of collaborative documents serving as scaffolded working areas. The site, developed for this purpose, included instructions for face-to-face collaborative activities, content resources, discussion forums, and shared documents that served as work areas for all RPP participants.
5. **Participants in partnership.** The main co-design work took place with a core team of nine participants (about half of the whole school personnel), including the principal, vice-principal, pedagogical coordinator, and advisory teachers.

## *Approach for analyzing change in teaching expertise*

Multiple sources of data were collected throughout the two years of the study. The main source was extensive field notes kept by the research-team detailing significant events throughout the process, with a focus on describing interactions during the three visits to the LINKS-FLS, where emphasis was made on the ways technologies, and specifically the large digital displays, were used. Additional resources that helped us triangulate our findings included eight transcripts of 20-40 minute interviews with different practitioners at different times during the two years (beginning and end of each year); short teachers' reflective notes written periodically, artifacts developed by the school-practitioners (e.g., lesson plans they designed for their students); and emails and text messages between the researchers and practitioners.

Data interpretation was based on the premise that learning within an RPP is a process of negotiating problems of practice between researchers and practitioners (Penuel, Coburn, & Gallagher, 2013). Although our focus was on the learning of the practitioners, we delineated and interpreted practitioners' learning as part of a series of action-reaction progressive developments along a timeline of the two years of the study. These developments represent negotiations between researchers and practitioners in which (re)actions taken by each party can only be understood in light of the (re)actions of the other party.

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To develop a valid account of the intertwined developments between researchers and practitioners, we adapted Chi's (1997) technique for analyzing verbal data by adding the notion of an action-reaction timeline. Our first step was to segment and reduce the voluminous amount of data. To do this, the authors of this article carefully reviewed their field notes. Each one separately noted what she had viewed as important events on the timeline, and wrote each event on a separate card. Then, the five researchers used the cards to develop a series of events to negotiate and refine the meaning of the occurrences, using other sources of data for triangulation. At several stages the principal was consulted to verify any tentative conclusions until a final consensus was reached (Schoenfeld, 2007).

It is important to note that in most cases, our analysis refers to the (re)actions of each of the groups—practitioners and researchers—blurring differences within each group. This strategy was taken to simplify the already complex picture. In some cases, when differences were prominent—such as between the principal's actions and the rest of the practitioners—we describe and analyze their different paths.

# Findings

The findings from this study, represented on an action-reaction timeline, include major developments that were consequential as the practitioner and research-teams (re)acted to what the other team brought to the table (Figure 3).

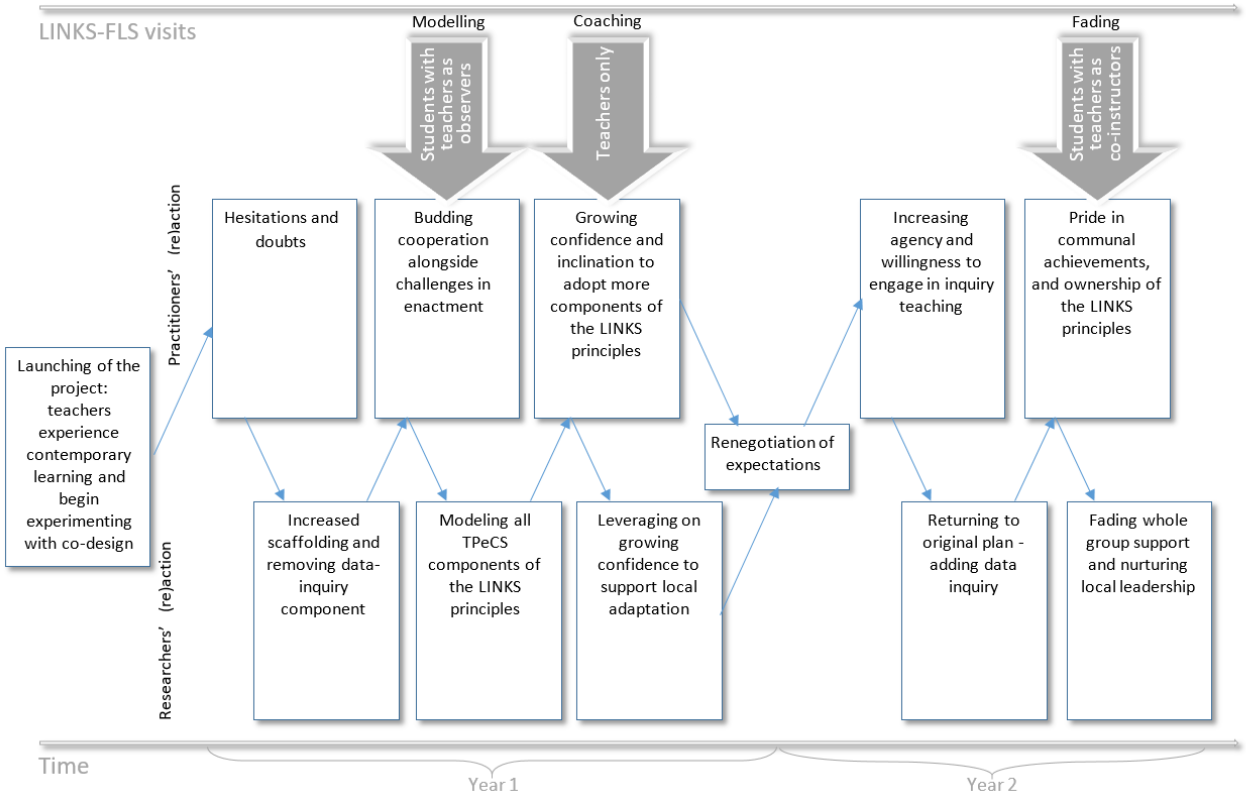


**Figure3.** Action-reaction timeline of developments throughout the 2-year study

## *Hesitations and doubts*

### Practitioner-(re)action

The first weeks of the program followed the goals of acquainting practitioners with relevant marine-biology content knowledge, as well as building their repertoire of learning experiences based on LINKS principles. Practitioners participated in activities including (1) working in teams to develop research questions about jellyfish and marine-biology; (2) actively reviewing relevant online resources to develop preliminary insights on these questions; (3) conducting an online survey in their community to probe what people think about jellyfish; (4) synthesizing their insights into shared Googleslides that they presented, critiqued, refined, and reflected on. The activities took place in the school's computer-lab. To enable the groupwork, some rearrangement of the furniture was required in the space that was originally organized for individual work. That is, the main focus at this stage of the program was on the domains of content and pedagogy within TPeCS. These were lightly supported by technology and space adjustments.
From the beginning of this stage, practitioners expressed doubts about the content area of marine-biology and jellyfish. They were concerned that students would not find the topic interesting and doubtful about the students' capability to pursue PBL open-ended inquiry. These concerns were expressed in their reflective notes, for example:

> "Will this work with the students? Will they be curious enough?"[4]
> "How will I be able to simplify these notions for the students? It is very difficult to use data sources or to come up with new ideas"

When it came to co-designing activities to launch the program with the students, practitioners had difficulties designing activities that incorporated these new ideas and resisted to cope with the challenge. The hesitations they expressed resulted from gaps in both the domains of content and pedagogy. Their concerns were less about teaching practices and use of technology, and more on how students would accept these contents and pedagogies. Although practitioners expressed satisfaction from their experiences as learners in the activities designed by the researchers up until now, they refrained from designing such activities for their students.

### Researcher-(re)action

The researchers, having recognized the practitioners' resistance, decided to remove some components of the LINKS principles and adjust the way they supported the co-design process. Specifically, they eliminated the technology-supported data-inquiry that involved working with students to analyze data collected via the jellyfish online platform using collaborative online worksheets. Likewise, the research-team added scaffolds to the co-design process by adding several pre-designed online learning materials to the teachers' website for the practitioners to adapt for their students (see Kali, McKenney & Sagy's framework from 2015, delineating various ways for teachers to engage in designing technology-enhanced learning environments).

[4] All quotes were originally said or written in Hebrew and have been carefully translated to fit the author's intended meaning.

## *Budding cooperation alongside challenges during enactment*

### Practitioner-(re)action

Despite the difficulties, the RPP leadership decided to launch the program with students, as planned, around the second trimester of the first school year. This left a couple of months to design activities. The scaffolds provided by researchers eased this process. Gradually, practitioners' felt more comfortable with co-designing and embarked on the challenge. However, as practitioners began enacting the designed activities with students, they reiterated their earlier concerns—especially regarding open-ended inquiry. Their lack of confidence and frustration came up in many of the teacher interviews, for example:

> I didn't think it would be so difficult. In a way it made me stop ... they [the students] did not know how to ask questions. … We had to stop …and explain what question words are. I was sure the lesson would flow much smoother. It surprised me that it didn't.

### Researcher-(re)action

In response to the teachers' partial success, the research-team decided to model a classroom session hosted at the LINKS-FLS. By doing so, the researchers sought to mitigate the practitioners' most serious concern regarding students' capability to negotiate ideas as part of an inquiry process The visit started with individual student interactions using various online activities (e.g., an interactive visualization of jellyfish distributions, Figure 4), located at different stations in the FLS, each, equipped with a large touch-screen. Students chose their own paths among stations and documented their new ideas. Next, they worked in small groups to share, discuss, summarize, and contribute main insights into an online co-created presentation, which was displayed on a large screen at the front of the room. Finally, students presented and discussed their aggregated insights with the entire class, with the practitioners observing the entire process.


Figure 4: interactive visualization of jellyfish distributions in one of the stations

This modeling session emphasized the pedagogy and content to address practitioners' concerns. But it also enabled the research-team to model the use of space and technology afforded by the LINKS-FLS to support students' learning of the marine-biology content with activities designed based on LINKS pedagogical principles. For instance, building on Tissenbaum and Slotta's (2019) findings regarding the importance of large shared digital displays to orchestrate peer-learning in a community, the number of touch-screens was set so that multiple students would gather around each station. These enabled practitioners to observe their students' peer learning in-situ, as well as pay attention to the way the technology-enhanced inquiry activities could support the flow of learning between individuals, groups, and whole class.

## *Growing confidence and inclination to adopt more components of the LINKS pedagogical principles*

**Practitioner-(re)action**

The visit to the LINKS-FLS marked an upturn in practitioners' attitudes towards ideas brought by the researchers. In their reflection notes many practitioners expressed their students' excitement and keen interest in the topic studied, and were encouraged to see their students' seriousness and accomplishments. For example:

> "The students had a meaningful and refreshing learning experience that led them to significant outcomes"
> "The students really enjoyed it, they felt as active partners. We all enjoyed and learned a lot from the experience"
> "This visit made me open up, understand more, be more into it."

The practitioners' growing confidence in the LINKS principles was expressed throughout the remainder of the year. This was evident during reflection meetings, where teachers brought up significantly fewer challenges regarding enactment of activities with their students. They also began to incorporate project-based activities in some of the other subject areas they taught. Still, these new activities were more surface-level renditions of the LINKS principles. For example, they made space adjustments without seriously considering pedagogical issues nor how this can be supported by technology.

**Researcher-(re)action**

To leverage the practitioners' newfound insights and excitement that stemmed from their visit, the researchers offered to host a second meeting at the LINKS-FLS. The goal was to emphasize the second LINKS principle of cultivating technology-enhanced learning community norms. In contrast to the first meeting, this time only the practitioners and researchers were invited, which enabled researchers to play a coaching role. The objective of the session was to assist practitioners to develop their own activities as part of a school-wide project they initiated. Designing the activities for this project required practitioners' collective effort that the researchers leveraged to cultivate learning community norms, capitalizing on the LINKS-FLS facility. For instance, practitioners formed teams who worked in the teamwork niches using the large digital displays. They were encouraged to define various aspects of the project according to their expertise. Finally, a gallery walk around the digital displays enabled sharing ideas and peer-feedback, to further promote the collective design effort.

## *Renegotiation of expectations*

At the beginning of the second year, tensions between practitioners and researchers developed around the issue of who should lead the design of students' activities. Although it was agreed earlier that practitioners would assume more responsibility, there were gaps regarding what this entailed in practice. The researchers expected the practitioners to come up with draft design artifacts that would be discussed and revised in the meetings prior to their enactment. Likewise, they expected to see the practitioners' designs promote deeper inquiry based on student-generated questions. In contrast, the practitioners expected the researchers to prepare preliminary design solutions as they had done during the first year. They were still finding it difficult

to translate their ideas into assignments for students and cede control of the inquiry process to the students. This mismatch in expectations created discomfort on both sides, and led to a renegotiation of the collaborative effort. The solution entailed the principal committing to lead and assist teachers in the design process and co-teaching some of the more challenging lessons. The researchers committed to providing more scaffolds to support practitioners in employing pedagogical notions such as supporting students' questioning in their designs. To do so, the researchers designed each meeting to first model notions of contemporary teaching, before reflecting on them to advance the practitioners' understanding of the pedagogical concepts.

## *Increasing agency and willingness to engage in contemporary teaching*

### Practitioner-(re)action

As the new means of collaboration within the RPP became routinized, practitioners gradually took more responsibility and agency in designing and enacting LINKS-inspired activities that provided students with more intellectual autonomy. Encouraged by students' reactions and accomplishments, practitioners incorporated more student-led collaborative inquiry activities. Additionally, they took responsibility over the success of the marine-biology project by, for example, continuously encouraging the students to collect and report data at the beach. The increased confidence and collaborative agency was evident in many of the reflection notes and interviews conducted throughout year 2, for example:

> All of a sudden it became so easy… in one of the lessons we presented a topic, and then we divided students into groups. Each group wrote 10 research questions that interest them in relation to the topic. We gathered all the questions for students to choose from, and created new teams who chose a common research question to work on. Today it's so easy for me to do this. Something that I can pull off at any time.

These developments increased the principal's confidence in the staff's capability to incorporate contemporary teaching. As a result, she led the writing of a proposal for the M21 initiative, in which some of the notions developed in the RPP were expressed:

> The space will enable collaborative learning, creating global learning communities that inquire and discover beyond the borders of school… Students will experience collaborative inquiry by learning in a space that allows their physical movement while searching for information-sources in groups, or whole class discussions.

### Researcher-(re)action

At this stage the researchers felt that practitioners were ready to go one step further in implementing more sophisticated TPeCS combinations. Specifically, the researchers decided to bring back the technology-enhanced collaborative data-inquiry component that was eliminated from the program at earlier stages, and to host a third meeting at the LINKS-FLS where practitioners would have an opportunity to experience supporting their students' data-inquiry.

## *Pride in communal achievements and ownership of the LINKS principles*

### Practitioner-(re)action

In contrast to the first two visits, this time the researchers "faded away" from their role as instructors, in favor of co-enacted activities by the researchers and practitioners. Practitioners took an active role in mentoring and guiding students as they explored a copy of the citizen science jellyfish database and reports that aggregated online over the course of the year. The learning niches around the large touch-screens within the LINKS-FLS enabled students to immerse into collaborative sense-making of various digital data visualizations. At the same time, this socio-techno-spatial configuration (Bielaczyc, 2006) enabled the practitioners and researchers to readily grasp and engage in students' conversations, as well as get a sense how all groups progressed.

Overall, the active involvement as group-mentors and discussion leaders increased practitioners' confidence in their students' capability to discuss, explore, and make sense of data using digital tools. It also strengthened their self-confidence in designing and guiding technology-enhanced activities that take space considerations into account when employing LINKS principles in other content domains. For instance, one of the teachers reported the following:

> We were exposed to new ways of teaching: teaching that promotes collaborative technology-enhanced learning, enabling students to develop skills and independently explore [phenomenon] in the computer-lab. This will allow us to use the FLS in other topics—it's already happening and we will continue to invest in this next year… we have already set the grounds for doing so.

Towards the end of the visit, the principal shared her insights with all participants, in which she connected students' and teachers' experiences, and related both these experiences to the type of change that the school was going through. Based on the M21 proposal, which by then had been accepted, she expressed her vision for a future focused on inquiry and collaboration around FLSs:

> ...learning becomes collaborative both for us teachers and for you students… this is a meaningful process… you will keep doing inquiries like this down the road… we will also have spaces like this [the LINKS-FLS] in our school, this is the way to go.

The remainder of the second year was characterized with increased LINKS-inspired activity led by the practitioners. The principal continued to foster collaborative community norms by using digital tools, such as WhatsApp, for ongoing consultation about challenges that teachers faced. Likewise, the practitioners showed more signs of working as a team. One key effort that brought the community together was in planning and enacting a school-wide event in which they presented the renewed school's vision alongside students' artifacts from the whole year. Visiting colleagues from a neighboring school, dignitaries from the municipality, and representatives from the ministry of education, were all impressed with the outcomes. By the end of the second year, practitioners expressed great pride in their achievement as a community, as expressed by one of the teachers:

> Unlike other schools that have a new FLS waiting for the teachers to start using it, our team is ready and waiting for the FLS to be finished. It's not just the leading teachers, it's everybody. A new teacher will need to learn a lot.

**Researcher-(re)action**

Based on the progress that the school had made, the researchers concluded that it was appropriate to continue fading their roles and to prepare for a third year with only minimal consultation and ad-hoc involvement according to emerging needs to sustain the process.

# Discussion

Our view of TPeCS as a theoretical bridge between the field of teacher professional growth (Clarke & Hollingsworth, 2002) and FLSs served as a lens to elucidate the role of technology-enhanced spaces in school-practitioners' development of teaching expertise. We draw out three points from our findings on the action-(re)action timeline as part of our ethnography.

## *The role of FLS-site visits in supporting practitioners' development of teaching expertise*

The three on-site visits to the LINKS-FLS were consequential parts of an unscripted process of the two-year voyage we embarked on to foster teacher expertise in a sustainable school learning community (Tau & Zhang, 2018) Retrospectively, we realized that these visits followed a pattern of modeling (first visit) coaching (second visit) and fading (third visit). Indeed, we found ourselves within a realm of cognitive apprenticeship (Collins, 2006; Collins, Brown, & Holum, 1991) rather than the more mutualistic approach we had envisioned that typically characterizes RPPs (Coburn & Penuel, 2016; McKenney, 2016). The cognitive apprenticeship approach was originally developed following the realization that "standard pedagogical practices render key aspects of expertise invisible to students"(Collins et al.,1991, p.1). We contend that teaching expertise too should be made visible as part of the process of teachers' learning and professional development. The LINKS-FLS served as an ideal venue for making pedagogy (and its relation with technology, space and content) visible for both researchers and the practitioners.

Each visit served to significantly advance practitioners' professional development. This was expressed in the form of *beliefs, conceptions and understandings* of the pedagogical approach promoted in the first (modeling) visit; *competencies* for their implementation fostered in second (coaching) visit; and *agency* to do so beyond the scope of the RPP advocated in the third (fading) visit.

The first visit, in which researchers modelled implementation of all TPeCS components, was critical in practitioners' willingness to adopt the LINKS principles. By observing this session, practitioners overcame their resistances as they began to gain confidence in their students. This change was expressed in their beliefs and conceptions of learning and enhanced their understanding of the pedagogical approach. The coaching in the second visit boosted practitioners' confidence in their own ability, as a learning community, to implement LINKS-inspired practices. This confidence was an important step in their development of competencies for designing activities in various content areas later on. Finally, in the third visit, practitioners

were actively involved in guiding their students' data inquiry activities, supporting it with space and technology, as afforded by the LINKS-FLS. This was a cornerstone in practitioners' willingness to implement their increased understandings and competencies regarding contemporary teaching beyond the scope of the RPP. The school's application for an FLS via the M21 initiative indicated this agency. We view the acceptance of the school's FLS proposal by the ministry of education (against a competitive pool of applicants) as a sign of the school's staff maturation.

## *The capacity of RPPs in supporting schools' readiness to meaningfully incorporate FLSs*

Learning within an RPP is a process of negotiating problems of practice between researchers and practitioners (Penuel et al., 2013). Following such negotiations, the RPP in the current study was initiated with the joint vision of advancing contemporary teaching that takes into account all the TPeCS dimensions and the interconnections between them. The means and strategies of intervention were created ad-hoc, including the three visits to the LINKS-FLS to address practitioners' emerging needs and to balance them with the original goals of the RPP.

The decisions we made throughout the two-year study could not have been planned in advance. This flexibility, in comparison to a more formal teacher professional development approach, enabled us to customize our support, and even change its nature to follow a cognitive apprenticeship approach (Collins, 2006). The tensions involved in this process, as indicated by the action-reaction timeline (Figure3) are a known feature in RPP dynamics (e.g., Penuel et al., 2013), as well as in learning communities (e.g., Hod & Ben-Zvi, 2015). However, as a consequence of this process, the school staff significantly developed their TPeCS knowledge and skills and the school's readiness to incorporate an FLS. The teachers' quote about the practitioner team's readiness and "waiting" for the construction of the FLS (as opposed to other teams where the FLS is "waiting" for the teachers to learn how to use it) indicates this readiness.

## *Development of TPeCS knowledge and skills*

Over a decade ago, Mishra and Koehler (2006) maintained that teachers' knowledge of technology cannot be separated from their knowledge of pedagogy and content, due to the ripple-effect that technology-related considerations have on other pedagogical decisions. That is, technology cannot be treated independently because technology, pedagogy, and content are components of a strongly related system of teaching and design considerations. The dramatic influence that the visits to the LINKS-FLS had on practitioners' rethinking of their pedagogies in the current study echo the notion of ripple-effect, and strengthens our introduction of TPeCS as a framework for conceptualizing teaching in a networked society. This ripple-effect also echoes contemporary notions of FLSs stemming from the learning sciences, viewing space as a component within a dynamic system in which design decisions in each component require adjustments in all others (Hod, 2017; Hod et al., in-press; Ellis & Goodyear, 2016; Radcliffe, 2009).

The analysis of the two-year action-reaction timeline using the TPeCS lens in the current study indicated that of the four knowledge domains encapsulated in teaching expertise, *pedagogy* was the bottleneck in practitioners' professional growth. Our original intention was to work with practitioners on co-designing a set of technology-enhanced activities that would capitalize on the

affordances of citizen science to serve as a context for meaningful STEM learning. In practice, we understood that in the first stages, the gaps between this vision and practitioners' knowledge, competencies, and agency raised many challenges, especially in the domain of pedagogy. As practitioners' understandings, competencies and agency with regard to contemporary teaching pedagogies increased, the other aspects of TPeCS were much more readily adopted. This was prominent in the principal's sharing of her vision, when she first described the pedagogy, and only then the FLS that can support it. The "FLS waiting" quote also expressed the notion that once pedagogy was solved, the affordances of the FLS are clear. Further research is required to determine whether this pedagogy-as-bottleneck is characteristic of teachers' development of TPeCS expertise.

# Conclusion

FLSs are being constructed in schools like mushrooms under the rain. Unfortunately, as Hod et al., (2019) note, the billions of dollars that have already been allocated as part of this trend have by no means brought about the desired outcomes. This trend can provide an unprecedented opportunity for school communities to rethink their practices and develop the knowledge and skills required for teaching in a networked society. The current study illustrates that engendering such a change requires much guidance, in a process that can accommodate flexibility and responsiveness to local affordances and constraints, and that long-term RPPs are particularly suited for such a process. When carefully embedded within RPPs, in a modeling-coaching and fading process, on-site visits to state-of-the-art FLSs can provide pivotal experiences for practitioners, providing them with opportunities to develop contemporary teaching expertise. As such, FLSs are ideal for making pedagogy visible.

We therefore conclude that school-practitioners can, and should, be key players in initiating and leading FLS endeavors within their schools. This is true not only for wealthy schools, but also for underserved schools like the one in this study. Our conception of TPeCS as an extension to Mishra and Koehler's notion of TPaCK (2006) posits that FLSs do not necessarily require fancy and expensive designs, nor do they require cutting-edge technology. Rather, they express the know-how of adapting existing physical spaces and common technological tools to support negotiation of ideas in (data-driven) inquiry-processes within learning communities. Developing such knowledge is strongly dependent on deep understanding and competencies in the domain of pedagogy—the bottleneck of this process.

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## *Statements on ethics and conflict of interest*

There are no conflicts of interest involved in this study. We followed ethics rules and regulations—all teachers gave their consent to participate in the study and to publish its findings.

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