Professional Learning Communities

Theory and Practice Reciprocity in Science and Mathematics Teachers' PLCs

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Teachers are the most essential factor in achieving a good education. The McKinsey report (Barber & Mourshed, 2007), which investigated successful education systems, described two basic requirements for developing a high-quality education system: Attracting high-quality teachers when they first enter the system and continuously developing them professionally. The authors state, 1. The quality of an education system cannot exceed the quality of its teachers; and 2. The only way to improve outcomes is by improving instruction. The conclusion derived from these statements is that any effort to improve an existing educational system should focus on offering the teachers ways to keep developing their knowledge and skills effectively.

Professional Learning Communities (PLCs), where teachers meet regularly to scrutinize their teaching practices and their students' learning achievements, are a supportive framework for the continuing professional development of teachers (Grossman, Wineberg, & Woolworth, 2001). Having proven to impact teaching practices and student learning (Vescio, Ross, & Adams, 2008), many countries have adopted the PLC framework to develop teachers professionally. The present paper examines the reciprocal connections between five Israeli PLC networks and the existing research literature on the professional development of teachers within PLCs. Over the past decade, five science and mathematics teachers' PLC networks have been established in Israel as part of the Trump Foundation's systematic investment in improving the achievements of high school students in sciences and mathematics. The present article lays out their main features followed by their leading guidelines based on research publications and interviews with their academic heads.

The five PLCs presented cover five disciplines: physics, chemistry, middle school science and technology, mathematics (Club 5), and middle school mathematics school coordinators. The discussion also explores the interconnections between the theoretical research literature and the five networks' practical work.

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One definition of the Merriam-Webster dictionary for "community" is "A body of persons of common and especially professional interests scattered through a larger society." (Community, 2022). In the current paper, we refer to communities of science or mathematics teachers who share the common interest of developing their professional knowledge and skills to enhance the teaching of their disciplines in the school. The literature has recognized that belonging to professional communities with shared interests and characteristics supports the members' professional development (PD) throughout their careers (Blonder & Vescio, 2022).

Lave and Wenger's description (1991) of the social nature of professionals' learning explains why PLCs promote the development of their members. Teachers' PLC members may initially have a peripheral position but develop gradually to become active members who contribute more to the community based on the situated learning approach. The literature identifies five features that make PLCs a desirable PD path (Bolam, McMahon, Stoll, Thomas, & Wallace).

The descriptions vary somewhat as scholars like Bolam et al. (2005) identify additional attributes they assume necessary for the effective functioning of PLCs. Despite these slight variations, I engage in this chapter with the five main features mentioned across the different publications (Blonder & Vescio, 2022). The first is that PLCs function under a shared set of norms and values developed by their participants, providing a foundation for the PLCs' future work. The second is that PLC members focus on and are collectively responsible for student learning.

The key here is focusing on the learners' experience that results from the manner of teaching (Hadar & Brody, 2013), in contrast to using PLC work to merely improve student scores on standardized tests (Cochran-Smith & Lytle, 2009). The third PLC feature is that its members engage in a reflective dialogue about their teaching and student learning. Fourth is the PLC's focus on collaboration. The fifth and final PLC feature is that the educators involved must be willing to make public and put to the test their own teaching practices (Vescio et al., 2008). Collectively, these five features work in tandem to create a theoretical foundation for a successful teacher PD. Recognizing teacher communities as effective frameworks for teachers' PD highlights the centrality of collaborative learning for subject matter knowledge, pedagogical content knowledge, and teaching practice within the PLCs (Borko, 2004).

The teachers' PLC networks described in this chapter follow the fan model. According to this model, a lead PLC whose members are lead teachers meets twice monthly at their guiding academic institution. In the intervening weeks, they lead regional PLC gatherings in their schools or elsewhere in their geographic region. The fan model is bi-directional. The academic institution offers top-down knowledge produced through collaboration between the teacher leaders of the leading community.

In parallel, teachers in the regional communities propose bottom-up knowledge and activities influencing the lead PLC's agenda. These two processes are interconnected as the members of the leading community test the activities in their classes and communities, and their insights influence the original design of the lead PLC.

Five science and mathematics teachers' PLC networks

The following is a description of the five operating teachers' PLC networks. They appear in chronological order based on their establishment year.

The Physics Teachers' PLC

The physics PLC network of advanced-level high school physics teachers, initiated in 2011, has been centered at the Weizmann Institute of Science and runs with the support of the Ministry of Education and the Trump Foundation. The network has continuously comprised about 11 PLCs that have served as a platform for the PD of about 250 high school physics teachers, making about a third of the physics teachers in Israel, who teach about 15,000 students per year.

The present description of the Physics Teachers' PLCs leans on the following sources: 1. An interview conducted on March 20, 2022, with the former PLC leaders, Dr. Esther Bagno and the Principle Investigator (PI) Prof. Bat Sheva Eylon, and with the current leaders since 2017, Dr. Smadar Levy and Prof. Edit Yerushalmi (PI). 2. Scientific publications (e.g., (Levy, Bagno, Berger, & Eylon). 3. Research by Weizmann Institute physics department graduates (e.g., the Ph.D. dissertations of Smadar Levy and Michal Walter, supervised by Prof. Bat Sheva Eylon, Dr. Esther Bagno, and Dr. Hana Berger, and their post-doctoral research supervised by Prof. Edit Yerushalmi; M.Sc. student Noga Adi supervised by Prof. Edit Yerushalmi & Dr. Smadar Levy). 4. Documents prepared for the Trump Foundation, which funded the operation of the PLCs jointly with the Weizmann Institute of Science and the Ministry of Education.

The teachers' PD in the PLCs follows the situated learning approach. It offers opportunities to collaboratively reflect on teaching practices from a learner's perspective through new research-based instructional strategies and materials presented at PLC meetings, and meet physics teachers implementing the new activities in their classes and examining the evidences from their classroom experiences with their peers.

Goals of the physics teachers' PLCs

1. Promoting a learner-centered and diagnosis-based pedagogy towards 21st-century scientific and learning practices
2. Responding to the ongoing needs of physics teachers and students
3. Expanding the target physics student body
4. Developing in the teachers a reflective stance towards their practice.

Design principles to achieve these goals

The program derives from disciplinary content related both to the school syllabi and the scientific and learning practices recommended by prominent educational organizations to meet future needs of physics high school graduates. This allows the teachers to benefit from the programs' relevance and potential contribution.
The following are some examples:

• *Promoting a learner-centered and diagnosis-based pedagogy to suit 21st century learning and scientific practices.*
By this we refer to scientific practices meant to empower students as doers and learners of physics, including: constructing on their own the conceptual models required to explain natural phenomena, exercising personal agency in the process, and engaging in a nonlinear process of reflection and learning. Professional development themes, such as Deliberation Labs (Levy et al., 2020) are carefully designed to adjust existing norms and expertise to new goals. The activities' design follows the KI framework (Linn & Eylon, 2011) and involves four processes: *Elicitation* of learners' existing knowledge; *Adding* new ideas; *Developing* criteria to negotiate ideas; and *Sorting out* — consolidating learning.

• *Responding to the ongoing needs of physics teachers and students.* Teachers highly value learning from each other's experiences.

The program offers multiple opportunities for teachers to discuss physics and its teaching with peers in a non-judgmental learning environment and share inspiring practical ideas and teaching materials for their classes. The PLCs offer the teachers prompt responses to their questions and dilemmas, and assist them in handling difficulties.

• *Expanding the target physics student body.*
The PLCs play a vital role in strengthening teachers' resilience by offering an abundance of pedagogical materials and assisting them in adapting classes to diverse student populations. To tailor the instruction to more students, the PLCs introduce diagnostic activities and materials that allow teachers to identify students' naive conceptions and novice problem-solving approaches and propose instructional strategies and materials tailored to students' needs.

• *Developing in teachers a reflective stance towards their practice.* Examples appear in the next section.

Research-based insights

A study of the lead teachers' PLC revealed that it offers its members an interactive and supportive learning environment (Levy et al., 2021). It supports knowledge development by offering opportunities to reflect on the ideas it has put forward after the lead teachers implement them in their classes and the regional communities they lead, thus changing their attitudes and practices.
Another Ph.D. research (Walter, 2021) focused on promoting learner-centered considerations in the physics lead teachers' PLC through collaborative lesson planning. The term "junction" elaborates on the KI framework and was introduced to help the teachers notice pedagogical opportunities. The elicitation junction, for example, is an opportunity for the teachers to identify and expose their students' knowledge.
The researchers found that the focus of the teachers' pedagogical discourse changed over the eighteen months since the beginning of the PLC activity from describing their actions as teachers to centering attention on explaining their pedagogical considerations. Moreover, a shift occurred from general explanations to student-centered ones and increased usage of the adapted KI terminology.
Finally, Levy et al. (2022) studied teacher professional development within the "Flag Person Framework," a structured form of collaborative reflection on practice, recently introduced in the PLCs as a means to support teachers who make changes to their instruction. Teachers' attempts to address calls for granting students more agency over scientific practices are commonly hindered by former norms and habits, and by their surrounding structural constraints — shortage in time and resources, and external exams. The study examined the Flag Person Framework in the instructional lab context. It found that it supported teachers in a gradual process of change, allowing them to collaboratively explore goals and find ways to reorient instruction to achieve them.

The Chemistry Teachers' PLC

The description of the chemistry teachers' PLCs leans on an interview conducted on March 16, 2022, with Dr. Dvora Katchevich, who has headed the network since its establishment and on scientific publications (Blonder & Waldman, 2021; Waldman & Blonder, 2020). The author of this chapter has been the principle academic investigator (PI) of the chemistry teachers' PLCs since their establishment.

The chemistry PLCs, initiated in 2014, have been centered at the Weizmann Institute of Science and run with the support of the Ministry of Education and the Trump Foundation. They have continuously sustained since then a network of about 12 PLCs that have served as platforms for the PD of high school chemistry teachers across Israel.

Goals of the chemistry teachers' PLC

Other than developing knowledge and skills, the chemistry teachers' PLC encourages its members to explicitly articulate their pedagogical considerations in an environment that boosts their sense of belonging to the chemistry teachers' community. The teachers' professional development design aims to support them in applying their knowledge and skills and allow them to introduce varied pedagogical considerations into their teaching, thus benefitting their students. The chemistry teachers' PLC activities support the teachers and encourage them to transfer new ideas, knowledge, and skills related to chemistry teaching and implement them in their classes. Another PLC goal is to attend to the chemistry teachers' isolation at school and create in them a sense of belonging to their community.

Most Israeli schools employ a single chemistry teacher who works alone without a team of colleagues with whom to consult or collaborate. The PLC is a safe place where chemistry teachers meet regularly, explore their teaching practices, and share pedagogical considerations and artifacts from their students' learning. Lastly, the leading PLC is a platform for leadership development among the chemistry teachers in Israel. It offers excellent teachers a professional development path while sustaining their roles as chemistry teachers in school. They can thus enhance their professionalism as chemistry teachers in a different way from the traditional one that tends to direct the teachers to management roles.

Achieving the goals

The PLCs work under the academic umbrella of the Weizmann Institute of Science.[1] They differ from the DuFour PLCs (DuFour & Eaker, 1998), where the teachers of the regional PLCs learn on their own without external inputs. The academic umbrella provides research-based inputs broadening the perspectives of the participating teachers, as will be shown next in the description of the PLC activities' structure.

To achieve their goals, the chemistry teachers' PLC meetings adhere to the following guidelines:

• Create a sense of community (SoC) and build trust among the participating teachers. To foster and sustain SoC, every PLC meeting begins with a short opening session that deepens the participants' social and personal acquaintance.[2] To strengthen the SoC, the PLC leaders have opened a WhatsApp group for the PLC. In this closed WhatsApp group, the teachers keep contact between the meetings in a process that supports the development of SoC and teachers' knowledge, as is described below in the research insights section.

• Investigate students' understanding and misconceptions. PLC chemistry teachers can examine their students' misconceptions by using diagnostic tools designed specifically for this purpose. The diagnostic tools, developed and validated in the Weizmann Institute of Science (Easa & Blonder, 2022), offer the teachers a practical means of exposing student misconceptions in each high school chemistry curricular topic. In the PLC, teachers are introduced to the diagnostic tool, and discuss their own findings in the following PLC meeting.

• Examine pedagogical content knowledge (PCK). The PLC forum discusses pedagogical ways to deal with misconceptions teachers discover in their classes (based on evidence from the diagnostic tools' analysis in class). In these discussions, the teachers openly share their PCK and explain the pedagogical considerations behind choosing a specific way of teaching to address the diagnostic tools' findings about their students. The PLC teachers also present problems they face in their chemistry classes, to get help from the PLC forum. In their pedagogical discussion, the PLC members address the raised issue by sharing their experiences and pedagogical considerations.

• Expose the teachers to new laboratory and digital tools for chemistry teaching. In chemistry teaching, laboratory experiments demonstrate chemical phenomena and provide the students with opportunities to probe them. Digital tools and applications support the abstract explanation of chemical phenomena and concepts. The chemistry PLC is a safe environment to discuss the integration of these means in the chemistry class.

• Offer a stage to the PLC teachers. A dedicated part of the PLC meeting allows one of the teachers to present a short activity such as a lab experiment, a demonstration, or a technological tool, for the other teachers to easily adapt to their own classes. The speaker shares a successfully applied practice, explains the reasons for its success, and receives the PLC members' recognition. The presentation is a valuable opportunity for the presenters to receive feedback from their PLC peers. The feedback is twofold: verbal feedback immediately after the presentation, and teachers' reported impressions after they try out the presented activity in their classes.

Research-based insights

The chemistry teachers' PLCs have researched various issues, including the conditions for developing a sense of community (McMillan & Chavis, 1986), essential for fostering trust and creating a safe environment for sharing difficulties, questions, findings from class experiences, and teaching materials. Furthermore, the researchers issued written recommendations to guide other PLC leaders in using the PLC WhatsApp group to develop a sense of community (Waldman & Blonder, 2020). The WhatsApp group is a participant-driven constructivist tool for ongoing intensive interaction that facilitates sharing practical knowledge corresponding directly to the members' needs.

Blonder and Waldman (2021) outlined a novel mechanism of teacher knowledge development supported by the online communication platform routinely used by the PLC members. They found that the WhatsApp group interactions help teachers overcome the filters that hinder the implementation of new practices in their teaching, thus providing an alternative development path for their knowledge and skills.

Research of the variables that affected teachers' PD within the PLCs revealed that trust and implementation of PLC ideas in the classroom had a different impact on teachers at various points in their career (Blonder & Vescio, 2022). Trust among the PLC members proved essential for the development of new teachers, but its influence on teachers' PD decreased as they gained experience. In contrast, the implementation of knowledge and skills as introduced in the PLC meetings impacted the PD of experienced teachers but had no effect on the perceived PD of novice teachers. These insights suggest that the approach to teachers' PD should be differential.

The idea of adopting a differential approach to teachers' PD, which emerged in this research, lays the basis for a different framework for teachers' PD, which is in line with the personalization stance that puts the learner at the center of the learning process. The uniqueness of this research is that the learners here are the teachers themselves. Another research insight is related to different routes by which the leading teachers developed the lead identity. Most of the development routes guide the teachers towards management or administrative roles. The leading PLC provides a unique development platform for chemistry teachers who do not wish to leave the teaching profession but to develop themselves as teachers.

The Club-5 mathematics teachers' communities of practice

The description of the Club-5 mathematics teachers' communities is based on Leikin and Aisik (2020).

The Club-5 mathematics teachers' communities of practice (CoP)[3] initiated in 2014 are centered at Haifa University and run with the support of the Ministry of Education and the Trump Foundation. They have continuously sustained a network of about 18 PLCs supporting the PD of advanced-level mathematics high school teachers.

Goals of the Club-5 mathematics teachers CoP

The CoP was set up to improve the quality of mathematics teaching in the advanced-level mathematics track of Israeli high schools. Achieving this goal requires strengthening the teachers' proficiency and developing their skills to cope with the increasing heterogeneity that results from accepting more students to the advanced mathematics classes.

Achieving the goals

In its first year, the project was devoted to developing the lead teachers' knowledge and skills. They, for their part, applied those skills from the second year on to educate mathematics teachers in regional CoPs. The lead teachers took an academic course that explored the connection between research and practice and touched on issues encountered in mathematics teaching and the PD of mathematics teachers. The leading CoP defined four core guidelines for the Club-5 community operation based on literature dealing with teachers' PLCs and a dialogue with the lead teachers:

- Create a comfort zone within the Club-5 communities to continuously support the mathematics teachers in sharing their positive experiences and cooperating on problem solving and mathematics teaching.

- Adopt an inquiry-based learning approach by Club-5 teachers. Such an approach implies reading research literature in mathematics education to determine a common terminology, translating research findings into changes in instructional approaches, and analyzing the educational aspects of mathematics assignments and the specific characteristics of advanced mathematics students. To stimulate the participating teachers, the CoP meetings include implementing various types of cooperative learning. A unique principle of the Club-5 CoP is focusing on creativity-inspired activities by designing and implementing creative activities and redesigning existing activities accordingly.

- Devote time to designing special activities for implementation in class and experimenting with them in the CoP meetings.

- Collaborative reflection following the activities' implementation in class.

Research-based insights

The central insight from the Club-5 mathematics teachers CoP regards the specific creativity-oriented activities designed for the advanced-level mathematics classes. These CoP activities enhanced the teachers' mathematical, pedagogical, and educational knowledge and deepened their mathematical and meta-mathematical knowledge and awareness. The researchers (Leikin & Aisik, 2020) suggest expanding further the implementation of this approach to benefit basic-level mathematics schoolteachers as well. The community leaders' research underscored the central role of the lead teachers in sustaining the CoP.

The middle school science and technology teachers' PLC

The description of the middle school (grades 7-9) science and technology (S&T) teachers' PLCs project relies on a May 4, 2022, interview with Dr. Zahava Scherz and Dr. Yael Shwartz, who have headed the network, and on scientific publications (Eylon et al., 2020; Scherz et al., 2021). The PLC network, initiated in 2015 with a single leading teachers PLC, has been centered at the Weizmann Institute of Science and run with the support of the Ministry of Education and the Trump Foundation. The network has gradually expanded and currently includes 22 PLCs. The PLC network functions as a PD framework for S&T middle school teachers across Israel.

Goals of the S&T middle school teachers' PLC

The PLCs aim to offer a professional home to middle-school teachers of science and technology. In this supportive hub, teachers acquire new knowledge and teaching strategies and share their practices, successes and struggles. The participating teachers influence the PLC objectives and priorities to match their needs. The long-term goal of the PLC is to advance the teachers' practice and thus influence and improve S&T teaching and learning in Israeli middle schools.

Achieving the goals

S&T middle school teachers in Israel number about 3,500, since middle schools run an obligatory S&T curriculum. A unique approach was required to reach this high number of teachers. To address this challenge, the heads of S&T school departments formed regional PLCs and organized their S&T school colleagues in PLCs they ran within their schools.

Each PLC meeting had a predetermined structure adjustable to specific needs:

- An opening session aimed to develop and boost the teachers' connection to the PLC.
- A content knowledge session introducing new S&T topics and related pedagogical content.
- A community leadership session aimed to develop leadership strategies, cooperative learning, and psycho-pedagogy learning principles relevant to group dynamics, necessary for leading PLC and school S&T teams. As the S&T program is obligatory in middle school, the classes are highly heterogenic, including students with varying interest levels in S&T and learning abilities. In these circumstances, managing adolescents, the students' age group, is a key issue, and adolescent psycho-pedagogy must also feature in the PLC meetings' program.
- A closing session dedicated to reflection on the meetings and providing feedback.

Research-based insights

The observation and study of the PLCs yielded two main insights. The first regards a "Collaboration Model" that formalizes the design and implementation of collaboration skills in PLCs. The model comprises four collaboration levels developed by the lead PLC members over the years. The first level is participation: the teachers have to participate in the PLC meetings. Next comes sharing ideas, class activities, and other teaching experiences with the other PLC members. Third is cooperation: the teachers work together on a project that requires teamwork and responsibility sharing. The fourth and highest level of the collaboration model involves creating a partnership to initiate and manage a project and share challenges and experiences.

The second insight regards an emergent network model of knowledge transmission between the PLCs. Initially, the PLC network used the fan model, where knowledge transfer occurs top-down, from the academic institution to the PLC teachers, with the mediation of lead teachers. However, the research has indicated that other routes of knowledge transfer have developed within the PLCs. Analysis of these routes suggested that knowledge traveled across the PLC network. Any knowledge the teachers deemed relevant for their teaching found its way to their network partners regardless of who initiated it, whereas knowledge thought to be irrelevant was discarded.

The mathematics school coordinators' PLCs

The description of the middle school mathematics school coordinators PLCs relies on an interview conducted on May 24, 2022, with Dr. Jason Cooper and Prof. Boris Koichu, who have headed the network since its establishment and on scientific publications (Koichu, Cooper, & Widder). The PLC network, initiated in 2017, is based at the Weizmann Institute of Science and runs with support from the Trump Foundation and the Ministry of Education. It has been continuously active, supporting up to four concurrent PLCs. The PLCs provide a PD platform for middle school mathematics coordinators (titled Head of Department, HoD) across Israel.

The PLC goals

Every Israeli middle school has one mathematics teacher functioning as the school mathematics HoD, tasked with leading and supporting the professional work of the school's mathematics teachers. The PLCs aim to empower the middle school mathematics HoDs, help them value their role as change leaders, identify the changes they would like to make, and enhance their effectiveness in leading and coordinating change among the school mathematics teachers' team. The PLC leaders associated with the Weizmann Institute of Science, who form a lead PLC, do not dictate the desired changes. Instead, they provide the mathematics HoDs with the required resources to allow them define and lead changes in their schools.

Achieving the goals

The PLC leaders were well aware that the PLCs functioned under a set of shared norms and values developed by their members. Their primary interest was, therefore, to help the mathematics HoDs gradually divert their team meetings' focus from administrative issues to mathematics education issues they considered important.

One optional change proposed was introducing problem solving as a valued practice in mathematics classrooms, thus decreasing the prominence of drilling practices.

However, they soon discovered that the PLC participants tended to avoid discussing the challenge of leading change in their mathematics departments and were more comfortable maintaining the role of mathematics teachers in the PLC, sharing their classroom experiences and their students' reactions. They repeatedly noted that their school colleagues did not collaborate with them or share their ideas, while they did not possess the tools to influence them. Thus, the PLC leaders had to dedicate a significant part of their work to developing leadership. They often began by asking each participant to define the changes they wished to lead in their mathematics team and determine new experience-sharing routines reflecting their role as leaders.

Research-based insights

The interviewees and authors of the referenced articles described how the trust created among the PLC teachers led to an open sharing of their challenges as school mathematics HoDs. They admitted to being frustrated by their work as school mathematics HoDs, having to devote most of their time to the administrative management of the mathematics teachers' team.
The PLC teachers jointly put together a position paper outlining the role of school mathematics HoDs and defined the support they required to perform their duties successfully. This document empowered them in their negotiations with school principals and strengthened their feeling of belonging to a supportive community of peers.

Research of the PLCs' activity yielded two main theoretical insights. The first regarded the impact of the teachers' professional development (Cooper & Koichu, 2021).
The PLCs illustrated that PD had the desired impact on mathematics teaching practices, affirming that teachers' PD may have varied effects depending on the kinds of practices in which they engage. Tension emerged between disciplinary assignments, (e.g., problem-solving analysis during the PLC meetings to model scenarios for the participants and their teams at school) and addressing urgent needs the participants raised. This tension was also reflected in the expected impact of the PLC. It gradually dissolved with the maturing of the PLC communication norms, as the PLC leaders became more proficient in facilitating the activity, and when some of the participating mathematics HoDs assumed the prominent role of community co-leaders.

The second insight regards the implementation chain (Koichu et al., 2022), namely, the way a new pedagogical idea makes from its proposal by the PLC leadership at the academic institution until the teachers implement it in their classes. The implementation chain is a dynamic sequence of intended, planned, enacted, and experienced activities, shaped by interactions between researchers, PLC leaders, teachers and students, with possible changes in activity and aims along its junctions.

Discussion

While writing down the five PLC networks' descriptions, I felt privileged to have interviewed the PLC leaders and received from them the required information about their PLCs. They described the hugely positive influence a theory translated into practice had on science and mathematics education in Israel over the last ten years. Hundreds of science and mathematics teachers successfully trained to lead science and mathematics PLCs across Israel;

thousands of science and mathematics teachers became active PLC members, embracing the five PLC features to enhance their knowledge and practice; and hundreds of thousands of students have learned science and mathematics topics with teachers who invested much time to improve and perfect their professionalism, collectively exploring their teaching while trying out new pedagogies.

All the PLC networks became the professional communities of teachers who had previously felt isolated, being alone in high schools that mostly employ a single physics teacher, chemistry teacher, and high-level mathematics teacher, and in middle schools with a single S&T coordinator or head of mathematics department. Since collaborative learning requires a group, the PLC proved an effective framework for such learning and PD. All the PLCs presented in this chapter offered the teachers a "safe zone". Building trust among the community members supported "the willingness to be vulnerable under conditions of risk and interdependence" (Rousseau, 1998, p. 395). Trust was a fundamental condition for creating a sense of community that enabled the participating teachers to disclose their concrete challenges. The chemistry teachers' PLC probed trust building among its members, proposing practical tools for trust building and developing a sense of community among the participating teachers.

As mentioned in the introduction, the primary feature of PLCs is that they operate under shared norms and values developed by their participants serving as a foundation for their work. Each PLC negotiated its specific focus to address the needs and challenges raised by the participating teachers and the PLC academic leaders' ideas and agenda. The academic leaders' top-down agendas included the following examples: the Club-5 mathematics teachers' communities of practice focused on creativity-oriented activities, the chemistry teachers PLCs focused on implementing diagnostic assignments, and the physics teachers' PLC implemented the knowledge integration (KI) model. Notably, the academic leaders derived their top-down proposals from the teachers' needs and they were tightly connected to these needs. The diagnostic assignment served chemistry teachers as a tool to identify student misconceptions, essential for promoting differentiated instruction in the heterogenic chemistry classes, and a significant concern of the PLCs' chemistry teachers. The creativity-oriented activities of the Club-5 mathematics teachers' CoP increased the teachers' assignment repertoire. The implementation of the KI model in the physics teachers PLC led to developing a new pedagogical discourse that called the teachers' attention to pedagogical opportunities revealed during the physics lessons. However, in all the PLC networks, the presence of the bottom-up approach, where teachers raised their needs and influenced the PLC agenda was notable. For example, during the Covid-19 crisis and the abrupt transition to remote learning, the PLC networks all played a vital role in strengthening teachers' resilience by offering abundant online pedagogical materials and assisting in adapting lessons to online learning without leaving any students behind. The PLCs' mode of action, where teachers interact with fellow teachers, proved highly effective. It allowed for the clarifying of educational values and identifying impediments to their materialization, experiencing research-based instructional strategies, and reflecting collaboratively on classroom experiences. Together, these features fostered the teachers' motivation, determination, optimism, and inventiveness in those challenging times.

The second PLC feature is its members' collective responsibility for and focus on student learning. To shift the attention to student learning and analyze the impact of how one teaches on the students' understanding, teachers must base the PLC discourse on students' artifacts and engage in a reflective dialogue about their teaching and their students' learning, as the introduction's third feature suggested. A review of the five PLC networks exposed ways to achieve this goal. Teachers of all the PLCs were asked to implement PLC activities in their classes and bring the students' answers to the next PLC meeting. The purpose of this routine was to analyze the students' errors and misconceptions and not their scores. Sharing this information was the basis for the fourth PLC feature — teachers' willingness to share and examine their teaching practices openly. By presenting their students' mistakes and difficulties before the PLC forum, the teachers invited the other PLC members to collaborate in discussing and designing optional ways to address these difficulties. This reflects the fifth PLC feature — the underlying focus on collaboration. The middle school S&T teachers' PLC gave this point special research attention, defining four levels of collaboration among the PLC teachers. Over the PLC's period of operation, the researchers suggested how to build and develop collaboration.

These five fundamental PLC features proved collectively to be the pillars of the five PLC networks of science and mathematics teachers that worked in conformance with the theoretical foundations leading to a successful teacher PD. Notably, the connection to the academic research went beyond basing the PLCs on theoretical models, as the educational research supported the evidence-based learning of the leading PLC teams. As demonstrated in this chapter, the academic research insights provided the practitioners with guiding tools for promoting teachers' professional development in the PLCs. Therefore, I would like to conclude by re-emphasizing the great value of the reciprocal relations between research and practice as a foundation that guarantees the success of the science and mathematics PLCs in Israel. Philanthropy played an essential role in the successful reciprocal research-practice relations. The Trump Foundation's contribution was twofold: It financially supported the big vision of improving the achievements of sciences and mathematics high school students by promoting the teachers within the PLCs framework. At the same time, it trusted the research program of academic researchers, thus supporting the reciprocal relations that boosted the success of the PLCs.■

1 Since 2020, the chemistry teachers' PLCs in northern Israel have been running under the academic umbrella of the Technion. All the other PLCs remain under that of the Weizmann Institute.

2 For additional conditions supporting SoC development, see Waldman & Blonder, 2020, pp. 111-139.

3 A Community of Practice (CoP) is a professional development framework similar to the PLC. Both are based on the situated learning concept (Lave & Wenger, 1991). In this chapter, we use the two terms interchangeably.

References

Barber, M., & Mourshed, M. (2007). *How the world's best-performing school systems come out on top.* https://www.mckinsey.com/industries/education/our-insights/how-the-worlds-best-performing-school-systems-come-out-on-top

Blonder, R., & Vescio, V. (2022). Professional Learning Communities across science teachers' careers: The importance of differentiating learning. In J. A. Luft & M. G. Jones (Eds.), *Handbook of Research on Science Teacher Education* (pp. 300-312). Taylor & Francis Books. https://doi.org/10.4324/9781003098478-26

Blonder, R., & Waldman, R. (2021). The role of a WhatsApp group of a professional learning community of chemistry teachers in the development of their knowledge. In I. Information Resources Management (Ed.), *Research Anthology on Facilitating New Educational Practices Through Communities of Learning* (pp. 820-843). IGI Global. https://doi.org/10.4018/978-1-7998-7294-8.ch041

Bolam, R., McMahon, A., Stoll, L., Thomas, S., & Wallace, M. (2005). *Creating and sustaining effective professional learning communities* (No. RR637) http://effect.tka.hu/documents/OtherLibraryElements/Creating-and-Sustaining-Effective-Professional-Learning-Communities-Extracto.pdf

Borko, H. (2004). Professional development and teacher learning: mapping the terrain. *Education Researcher*, 33, 3-15.

Cochran-Smith, M., & Lytle, S. (2009). *Inquiry as stance: Practitioner research for the next generation.* Teacher's College Press.

Cooper, J., & Koichu, B. (2021). Design and practice of three innovative professional development programs for mathematics teachers. In: A. Hofstein, A. Arcavi, B.-S. Eylon, & A. Yarden (Eds.), *Long-term Research and Development in Science Education: What Have We Learned?*(pp. 333-359). Brill. https://doi.org/10.1163/9789004503625_015

DuFour, R. (2004). What is a 'professional learning community'? *Educational Leadershi*p, 61(8), 6-11.

DuFour, R., & Eaker, R. (1998). *Professional learnng community at work: Best practices for enhancing student achievement.* National Educational Service.

Easa, E., & Blonder, R. (2022). Development and validation of customized pedagogical kits for high-school chemistry teaching and learning: the redox reaction example. *Chemistry Teacher International*, 4(1), 71-95. https://doi.org/doi:10.1515/cti-2021-0022

Eylon, B.-S., Scherz, Z., & Bagno, E. (2020). Professional learning communities of science teachers: Theoretical and practical perspectives. In Y. Ben-David, Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM Teachers and Teaching in the Digital Era: Professional Expectations and Advancement in the 21st Century Schools* (pp. 65-89). Springer Publishing. https://doi.org/10.1007/978-3-030-29396-3_5

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *Teachers College Record*, 103(6), 942-1012. https://doi.org/10.1111/0161-4681.00140

Hadar, L. L., & Brody, D. L. (2013). The interaction between group processes and personal professional trajectories in a professional development community for teacher educators. *Journal of Teacher Education*, 64(2), 145-161. https://doi.org/10.1177/0022487112466898

Koichu, B., Cooper, J., & Widder, M. (2022). Implementation of problem solving in school: From intended to experienced. *Implementation and Replication Studies in Mathematics Education*, 2(1), 76-106. https://doi.org/https://doi.org/10.1163/26670127-bja10004

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge Universty Press. http://www.amazon.com/gp/product/0521423740?ie=UTF8&tag=jrtvre-20&linkCode=as2&camp=1789&creative=9325&creativeASIN=0521423740

Leikin, R., & Aisik, R. (2020). Creativity and openness as indicators of professional growth of leaders in communities of practice of teachers who teach the high-level track of high school mathematics. In *International Handbook of Mathematics Teacher Education* 3 (pp. 81-102). Brill. https://doi.org/10.1163/9789004419230_004

Levy, S., Bagno, E., Berger, H., & Eylon, B.-S. (2020). Motivators, contributors, and inhibitors to physics teacher-leaders' professional development in a program of professional learning communities. In Y. Ben-David, Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM Teachers and Teaching in the Digital Era: Professional Expectations and Advancement in the 21st Century Schools* (pp. 159-184). Springer International Publishing. https://doi.org/10.1007/978-3-030-29396-3_9

Levy, S., Bagno, E., Berger, H., & Eylon, B.-S. (2021). Professional growth of physics teacher-leaders in a professional learning communities program: the context of inquiry-based laboratories. *International Journal of Science and Mathematics Education.* https://doi.org/10.1007/s10763-021-10217-7

Levy, S., Noga, A., Kapach, Z., & Yerushalmi, E. (2022). *Collaborative reflection on the integration of "deliberation labs" into teachers' practice: Large-scale professional development perspective* GIREP, Ljubljana, Slovenia.

Linn, M. C., & Eylon, B.-S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. Routledge.

Little, J. W. (2002). Locating learning in teachers' communities of practice: Opening up problems of analysis in records of everyday work. *Teaching and Teacher Education*, (8), 917. https://doi.org/10.1016/S0742-051X(02)00052-5

McMillan, D. W., & Chavis, D. M. (1986). Sense of community: A definition and theory. *Journal of Community Psychology*, 14(1), 6-23. https://doi.org/https://doi.org/10.1002/1520-6629(198601)14:1<6::AID-JCOP2290140103>3.0.CO;2-I

Rousseau, D. M., Sitkin, S. B., Burt, R. S., & Camerer, C. (1998). Introduction to special topic forum: Not so different after all: A cross-discipline view of trust. *The Academy of Management Review*, 23(3), 393-404. http://www.jstor.org/stable/259285

Scherz, Z., Eylon, B.-S., & Yarden, A. (2021). Professional learning communities for science and technology teachers: models and modeling. In A. Hofstein, A. Arcavi, B.-S. Eylon, & A. Yarden (Eds.), *Long-term Research and Development in Science Education: What Have We Learned?* (pp. 290-305). Brill. https://doi.org/https://doi.org/10.1163/9789004503625_013 https://doi.org/10.1163/9789004503625

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education*, 24(1), 80-91. https://doi.org/10.1016/j.tate.2007.01.004

Waldman, R., & Blonder, R. (2020). A sense of community in a professional learning community of chemistry teachers: A study of an online platform for group communication. In Y. Ben-David, Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM teachers and teaching in the digital era: Professional expectations and advancement in the 21st Century schools (*pp. 111-139). Springer International Publishing. https://doi.org/10.1007/978-3-030-29396-3

Walter, M. (2021). Promoting *"Learning Centered" Considerations Within a Community of Physics Teacher Leaders Through Collaborative Lesson Planning* Weizmann Institute of Science.