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Empowering professional learning communities of secondary science teachers to uncover and address their students' misconceptions via research-oriented practices

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The Partnership for the Development and Success of Science Education in Secondary Schools project seeks to improve science education by fostering a dynamic environment for professional development and teacher-led inquiry within professional learning communities (PLCs). Addressing the long-standing problem of outdated pedagogical approaches, the initiative encourages secondary science teachers to actively engage in action research to identify and/or address student misconceptions of scientific concepts. Through collaboration with professional development leaders and university experts, teachers are empowered to implement and refine evidence-based instructional strategies and cultivate a culture of ongoing professional growth and reflective practice. The partnership emphasizes the importance of bridging the gap between educational research and classroom practice to improve the quality and effectiveness of science education. The project aims to bring about a positive change in teachers' instructional practices and reflections and an increased alignment with contemporary educational standards and evidence-based practices.

KEYWORDS

professional learning community, science education, secondary education, conceptual change, teacher-researcher, consortium

1 Introduction

In its latest TALIS 2018 survey, the OECD (2019) notes that more than half of science teachers still use teaching methods that are essentially based on the principle of transmitting scientific knowledge. In its report on science education in primary and secondary schools, the *Conseil Supérieur de l'Éducation* (CSE, 2013), which operates in the province of Québec (Canada), also paints a stagnant picture of science teaching, judging it to be at the same level as 30 years ago. Even though the use of sophisticated pedagogy, such as conceptual change and scientific inquiry methods, have the potential to produce higher-quality learning that is more durable and rooted in reality, and that modern national, state, or provincial (Gouvernement du Québec, 2008) curriculums encourage such evidence-based practices, a majority of teachers

appear to still essentially rely on deductive methods (Couture et al., 2015).

Unfortunately, in-service teacher professional development (PD) that could change this tendency most often uses unidirectional and top-down transmissive approaches that do not really *walk the talk*. The "do-as-I-say-and-not-as-I-do" professional development practices, as Souto-Manning (2012) denounced, still exist. This type of professional development also usually fails to address the issue of professional isolation that many teachers face (Dussault et al., 2003). Such isolation can lead to various problems such as decreased performance, hindering the development of a culture of professional growth, resistance to change and increased stress.

Most in-service training initiatives are also rather basic, and focus on knowledge of training programs or on concepts to be taught (Lowell and McNeill, 2023). Furthermore, PD initiatives that focus on one-off events (conferences, workshops, etc.) and rely on external experts often take a deficit approach (Bergmark, 2023) and are not always evidence-based (Popova et al., 2021). Many are ill-empowering commercial products, and often dogmatically present comforting solutions they put forward as definitive. Those motivated or organized by academics are rather rare. Some of them sometimes also end up as rather paternalistic recommendations or are poorly adapted to real-life practice contexts (or at least are perceived as such).

The *Conseil Supérieur de l'éducation* (CSE, 2014) also deplores the predominance in teachers' PD of one-off training meetings or courses and occasional participation in conferences and symposia. In response, many authors mention the importance of proposing large-scale sociocultural (Harrison et al., 2008) training activities that are more engaging and sustained in time (Popova et al., 2021; Olsen and Curtiss Wyss, 2022). However, such sustained training activities are costly, both financially and in human energy, which perhaps explains their rarity and the rather ill-suited formulas they put in place. Although there is rather strong evidence that they have a positive effect of feelings of professional self-efficacy (Gesel et al., 2021; Zhou et al., 2023), there is still a lack of evidence that shows the effectiveness of the currently available ones to ultimately improve students' learning (Ventista and Brown, 2023).

In the province of Québec, the unfortunate result of the above described situation is a rather generalized disenchantment with the unidirectional PD offer, available in schools and school service centers and, ultimately, a kind of cynicism about research and somewhat of a disconnection and an increasingly difficult to bridge gap between research and practice (Broekkamp and Van Hout-Wolters, 2007). And so, the challenge of achieving genuine teacher professionalization (Harrison et al., 2008) mostly remains unresolved, and the needs repeatedly expressed by school communities and administrations in this regard have yet to be met. This dissatisfaction could be why, in recent years, many schools and school boards in the province have attempted to develop new models of PD, based on the principles of teachers and researchers working together (Saint-Cyr, 2020), and sometimes in what has been called a "culture of [research] data" (*culture des données*) (Labelle et al., 2020). Even if the effectiveness of community-based initiatives is still to be established, they have increased in popularity and have taken various forms.

2 Pedagogical framework

Based on recommendations from the scientific literature on effective PD and on our own previous experiences (Potvin et al., 2020), we chose an evidence-based approach to teaching interventions while considering principles for implementing of sustained changes in classroom instructional practices (Darling-Hammond et al., 2017). The chosen approach is a type of action research, specifically *teacher action research* (Capobianco and Feldman, 2006), where teachers become researchers in and about their own classrooms. To break professional isolation, they became part of a professional learning community (PLC) where they worked alongside PD leaders and university experts. Regarding content, we addressed a common issue in science education: students' misconceptions and ways to promote conceptual change.

2.1 Teacher action research as a means of professionalization

Teacher action research (Capobianco and Feldman, 2006) is a form of inquiry conducted by teachers in their own classrooms or educational settings to improve their teaching practices, enhance student learning outcomes, and increase understanding of educational phenomena. This form of action research is consistent with what Laudonia et al. (2018) as well as other scholars have described as "teacher-centered action research." It differs from a more "*technical* approach" (Mamlok-Naaman and Eilks, 2012) to action research, in which an external person initiates most of the research; from establishing research interests to data collection, evaluation, and even implications for action. Teacher action research emphasizes the active role of teachers as researchers, leveraging their insights and experiences to drive educational improvement and innovation. It involves systematic observation, data collection, reflection, and analysis of teaching methods and student learning, leading to informed and reflective changes in practice.

Based on educational action research, *teacher action research* involves typical activities or phases that are part of the action-research cycle (Elliott, 1991). Among these activities, teachers come to identify a situation they wish to change (or know more about), develop a plan of action, implement it and observe/collect data in their classrooms, to ultimately reflect on their choices and actions and inform subsequent planning, reflection, and interpretation. Finally, some authors, such as Capobianco and Joyal (2008) suggest an additional step that accounts for the dissemination of the results. This additional phase is present in other types of teacher action research (Tugel and Porter, 2010), as a mean of acknowledging the involvement of teachers and giving credit to their work.

Thus, we use the concept of teacher action research to insist on the teacher-as-researcher stance (Souto-Manning, 2012), and fully recognizing that teachers should conduct research that belongs to them, meets their needs, of which they are the primary beneficiaries and owners, and that gives them the opportunity to reflect systematically on their professional development. When adopting such a perspective, participants are seen as primarily responsible for selecting and formulating their research question or objective. This is a part of the metacognitive self-regulation process (Bañas et al., 2009) inherent to teachers' work. We also believe that this kind of PD

approach has the potential to reconcile teachers' action research not as a process detached from school practice, but rather as an initially not so natural, but progressively important component of their daily work.

Numerous sets of quality criteria have been proposed to describe successful action research or teacher action research. We will not comprehensively review them here, but use some of them, closer to science education and to the general mindset of our own project (Capobianco and Feldman, 2006), to organize its presentation. Among others criteria, it has been argued that successful science teacher action research should be (1) organized in communities of practice (p. 502); that these communities should also (2) act as "epistemic communities" (p. 504), and that they should (3) share knowledge about relevant research methods (p. 507).

2.2 Professional learning community

Professional learning communities (PLC) are communities of practice that share professional improvement goals and engage in research to acquire, share, mobilize and develop knowledge. Although often considered expensive, PD programs have been argued to be one of the most effective ways to bring about concrete and lasting change in classrooms (Vescio et al., 2008). PLC have been defined as "groups of people sharing and critically interrogating their practice in an ongoing, reflective, collaborative, inclusive, learning-oriented, growth-promoting way […] and operating as a collective enterprise (Stoll et al., 2006, p. 223)".

Many other -mostly composite- definitions have also been formulated, but most converge well around this general idea. Sets of effectiveness criteria have also been identified: (1) shared, explicit and emerging goals and objectives, values and vision; (2) reflective inquiry and a focus on knowledge about "how to learn"; (3) collaboration, constructive inter-individual- and self-critique and sharing; (4) group and individual learning being promoted; (5) diversity (and even exclusiveness) in expertise; (6) respect, and failure-safe principles; (7) presence of concrete- and quality-seeking of- productions; and (8) systematic valorization of people, their efforts and their products; a (9) sense of belonging, etc. (Bielaczyc and Collins, 1999; Stoll et al., 2006). More recently, Chiang et al. (2024) have revalidated Stoll's definition and, through an analysis of available studies, have suggested that although no consensus on a universal definition exists, some common characteristics can be identified: an involvement in conversations on educational issues, shared values and goals, the deprivatization of practice (making it explicit to peers), collaboration, and a focus on student learning.

2.2.1 The power of sustained activities

Another property of successful PLCs and teacher action research is the *sustained* character of such PD initiatives. Sustained action can be achieved through follow-up interventions or visits (Popova et al., 2021) or community activities that span over months (Megowan-Romanowicz, 2010) and even years (Capobianco and Feldman, 2006; Harrison et al., 2008; Potvin et al., 2020). Indeed, PD is a process that often calls into question the deep-rooted values and robust representations to which teachers adhere, sometimes for a very long time. It is therefore a delicate process of change that necessarily extends over time. In community work, teachers are not necessarily ready to admit their failings, blind spots or challenges as professionals in the first few months, or even sometimes the first few years. They first need to be convinced of the safety of community dynamics, and that takes time as well. We observe that it's often only after a few years of activity that they truly relax and are ready to serenely consider more profound changes to their practice. And it's often only after direct and sustained exposure to peer views and research-based discourse that they can adopt and fluently use research-derived constructs and methods, innovate, become concretely productive and ultimately be recognized by their colleagues as authorities and agents of change, when back in school. Thus, time is important. Without taking it, few real changes can occur.

2.3 Student's conceptions and conceptual change as a framework and repertoire

More than a mere community of practice, and according to Capobianco and Feldman (2006), an *epistemic community* should "create and warrant knowledge" (p. 504). This knowledge should also be "believable and trustworthy to others outside the local group" (p. 505), and refer to a "shared repertoire." (*Ibid.*). Among the classic characteristics of PLCs, the authors had already identified in a very general way this ambition to develop knowledge which is credible, even outside its members and activities. However, the idea of "epistemic community" will be borrowed here, because it provides us with more elements necessary to frame such a development. We will therefore sometimes call our PLCs "epistemic communities" when we want to emphasize this dimension.

The choice fell on a body of knowledge which challenges science teachers on an almost daily basis: the problem of conceptual change. Regardless of their subject matter or discipline, science teachers face common obstacles due to students' intuitive conceptions of certain phenomena that may interfere with or contradict scientific knowledge. These didactic problems fall under the category of pedagogical content knowledge (PCK), which is a sound starting point for generating professional knowledge and fostering student learning in science. The misconception/conceptual change subfield of research (Duit, 1999; Vosniadou, 2008) is a popular among researchers science education framework that studies and addresses matters of students' personal- or socially-derived- non-scientific knowledge that can lead to errors and that often interferes in teaching efforts. It addresses concerns of diagnosing the presence– and understanding the origins and nature- of such undesired ideas; and of didactical interventions that consider them systematically for successful science teaching and learning (Hewson, 1981; Posner et al., 1982; Potvin et al., 2020).

This "repertoire" of already well-developed pedagogical knowledge and research methods (questionnaires, interview, teaching/learning models) yet nevertheless fails to completely solve the problems elicited by misconceptions in science classes. It also fails to inform teachers of the specific misconceptions he/she will face in their specific contexts, and neither does it provide complete and fully pre-adapted wall-to-wall solutions. The field of research nevertheless offers a rich set of tools (conception inventories, interview methods and questionnaires), reflections, ideologically-driven possible solutions, lots of convincing research results; and many conceptual change models (Potvin et al., 2020), but from the perspective of teachers, *conceptual change* is still more an arena than a complete solution.

It thus remains an interesting problem that most teachers can immediately recognize as relevant. However, their respective levels of knowledge and experience of analyzing real-life situations using this grid are rather uneven. Some are very familiar with it, while others have only had an inkling about it. But all readily recognize the relevance of taking an interest in it to improve their practice. This field of research and intervention therefore has great potential to form a unifying and motivating basis for productive collective work.

2.4 The importance of developing a fairly good understanding of research

Capobianco and Feldman (2006) argue that true *epistemic communities* should share knowledge about relevant research methods (p. 507). We agree but stress that knowledge about research is infinite and complex. It takes a lot of time and effort to develop some kind of familiarity with it. This is why we believe a repertoire of methods should be prepared in advance, to facilitate appropriation by our participants. We have chosen to introduce some methodological approaches in small number, by prioritizing the ones that are among the most common in the conceptual change field of research. We have also selected and prepared summarized presentations that might better suit professional practitioners' goals of better knowing their students and the beliefs they hold about natural phenomena, as well as the goals oriented toward a better knowledge of the effectiveness of teaching methods. Thus, we identified (1) *Diagnostic research*, which aims at identifying the beliefs or initially prevailing conceptions of their students; (2) *Design research* (or *development research*), aimed at creating new interventions or fine-tuning existing ones on the basis of objective data, the advice of peers or experts; and (3) *Comparative studies*, that most often use quantitative data to compare the state of misconceptions between presumably different groups, between pre- and post-tests, or gains between experimental conditions that refer to concurrent interventions. With such a sub-selection and formatting of research methods, we believe that teachers might be able to better concentrate right from the beginning on a fast realization of a first classroom-based research project which appeals to them.

3 The learning environment

3.1 A university-based consortium for the development and success of science education in secondary schools

The *Partenariat pour le développement et la réussite de la formation scientifique au secondaire* (*Partnership for the Development and Success of Science Education in Secondary Schools*) is a large-scale project involving 12 school service centers, 3 associations, 4 research centers and chairs, and 5 universities, with 15 researchers. This partnership, funded by the Social Sciences and Humanities Research Council of Canada (SSHRC) and the partners, is supported with $3 million. It will run for 7 years and is based on the egalitarian meeting and matching of knowledge derived from educational research and the experiential knowledge of secondary science and technology (S&T) teachers within Professional Learning Communities (PLCs) Objectives of the PLC.

3.2 Operation

The mission of the Partnership is to contribute to the development and success of secondary science education for teachers and, ultimately, their students. Its goals are to: (1) to create, manage and develop a training environment that is engaging, safe and rewarding, and that encourages the co-construction and dissemination of concrete solutions to shared problems; (2) to encourage teachers to mobilize evidence-based data in science education; (3) to contribute to the professionalization of teachers through the concept of teacher-researcher, while breaking down professional isolation; (4) contribute to the sustainable development of the scientific culture and mindset of science and technology teachers and, in a cascade, of their students; and (5) generate and disseminate new knowledge about the effectiveness of targeted interventions and the impact of a Professional Learning Community (PLC) training dynamic over time.

While each school partner is responsible of identifying the participant teachers, and agrees to provide five release days per year for one, as well as the accompaniment and support services of at least one PD leader. The university partners provide the organization, management, facilitation and content. With the support (facilitation) of experienced researchers, and PD leaders and following the example of work previously initiated by (CRIJEST), teachers assume the role of "teacher-researchers" (Potvin et al., 2017, 2020). Their results will then be communicated to their peers through a variety of channels, including partner-supported communications and publications, as well as the Partnership's annual colloquium. Results may also be published in academic journals.

The PLCs in the first half of the project focus their attention and actions on the non-scientific representations (conceptions) that students mobilize in their interpretation of natural phenomena, as well as on the best ways to move them (conceptual change (Duit and Treagust, 2003)) toward scientific knowledge as considered in the program. In the second half, PLCs will turn their attention to the development of scientific thinking and the social (e.g., biological racism), economic (e.g., 5G), environmental (e.g., climate change), health (e.g., vaccines) and other issues associated with it. Through the support provided by the experts within these PLCs, the project aims to make a direct contribution to all these crucial issues, as well as to those that are bound to arise in the future, through the sustainable development of teachers' scientific and didactic (PCK) culture, and the emergence of thinking applicable to the professional, scientific and pedagogical problems they are called upon to solve on a daily basis.

Ongoing research will also be carried out on the participating teachers, as they evolve during the school year. This research will attempt to answer questions related not only to their level of satisfaction with the services they receive, but also to the evolution of their perceptions of how science works (epistemology), the practice of teaching science, and finally their sensitivity to the results of educational research. The methodology will involve questionnaires and interviews.

3.3 Timeline of events

The teachers, PD leaders and researchers of the PLCs gather five times a year, each time at least for 1 day. The first three meeting sessions require overnight stays and at least 1 day of work and training. These retreats provide a pleasant, relaxed, and safe environment for PD

activities. The conditions foster individual and collective work, while also facilitating socialization and networking. They offer an opportunity to focus on the task at hand, free from the constraints and distractions of the usual work environment. They are held in great locations, far from major centers, in beautiful hotels at the foot of ski mountains or lakes. The choice of nice locations contributes to their professional valorization and the enhancement of their efforts. Everything is provided: hotel, transportation, restaurant meals, and a few gifts (books).

During these first three sessions (October, December and February), teachers are gradually introduced, through a wide range of activities led by researchers and educational consultants, to available and emblematic research findings on misconceptions and conceptual change, about both diagnostic and possible interventions, as well as to certain dimensions of research methodologies how to conduct interviews; how to analyze quantitative data with software (*t*-tests and effect sizes) and ethics (obtaining consent, composing comparable groups). Experience-sharing and co-construction activities are proposed and alternated.

Right from the start, teachers are provided with the written "specifications" and constrains of the project, detailing the requirements, as well as a "project statement and structuring sheet" (allowing them to organize their work and make their progress known to the researchers). In the written specifications, which acts as somewhat of a "contract," is explicitly mentioned that participants are encouraged to adopt a teacher-researcher stance and design a class-wide research project. Such a project "should aim to learn about their students' conceptions or the most effective ways to change them." Also, their research project must fit into one of the following types of research: (1) diagnostic; (2) design research; or (3) comparative research. Teachers are made aware that the culminating point in the process will be the sharing of results with peers. The "project statement" sheet includes prompts that guide teachers as they plan and reflect upon the process. It helps them write their inquiry report and prepares them to share their research (colloquium). Since it is an online collaborative document, it can be consulted by the university research team and PD leaders to provide timely support. Other resources, like useful research articles, examples of validated diagnostic questionnaires, summaries of methodologies, and the like is also shared online via a sharing platform.

The anticipated outcome is a brief oral presentation of the project, its findings, and the educational or instructional implications it produces. The presentation is expected to last 15 min and is followed by a seven-minute question period. It describes the context and intention behind the project, the research questions chosen, the methodology used, and the results obtained. It aims to demonstrate the rigorous execution of the project and provide a reflection on the resulting pedagogical or didactic perspectives.

During training sessions, particular attention is paid to ensuring that input is egalitarian. Content, previously negotiated with pedagogical advisors, is sometimes introduced by academics, but at other times by teachers. There is always room for discussion. Time is also set aside to explicitly address teachers' concerns about the development of their projects. Here are a few examples of scheduled activities:

- A 90-min workshop enabling participants to reflect on the distinction between student errors due to misconceptions and other types of errors (Figure 1).
- A 60-min workshop on teachers' identification of misconceptions commonly found in their practice, in relation to the different scientific disciplines they teach.
- A 30-min presentation of an "emblematic of the conceptual change research field" article, followed by a 30-min discussion of the possible implications of the findings for practice.
- Pairing of participants to allow two-way exchanges on the value and limits of candidate research questions (and their exact formulation) for their project.
- A presentation by a guest researcher (with extensive experience) of results of a statistical validation of a research questionnaire, followed by a discussion of what can be learned from the results for participants' own projects.
- A short 30-min workshop on how to use Excel™ to support a comparative analysis.

In each session, a fair and increasingly important amount of time is also devoted to developing their respective research projects. Participants are then accompanied and supported by researchers and PD leaders, according to their needs. Every effort is made to create a safe environment, free from nonconstructive criticism and judgment. The magnitude and scope of their respective projects are not commented on, nor judged. Time is set aside for systematic feedback between members. There are long breaks to set a relaxed pace and provide opportunities for fraternizing and developing a sense of belonging to the group and to the project. We seize every opportunity to remind them of their important role as teachers, their professionalism, and their mission.

FIGURE 1
Science teachers working together on their research projects.

The fourth meeting is not a stay but a single day gathering, usually held in April, after data collection. This working day aims to consolidate the data, carry out their analysis and prepare for the conference which takes place a month later. Many participating teachers also requested private meetings with researchers, sometimes with their PD leaders, to obtain additional support.

The fifth meeting day is held in the university and gathers all the participants from all PLCs around the Greater Montréal area. This conference is held in the most prestigious room of the university, and the rector of the university, as well as the chief scientist of Quebec, are invited to address the conference participants at the opening. The day then takes place in several rooms, in which the teachers are featured and present their projects and their results in accordance with the specifications. They then answer questions from those present and defend their project as researchers would. During this event, care and kindness is required because some teachers are undertaking such an exercise for the first time, and our goal is evidently to make this experience a positive one. We also invited guest *stars*: teachers from France, who also carry out action research projects on related themes, are invited to present their results. And we have prestigious guests, big names in research on students' conceptions, who give short conferences. Every effort is made to ensure that participants are aware of the importance of the efforts they are being recognized for and have made during the school year.

Additional dissemination efforts are also being implemented: (1) participation of certain teachers in provincial association conferences; (2) representations at research conferences and (3) publication of short written research reports on our platforms.

In the general organization, initial development and ongoing fine-tuning of our professional learning community activities, we have used as explicit quality criteria the nine dimensions of effective communities, as presented in 3.2 and inspired by Bielaczyc and Collins (1999) and Stoll et al. (2006).

4 Assessment and results: lessons from the first year

4.1 Participation

During the first year of the project (2023–24), a total of $N = 44$ teachers (about 2/3 female) were involved from the beginning, as well as 12 PD leaders and an ICT specialist, and a total of 8 researchers (directly involved in the communities). They were divided into two PLCs; one for each bank (north and south) of the St. Laurent River. At the time of writing, there are 30 research projects (some of which have chosen to work in collaboration) that will be completed by the end of the school year and presented at the colloquium in May. Throughout the school year, the atmosphere was generally very good and the teachers were very enthusiastic, sometimes even a little too enthusiastic (see below). The numbers of students they involved varied widely, and the types of research favored revealed a clear preference for comparative research, although diagnostic research was also used, sometimes as a plan B when time ran out. The themes explored were varied: electricity, forces and movements, technology, immunity, epistemology, etc.

4.2 A first set of measures

Throughout the years, the dynamics and effects of the PLC will be the object of measures, taken on participating teachers. It is expected that we can monitor the evolution of variables of interest such as self-efficacy, attitude toward research, epistemological commitments, and representations of science [nature of science (n.o.s.)], pedagogical content knowledge, etc. For the first year, a semantic differential questionnaire that tests for the presence representations about scientific knowledge and student's learning was administered. A rough preliminary analysis of the pretest data appears to reveal that our participants have a rather high level of epistemological and pedagogical sophistication, suggesting that they were recruited (by PD leaders) on the basis of their initial aptitude to carry on a research project, more than on the basis of their potential to increase in sophistication. An eventual post-test will possibly allow us to record changes between end and beginning of the PLC activities, but we rather somewhat of a ceiling effect.

5 Discussion on implications and lessons learned

The establishment and nurturing of a PLC within the context of secondary science education has presented a unique opportunity to bridge the gap between educational research and pedagogical practice. This discussion delves into the critical aspects that underpin the success of our specific PLC in its first year of existence, highlighting the integral conditions for its effective implementation, the project's originality, the significance of flexibility, and an examination of participant behavior.

We have come to the following conclusions through discussions held at meetings of the organizing committee. These reflections, carried out systematically on a regular basis, were conducted in the light of the self-imposed readings by this committee from the outset, and which also served to frame the present article. These findings were also obtained from the aftermath of the "training steering committee" meetings, as well as from the satisfaction surveys that were held with participants just after the first four meetings.

5.1 Implementation conditions and success

The conditions identified by Linder et al. (2012) for the successful implementation of a PLC have played a foundational role in the success of our initiative. Among these, regular meetings, in-depth study of selected topics, and the integration of new materials pertinent to the PLC's focus area have fostered an environment conducive to professional growth and effective practice. Crucially, the ability to study a topic in depth, facilitated by sustained engagement and the support of tailored materials, has enhanced the participants' pedagogical content knowledge and their understanding of students' misconceptions in science. Moreover, our PLC has emphasized the importance of creating a "self-esteem safe" environment. This has been instrumental in encouraging participants to engage with research, both in terms of understanding existing studies and in conducting their own. The reflexive processes initiated by this engagement have

led to significant professional development, evidenced by the valorization of participants' work and the cultivation of a sense of belonging. The establishment of a culture of constructive inter-critique has further enriched this experience, enabling the collective advancement of pedagogical practices.

5.2 Originality of the project

Our project distinguishes itself through several original aspects, beyond its interest in misconceptions and conceptual change. Foremost among these is the adoption of a "teacher action research" approach, granting teachers full autonomy over key decisions. This empowerment extends through the entire research process, from conception to dissemination, a rarity in action research initiatives. The project's commitment to research ethics (which we have not seen as strong in other existing PLC projects) and its seven-year duration further underscore its originality. The extended timeline, in particular, allows participants to project their involvement over many years, fostering the development of more robust research competencies and a more open and constructive professional demeanor.

5.3 The importance of flexibility

The unprecedented educational strike event that occurred within the province in 2023–24 underscored the importance of flexibility in the face of external disruptions. The project's ability to adapt–shifting meetings online and rescheduling activities–demonstrated the resilience of the PLC and its organizing committee. This flexibility not only maintained the momentum of the project but also minimized participant attrition, highlighting the critical role of responsive, collectively driven, and adaptive leadership in sustaining PLC.

5.4 Participant behavior and challenges in an epistemic community

Despite the high levels of motivation observed among participants, the project illuminated certain challenges. The drive to advance quickly sometimes led to hasty decisions, which participants later regretted. Additionally, a tendency among some teachers to demand too much of themselves or to undervalue their work points (as was seen in Capobianco and Feldman (2006)) to the nuanced complexities of fostering a balanced approach to professional development. These observations reflect broader themes in scientific literature concerning the pressure self-inflicted by our participants for achieving "*good-enoughness*" (Megowan-Romanowicz, 2010), suggesting an area for ongoing attention and support.

In conclusion, the success of our PLC in secondary science education is multifaceted, grounded in well-established conditions for effective PLCs (Stoll et al., 2006; Linder et al., 2012; Souto-Manning, 2012), the originality and depth of our project, the indispensability of flexibility, and a nuanced understanding of participant behavior. As we move forward, the insights gained from this endeavor should contribute, we hope, to the refinement and replication of similar initiatives, with the ultimate goal of enhancing science education through sustained, teacher-led action research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

PP: Writing – review & editing, Writing – original draft, Investigation, Funding acquisition, Conceptualization. BB: Writing – review & editing, Conceptualization. ED: Writing – review & editing, Conceptualization. AH: Writing – review & editing, Supervision, Investigation, Conceptualization. MR: Writing – review & editing, Supervision, Investigation, Conceptualization.

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Conflict of interest

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

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References

Bañas, C., López, A., Mellado, V., and Ruiz, C. (2009). Metacognition and professional develpment of secondary education scientice teachers: a case study. *J. Educ. Res.* 3, 204–221.

Bergmark, U. (2023). Teachers' professional learning when building a research-based education: context-specific, collaborative and teacher-driven professional development. *Prof. Dev. Educ.* 49, 210–224. doi: 10.1080/19415257.2020.1827011

Bielaczyc, K., and Collins, A. (1999). Learning communities in classrooms: advancing knowledge for a lifetime. *NASSP Bull.* 83, 4–10. doi: 10.1177/019263659908360402

Broekkamp, H., and Van Hout-Wolters, B. (2007). The gap between educational research and practice: a literature review, symposium, and questionnaire. *Educ. Res. Eval.* 13, 203–220. doi: 10.1080/13803610701626127

Capobianco, B. M., and Feldman, A. (2006). Promoting quality for teacher action research: lessons learned from science teachers' action research. *Educ. Action Res.* 14, 497–512. doi: 10.1080/09650790600975668

Capobianco, B. M., and Joyal, H. (2008). Action research meets engineering design. *Sci. Child.* 45:22.

Chiang, K. M., Yin, H., Lee, I., and Chang, C. H. (2024). Taking stock of the research into professional learning communities: paradigms, pathways, and possibilities. *Teach. Teach. Educ.* 139:104431. doi: 10.1016/j.tate.2023.104431

Couture, C., Dionne, L., Savoie-Zajc, L., and Aurousseau, E. (2015). Développer des pratiques d'enseignement des sciences et des technologies: selon quels critères et dans quelle perspective? *Recherches Didactique Sci. Technol.* 11, 109–132. doi: 10.4000/rdst.1004

CSE. (2013). *L'enseignement de la science et de la technologie au primaire et au premier cycle du secondaire*. Gouvernement du Québec (Conseil Supérieur de l'Éducation). Available at: https://numerique.banq.qc.ca/patrimoine/details/52327/2316336.

CSE. (2014). *Le développement professionnel, un enrichissement pour toute la profession enseignante: avis au Ministre de l'éducation, du loisir et du sport et Ministre de l'enseignement supérieur, de la recherche et de la science*. Gouvernement du Québec (Conseil Supérieur de l'Éducation). Available at: https://numerique.banq.qc.ca/patrimoine/details/52327/2391031.

Darling-Hammond, L., Hyler, M. E., and Gardner, M. (2017). Effective teacher professional development. Palo Alto: Learning Policy Institute.

Duit, R. (1999). "Conceptual change approaches in science education" in New perspectives on conceptual change. eds. W. Schnotz, S. Vosniadou and M. Carretero (Turkey: Pergamon).

Duit, R., and Treagust, D. (2003). Conceptual change - a powerful framework for improving science teaching and learning. *Int. J. Sci. Educ.* 25, 671–688. doi: 10.1080/09500690305016

Dussault, M., Deaudelin, C., and Thibodeau, S. (2003). Les causes de l'isolement professionnel des enseignantres et des enseignants. *McGill J. Educ.* 38, 49–63.

Elliott, J. (1991). Action research for educational change. *1st* Edn. Buckingham: Open University Press.

Gesel, S. A., LeJeune, L. M., Chow, J. C., Sinclair, A. C., and Lemons, C. J. (2021). A meta-analysis of the impact of professional development on teachers' knowledge, skill, and self-efficacy in data-based decision-making. *J. Learn. Disabil.* 54, 269–283. doi: 10.1177/0022219420970196

Gouvernement du Québec. (2008). *Programme de formation de l'école québécoise, Enseignement secondaire, Deuxième cycle*. Les publications du Ministère de l'Éducation du Québec.

Harrison, C., Hofstein, A., Eylon, B. S., and Simon, S. (2008). Evidence-based professional development of science teachers in two countries. *Int. J. Sci. Educ.* 30, 577–591. doi: 10.1080/09500690701854832

Hewson, P. W. (1981). A conceptual change approach to learning science. *Eur. J. Sci. Educ.* 3, 383–396. doi: 10.1080/0140528810304004

Labelle, J., Leclerc, M., and De Granpré, M. (2020). Développement d'une culture de données et de collaboration chez des enseignants travaillant en communauté d'apprentissage professionnelle. *Trans Form.* 1, 66–82.

Laudonia, I., Mamlok-Naaman, R., Abels, S., and Eilks, I. (2018). Action research in science education – an analytical review of the literature. *Educ. Action Res.* 26, 480–495. doi: 10.1080/09650792.2017.1358198

Linder, R. A., Post, G., and Calabrese, K. (2012). Professional learning communities: practices for successful implementation. *Delta Kappa Gamma Bull.* 78, 13–22.

Lowell, B. R., and McNeill, K. L. (2023). Changes in teachers' beliefs: a longitudinal study of science teachers engaging in storyline curriculum-based professional development. *J. Res. Sci. Teach.* 60, 1457–1487. doi: 10.1002/tea.21839

Mamlok-Naaman, R., and Eilks, I. (2012). Different types of action research to promote chemistry teachers' professional developement- a joined theoretical reflection on two cases from Israël and Germany. *Int. J. Sci. Math. Educ.* 10, 581–610. doi: 10.1007/s10763-011-9306-z

Megowan-Romanowicz, C. (2010). Inside out: action research from the teacher–researcher perspective. *J. Sci. Teach. Educ.* 21, 993–1011. doi: 10.1007/s10972-010-9214-z

OECD (2019). Résultats de TALIS 2018, vol. *1*. Paris, France: OECD.

Olsen, B., and Curtiss Wyss, M. (2022). *Teachers can change the world: scaling quality teacher professional development*. Available at: https://policycommons.net/artifacts/4140772/teachers-can-change-the-world/.

Popova, A., Evans, D. K., Breeding, M. E., and Arancibia, V. (2021). Teacher professional development around the world: the gap between evidence and practice. *World Bank Res. Obs.* 37, 107–136. doi: 10.1093/wbro/lkab006

Posner, G., Strike, K., Hewson, P. W., and Gertzog, W. (1982). Accomodation of a scientific conception: toward a theory of conceptual change. *Sci. Educ.* 66, 211–227. doi: 10.1002/sce.3730660207

Potvin, P., Hasni, A., and Boissard, B. (2017). *Accompagner les enseignants pour rehausser l'intérêt de leurs élèves à l'égard des S&T: cinq années de communauté d'apprentissage professionnelle (CAP) à la CRIJEST Congrès annuel de l'AESTQ, St-Augustin-de-Desmaures, QC.*

Potvin, P., Hasni, A., and Sy, O. (2020). Attempting to develop secondary Student's interest for science and technology through an in-service teacher training initiative based on the principles of the learning community. *J. Res. Sci. Math. Technol. Educ.* 3, 15–34. doi: 10.31756/jrsmte.312

Potvin, P., Nenciovici, L., Malenfant-Robichaud, G., Thibault, F., Sy, O., Mahhou, M. A., et al. (2020). Models of conceptual change in science learning: establishing an exhaustive inventory based on support given by articles published in major journals. *Stud. Sci. Educ.* 56, 157–211. doi: 10.1080/03057267.2020.1744796

Saint-Cyr, C. (2020). *LE PROJET CAR Une initiative québécoise visant le développement professionnel des cadres et des employés du système scolaire public ainsi que le renforcement des apprentissages et de la réussite de tous les élèves*. Available at: https://www.cnesco.fr/wp-content/uploads/2021/02/210202_Notes-experts_St_Cyr.pdf.

Souto-Manning, M. (2012). Teacher as researcher: teacher action research in teacher education. *Child. Educ.* 88, 54–56. doi: 10.1080/00094056.2012.643726

Stoll, L., Bolam, R., McMahon, A., Wallace, M., and Thomas, S. (2006). Professional learning communities: a review of the literature. *J. Educ. Chang.* 7, 221–258. doi: 10.1007/s10833-006-0001-8

Tugel, J., and Porter, I. (2010). Uncovering student thinking in science through CTS action research. *Sci. Scope* 34, 30–36.

Ventista, O. M., and Brown, C. (2023). Teachers' professional learning and its impact on students' learning outcomes: findings from a systematic review. *Soc. Sci. Hum. Open* 8:100565. doi: 10.1016/j.ssaho.2023.100565

Vescio, V., Ross, D., and Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teach. Teach. Educ.* 24, 80–91. doi: 10.1016/j.tate.2007.01.004

Vosniadou, S. (2008). "Conceptual change research: an introduction" in International handbook of research on conceptual change. ed. S. Vosniadou (Abingdon: Routledge), xiii–xxviii.

Zhou, X., Shu, L., Xu, Z., and Padrón, Y. (2023). The effect of professional development on in-service STEM teachers' self-efficacy: a meta-analysis of experimental studies. *Int. J. STEM Educ.* 10:37. doi: 10.1186/s40594-023-00422-x