USING PRACTICAL WORK EFFECTIVELY IN THE SCHOOL SCIENCE LABORATORY: A TEACHER TRAINING PROGRAMME BASED ON THE LEARNING COMMUNITY APPROACH

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This study describes the design and implementation of an in-service teacher training programme for high school teachers aimed at improving their competence in the use of the laboratory for physics education. A framework for designing the programme was constructed based on PER literature, containing the following features: linking content, practice and research; action research; focus on teachers' beliefs; sufficient duration; and the learning community approach. The intervention aligns with recent international recommendations, and in particular with the need of providing teachers with meaningful, research-based professional development on inquiry teaching and opportunities to work collaboratively. Data for the evaluation of the programme were obtained using multiple instruments. The results suggest that all the identified features were effective, with action research and the learning community approach being decisive for promoting real change.

Keywords: Communities of Practice, In-service Teacher Training, Practical Work in Science

INTRODUCTION

In recent years, a renewed attention to the role of the laboratory in science education has been acknowledged not only by research (Hofstein & Lunetta, 2004; Rundgren, 2018) but also by several international reports and standards. A milestone was the document known as 'Rocard report' (Rocard et al., 2007), that called for "A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods" (p. 2). The National Research Council clarified the meaning of inquiry teaching by identifying eight 'scientific practices' that should be developed in the classroom together with disciplinary core ideas and crosscutting concepts (National Research Council [NRC], 2012), and, more recently, the National Academies of Science, Engineering, and Medicine recommended that 'investigation should be the central approach for teaching and learning science' (National Academies of Science, Engineering, and Medicine, 2019, p. 5).

Despite the emphasis placed on inquiry education, the term 'inquiry' is often misunderstood and confused with simply proposing 'hands-on' activities (Crawford, 2014; Osborne, 2014). In contrast, effectiveness in the use of laboratory activities is only achieved if they are well-designed, their purpose is clear, and they are embedded in a carefully planned teaching-learning sequence (Abrahams & Millar, 2008; Millar, 2010; NRC, 2006). The situation is complicated by issues such as the inadequacy of laboratory facilities, classroom organisation, and the need to comply with national standards (Nivalainen, Asikainen, Sormunen, & Hirvonen, 2010).

This situation calls for a reflection about teacher training. Many teachers have had little personal experience in the lab in their education and pre-service training (Yalcin-Celik, Kadayifci, Uner, & Turan-Oluk, 2017) and, on the other hand, few in-service teacher training programmes address the problem specifically using the results of research in physics education (NRC, 2006). For these reasons, actions should be taken in order to provide teachers 'with appropriate instructional resources, opportunities to engage in sustained professional learning experiences and work collaboratively to design learning sequences, choose phenomena with contexts relevant to their students, and time to engage in and learn about inclusive pedagogies to promote equitable participation in science investigation' (National Academies of Science, Engineering, and Medicine, 2019, p.6).

In the light of these considerations, this study aims to provide insights into the following research question: *What features should an in-service teacher training programme have in order to promote an effective use of the school science laboratory, and which of these features are most effective?*

THEORETICAL BACKGROUND

A meaningful model for successful teacher training was proposed by Adey, Hewitt, Hewitt, and Landau (2004), who identified the following characteristics: theoretical justification (research-based); high quality (sufficient duration, coherent methodology, intense/engaging activities, tutoring for implementation); support by the school management; and sharing with colleagues. However, according to many accounts, teacher training courses are often short and factual in nature, which is unlikely to promote real and long-lasting change (Gilbert, 2010; NRC, 2006).

Desimone (2009) identified five 'core features' for effective teacher training, based on the results reported in previous literature: content focus; opportunities for teachers to engage in active learning; coherence between teacher learning and their knowledge and beliefs; sufficient duration; collective participation. In a comparative study, Capps, Crawford, and Constas (2012) investigated the effectiveness of the above-mentioned features in the context of professional development (PD) on inquiry, considering 17 PD programmes. Their results show a general alignment with these features, but also suggested a need of additional research into PD programmes on inquiry, in order to identify which features are more effective in this context.

In recent times, the topic of collective participation has been emphasized and expanded by focussing on teachers' collaboration. Some benefits of teacher collaboration are improved instructional practices, improved student learning, and a better breeding ground for innovation (Vangrieken, Dochy, Raes, & Kyndt, 2015). A structured, bottom-up approach to teacher collaboration are *learning communities*, or communities of practice (Wenger, 1998; Vangrieken, Meredith, Packer, & Kindt, 2017). Even in the context of science education, research suggests that learning communities can promote authentic innovation (Couso, 2008), and a number of teacher training programmes have been developed according to a learning community paradigm (Singer, Lotter, Feller, & Gates, 2011; Lotter, Yow, & Peters, 2014).

Another aspect that has received attention recently is action research (Gilbert, 2010; Laudonia, Mamlok-Naaman, Abels, & Eilks, 2017). Teachers engaging in action research identify a problem relevant to their context, formulate a research question, select the data they need to answer it, design and implement some actions, evaluate their results and draw conclusions in order to identify new research questions. Action research is particularly effective when practitioners are supported by experts who put them in contact with research results, provide coaching and feedback, and offer emotional support (Gilbert, 2010). A positive intercorrelation between action research and the learning community approach has been suggested (LINPILCARE project; Mamlok-Naaman, 2018).

RESEARCH DESIGN AND METHODOLOGY

Based on the background described above, we outlined a revised framework for our teacher training programme. Specifically, we identified five core features, the effectiveness of which was the core of our research question and was investigated using multiple methods and perspectives as described below. Based on the revised framework, we designed a programme, named 'CoLLABORA – a Community of Learners on LABORAtory work', which was implemented between May 2018 and June 2019.

Revised framework

Developing on Desimone's 'core features' we identified a revised set of five 'core features'.

Linking content, practice and research. Laboratory activities was contextualised into the topic 'waves and their applications', one of the core ideas of physics education (NRC, 2012). We proposed and discussed research-based activities and participants had the opportunity to design their own activities. We also discussed the purpose of laboratory activities into a teaching-learning sequence, the construction of effective laboratory worksheets, some issues related to assessment, and specific disciplinary and didactical issues about the topic.

Action research. Each participant designed his/her own action research project to be applied in their classroom. Two sessions at the beginning of the course were devoted to formulating an investigable research question and writing an action research plan. Opportunities from feedback and coaching were given throughout the course.

Focus on teachers' beliefs. We focussed on *self-efficacy beliefs*, i.e. context-dependent judgments about being able to perform a particular task and obtaining the desired outcomes (Bandura, 1986). Teachers who have a high sense of efficacy are more likely to teach effectively (Tschannen-Moran, Hoy & Hoy, 1998; Crawford, 2007; Lotter et al., 2018; Chicherkian, 2016). During the programme we monitored these beliefs using specific instruments.

Sufficient duration. The programme featured 45 hours of contact time over one year.

Learning community. We set up the group as a learning community, sharing expectations, goals, rules, and style. Participation of teachers from the same school was encouraged.

Methods

In order to gain information from multiple perspectives, we used a variety of instruments:

Individual questionnaires. An individual questionnaire was delivered at the beginning and at the end of the programme. The initial questionnaire investigated the participants' background, their use of the laboratory, the presence and characteristics of their school laboratory, their expectations about the programme and their knowledge of the learning community approach. The final questionnaire investigated if and how the participants' use of the laboratory had changed during the course, in which dimensions (physics content, use of practical work, etc.) they thought they had improved the most, what activities they had found more useful, the extent to which the learning community was helpful, and how much the course met their expectations.

Focussed group interview. At the end of the programme, a semi-structured focussed group interview was led, containing five questions: (1) What were the advantages of discussing laboratory practices within a specific disciplinary content? How did research results contribute to enhance the discussion about the use of the laboratory? (2) To what extent, and how, engaging in action-research was useful in order to enhance the use of the laboratory at school? (3) To what extent are self-efficacy beliefs relevant in enhancing the use of the laboratory? (4) To what extent was the course structure (duration, meeting schedule, etc.) relevant to promote enduring change in your practice? (5) What was the added value of setting up our group as a learning community and in what ways did this approach influence your practice?

Teaching Science as Inquiry test. We used the Teaching Science as Inquiry (TSI) test (Smolleck, Zembal-Saul, & Yoder, 2006) for assessing changes in the participants' self-efficacy beliefs about inquiry teaching. Consistently with Bandura's (1986) construct of self-efficacy, the TSI explores both personal self-efficacy (the belief of being capable of doing something) and outcome expectancy (the belief that teaching will have a positive outcome). Moreover, it allows assessing different dimensions and levels of inquiry (NRC, 2000).

Individual action research reports. At the beginning of the programme, each participant formulated his/her own research question and developed an action research plan. During the last meeting, each participant presented a report about their action-research project.

Participants

The programme involved 15 teachers from 11 secondary schools (grades 9-13). Most of them (9) had a degree in Mathematics, while the others had a degree in Physics (3), Engineering (3) or Astronomy (1). The participants' teaching experience ranged from 5 to >20 years.

Programme schedule

The programme, named 'CoLLABORA - A Community of Learners on LABORAtory work', was delivered between May 2018 and June 2019. Table 1 summarises the schedule and content of the meetings. In-between the meetings, collaborative online activities were proposed via the Moodle platform, which also contained all the course resources and a 'course journal'.

Table 1. Programme schedule and content.

Date	Topic/activities
May 11th, 2018	Learning community setup. Pre-course administration of the TSI test. Analysis of a research-based laboratory activity.
May 18th, 2018	Laboratory activity on ray optics + discussion.
September 7th, 2018	Laboratory activity on mechanical waves. Formulation of personal research questions + feedback from peers and researchers.
September 14th, 2018	Didactical issues about 'waves and their applications'. Design of personal action research plan + feedback from peers and researchers.
October 12th, 2018	Disciplinary and didactical issues about 'mechanical waves'. Reflection on scientific practices. Laboratory activity on standing waves + discussion.
November 9th, 2018	Disciplinary and didactical issues about 'sound waves'. Laboratory activity on sound waves + discussion; focus on the use of technology.
December 14th, 2018	Visit to the Museum of the History of Physics and discussion/reflection on learning in out-of-school contexts. Group work on the different purposes of laboratory activities into a teaching-learning sequence.
January 11th, 2019	Reflection+discussion on the assessment of practical work. Co-design of a laboratory activity on ray optics.
February 15th, 2019	Laboratory activities on wave optics according to the three types of experiments + discussion.
March 8th, 2019	Laboratory activity on light sources and their spectra + discussion.
April 12th, 2019	Laboratory activity on atomic spectra + reflection/discussion on the didactical issues of modern physics.
May 10th, 2019	Final workshop: each participant presented the outcomes of his/her own action research project.
June 7th, 2019	Final focussed group interview.

RESULTS

General outputs of the programme

According to the individual questionnaires, 70% of the teachers changed their use of practical work at school since they had started the course. Self-reported changes include using different kinds of activities, adopting a more open inquiry, and developing improved didactic and assessment tools. Besides gaining a better understanding of the role of practical work in physics education, participants also think they became more capable of designing a laboratory activity. The most appreciated activities during the programme were experimenting and constructing research-based experiences. Participants also valued the active engagement, the connection between physics content and scientific practices, and the collaborative approach.

Effectiveness of the five features

Below we report our results with respect to the five features of our framework.

Linking content, practice, and research. The participants considered useful to include the reflection on the laboratory into a content strand that is central throughout the curriculum. The use of research-based materials was relevant 'in order to qualify [their] didactic choices' (Lucia). In particular, discussing the purpose of the different laboratory activities in a teaching-learning sequence provided 'new ways of thinking about practical work […]' and it 'left room to the participants' creativity about how to use them in the classroom' (Sara).

Action research. According to the participants, engaging in action research was effective in fostering a more scientific attitude towards teaching: 'Even when I don't do planned action research, now I look at my everyday practice with a research attitude' (Alberto); 'I have learnt that there are many aspects of my practice I can experiment on' (Giorgio). Action research also fostered the development of positive self-efficacy beliefs, as it is discussed below. The time spent in formulating an investigable research question and developing an action research plan was considered particularly relevant: 'The best part of it was stopping to think about my practice in order to pose the right question' (Maria Rosa).

Focus on teachers' beliefs. The TSI scores at the beginning and at the end of the programme suggest that there was a slight overall improvement for self-efficacy (+0.14 on average for self-efficacy, +0.08 for outcome expectancy), but a large variability among participants was observed. A deeper analysis into the personal path of each teacher would be required in order to identify the factors that contributed to the evolution of their beliefs. However, a connection was suggested between high TSI gains and the completion of action research projects: 'Beliefs change if you try for yourself and you see that you like what you are doing' (Giorgio). The case study described below also supports this hypothesis. Concerning the five dimensions and levels of inquiry (NRC, 2000), the largest average improvement was observed for 'learner gives priority to evidence in responding to questions' (+0.28) and 'learner formulates explanations from evidence' (+0.20), and an overall increase towards a higher students' autonomy was observed (+0.28).

Sufficient duration. Consistently with the literature, the duration of the course was judged 'necessary for letting things settle' (Maria Rosa) and even 'not enough' (Alberto). Participants agreed that real change is a long-term process and that even more opportunities for meeting and working together would be needed.

Learning community. Working collaboratively with colleagues and establishing a relationship environment where ideas and difficulties could be shared 'without the fear of judgement' (Lucia) was decisive: 'I see the foundations for building a community of teachers who share materials and ideas' (Francesco). Participants particularly appreciated the possibility of interacting with colleagues from different backgrounds and contexts, which gave them the possibility to 'experience a wider network of relationships beyond the one in our schools' (Alberto). When two teachers from the same school were present, this was recognised as 'a seed to start a learning community in each school' (Francesco). The learning community was also identified as 'a powerful strategy for reinforcing the relationship between schools and university' (Giorgio). Collaborating online was however a critical aspect: according to the participants, part of the problem lay in the specific platform (Moodle, judged 'not very user-friendly', but they also acknowledged that working collaboratively is not automatic and requires training.

A case study: Lucia

We describe the experience of one of the participants, Lucia, more in detail, in order to describe how the course influenced a teacher's practice in her specific case.

Background. Lucia got her degree in Mathematics in 2008; during her degree she followed no laboratory courses. At the beginning of the programme, Lucia had been teaching physics for 8 years and she was teaching in grades 9-10 in a technical high school. According to her initial interview, before the course she 'occasionally' proposed laboratory experiences. Lucia's initial score in the TSI was 2.80 for self-efficacy and 2.90 for outcome expectancy.

Action research plan. Lucia's action research plan was implemented in her 10th grade classrooms in January 2019. Her research employed a quasi-experimental design involving an experimental and a control classroom. Specifically, she wanted to test the effectiveness of a research-based observational experiment in the context of a teaching-learning sequence on mechanical waves, compared with a traditional laboratory. She evaluated her research using two different rubrics (an observation rubric filled in by herself and by an external observer, and the students' self-evaluation), the analysis of students' lab reports, and a test administered three months after the lab. Her results supported the effectiveness of the research-based laboratory and, as the start of a new action research cycle, she refined her research question as how to re-design the lab in order to engage all of the students, including the weakest ones.

Impact of the programme and effectiveness of the five features. In her final questionnaire, Lucia listed some of the new habits she implemented in her classroom: 'Now I provide the students with the rubrics I use for assessment; I use a larger variety of laboratory activities; I have modified the structure of my lab worksheets in order to give the students more room for inquiry; and I encourage my students formulate their own questions'. Lucia particularly appreciated the research-based proposals, which she 'thirsted for': 'It was like a pat on the back. It is good to know that someone is thinking about it'. She judged the experience of action research a crucial point of the programme: 'During our pre-service teacher training, we were asked to design imaginary plans for imaginary classrooms; on the contrary, in everyday practice we just do the same things year after year. Engaging in action research gave me the opportunity to design and carry on a real project on a real classroom'. Lucia reported large gains in the TSI test (+0.93 for self-efficacy and +0.58 for outcome expectancy). She connected this improvement to her action research experience: 'I felt a need for change, but, in my school, there is a traditional approach to lab activities… I used to think, "maybe I am a mathematician and I cannot do practical work, probably I am the wrong one". This year I have worked on myself and now I believe that I can be comfortable in the lab and that I can promote change in my school'. For Lucia, improving her beliefs meant not only promoting personal change, but also making her think of herself as a change agent in her school. Lucia also appreciated the course organization and the learning community approach: 'The monthly schedule allowed us to set our goals on a timeline pattern, then meet to build the community and step forward. The yearly duration allowed us to make small changes, with the opportunity discuss them soon after'. According to Lucia, 'The strength of the programme was to offer stimuli while at the same time bringing out the very best from each participant. In most programmes, we listen to an expert and then we do some group work… here I found room for personal reflection and adequate input based on research, that motivated me to change; I found helpful colleagues and researchers who gave me precious feedback. This year I did not feel alone.'

DISCUSSION AND CONCLUSIONS

From the data collected with multiple instruments, we can conclude that all the features considered in our programme were effective, with action research and the learning community approach being decisive. In fact, engaging in action research impacted the teachers' attitude towards their teaching (fostering a more evidence-based approach). Moreover, a successful action research project boosted the improvement of self-efficacy beliefs and promoted a sense of agency. Concerning the learning community approach, the participants highlighted the need of a 'non-threatening, inspiring, trustful and collaborative' context in which to grow as teachers and persons. These comments reinforce our choice of adopting this approach as out working model and supports us in envisaging actions to further improve it.

The focus on teachers' beliefs seems relevant as a means to effectively impact teachers' practice, though personal stories and paths should be taken into account to interpret the results. Qualitative, in depth instruments are needed in order to gain further insights on development of the participants' beliefs. In the light of the results about action research and programme duration, we argue that even more time and opportunities for action research would be needed as sources of self-efficacy. This will be a priority for the continuation of the programme.

Based on the results of this study, we plan to continue the programme for another year, focussing on action research and experimentation in the classroom. We also plan to introduce more collaborative practices such as co-planning, engaging in micro-teaching sessions, observing and being observed by peers, giving and receiving feedback, with the aim of reinforcing the community and foster collaborative approaches to the teaching of physics. Secondly, we plan to design a revised version of the programme to be implemented with a new group, with the aim of enlarging the community and promote the establishment of local teachers' networks. We hope that, in the long term, this effort will contribute to the formation of productive links between research and practice, the schools and the university, and foster change and innovation as well as personal and professional development.

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