Part 14 / Strand 14

In-service Science Teacher Education, Continued Professional Development

Editors: *Claudio Fazio & Pedro Reis*

Part 14. In-service Science Teacher Education, Continued Professional Development

In-service science teacher education, teachers as lifelong learners; methods, innovation and reform in professional development; evaluation of professional development practices, reflective practice, teachers as researchers, and action research.

Part 14: IN-SERVICE SCIENCE TEACHER EDUCATION, CONTINUED PROFESSIONAL DEVELOPMENT

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INTRODUCTION

The area of in-service teacher education and continued professional development of teachers is of growing interest internationally, and it has been given increasing importance in the last years throughout many countries in the world. Clearly, the value and success of any educational system strongly correspond with the quality of its teachers' competencies and practices, and for a long time, Strand 14 of ESERA has been dealing with high-quality research in this science education field.

The present edition of the 2021 ESERA conference proceedings portrays a wide array of research pieces addressing several issues and aspects of science teacher education and continued professional development, mainly from an empirical point of view. Compared to the last ESERA conference proceedings, the number of papers presented in this strand is reduced from 32 to 18. The papers included in the strand come from all over the world. There is a strong European presence, with papers/contributions coming from research institutions in Austria, Belgium, Czech Republic, Germany, Greece, Ireland, Italy, Poland, Portugal, Slovenia and Switzerland. Non-European, international presence and collaboration are also strong, with papers from the U.S.A., South Africa, South America (Brazil and Uruguay), Asia (Singapore), and Oceania (New Zealand). This collection has a clear international character and confirms once more that including research pieces from all over the world is a trend that is gaining momentum in each ESERA edition.

Looking at the contents and approaches of studies, we see that there are mainly empirical studies, and one theoretical study is also present. In addition, studies are related to innovations concerning specific course developments and applications, including investigating the effects and the possibilities of evaluating science teaching. That variety demonstrates well how the complexity of in-service science teacher education and continued professional development is scientifically approached and addressed by the ESERA community.

The theoretical study at the beginning of this chapter investigates and discusses the link between Pedagogical Content Knowledge (PCK) and teaching practice through the lenses of the recently proposed Refined Consensus Model of PCK.

The empirical studies found in this chapter deal with several topics, such as the study of three dimensions of inquiry in physics teacher professional development (in a paper synthetizing the discussion held during a Symposium at the ESERA 2021 Conference), the professionalization processes of teachers in all phases of their careers and their assessment; PCK development in pre- and in-service teachers; visual representations of teaching practices; teaching/learning sequences development and validation. Qualitative, quantitative, and mixed methods are used to analyze the empirical results and draw conclusions and implications for improving in-service teacher education and continued professional development of science teachers.

Looking at the selection of papers presented in Strand 14 and accepted for publication, it is possible to say that the ESERA community continues to show strong support for the improvement of in-service teacher education and continued professional development of science teachers all over the world by means of high-quality research pieces that deal with topics of great interest.

Linking Pedagogical Content Knowledge and Teaching Practice

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Science education researchers have developed a refined understanding of the nature and sources of science teachers' pedagogical content knowledge (PCK), but how to develop applicable and situation-adequate PCK remains unclear. Since (classroom) teaching experiences are acknowledged as a rich source of PCK in science teacher education, this study sought to systematize existing science education research on PCK and practice through the lens of the recently proposed Refined Consensus Model (RCM) of PCK as a means of exploring, and explore in what ways teaching experiences contribute to teachers' PCK development. In this review, selected studies' approaches to their investigation of PCK and teaching practice and selected findings were characterised and synthesised as an overview. We found that studies largely employed a qualitative case-study methodology featuring specific PCK models and tools. Major findings from the researched studies indicated links between PCK and practice were summarised and the potential for further research was identified. The RCM proved to be a meaningful theoretical lens for conceptualizing links between teaching practice and PCK development by virtue of pedagogical reasoning as a de facto mechanism and/or explanation for PCK development in the context of teaching practice.

Keywords: PCK, teaching practice, pedagogical reasoning

INTRODUCTION

While classroom learning can be affected by a variety of factors, Hattie (2003) argues the educational research community should focus on the greatest source of variance that can make a difference to learning in class – the teacher – if findings are to inform more effective learning. Within the broad context of science education, researchers recognise the importance of teachers in supporting student learning with many turning their attention to the pivotal role of school teachers' professional knowledge for quality teaching (e.g., Shulman, 2001; Berliner, 2001; Magnusson et al., 1999). To characterise quality teaching, researchers conceptualised the necessary professional knowledge as the pedagogical content knowledge (PCK) of teachers (Baumert et al., 2010; Sadler et al., 2013). However, some researchers (e.g., Gess-Newsome et al., 2017) point out that while previous studies confirm positive links between PCK and effective teaching, they do not uncover developmental mechanisms related to PCK. A possible barrier to such research is the lack of a testable model for PCK, related to teaching practice, that could facilitate exploration of links between science teachers' PCK and practical teaching experiences.

In the Refined Consensus Model (RCM) of PCK Carlson et al. (2019) conceptualise practical teaching experiences as core to teachers' PCK. By recognising classroom teaching activities are opportunities for this unique form of teacher professional knowledge to be both manifested and generated, because teachers engage in pedagogical reasoning during the teaching cycle (plan-teach-reflect lessons), the RCM stresses the context-specificity and situated nature of PCK.

In this paper, it is our intention to explore links between PCK and practical teaching experiences in the context of science teacher education, notably the role of pedagogical reasoning, by using the RCM of PCK as a conceptual framework.

MODELLING PCK

PCK emerged as a particularly important construct for science teaching because it has the potential to characterise expert teachers' professional knowledge and skills and predict effective teaching (Baumert et al., 2010; Sadler et al., 2013). As a result, PCK has become a central component of many university-based science teacher education programmes (Gess-Newsome et al., 2017). Instruction featuring the nature of students' preconceptions, conceptual difficulties, instructional strategies, assessment, and curriculum was promoted to afford pre-service science teachers with opportunities to begin building relevant PCK for their profession (Park & Oliver, 2008).

However, modelling PCK in teacher education has proven difficult and has a diverse history (Gess-Newsome, 2015). Initially, Shulman (1987) viewed PCK as an amalgam of two forms of knowledge i.e., content knowledge (CK) and pedagogical knowledge (PK). To Shulman, PCK was a distinct and new form of knowledge transformed from CK and PK, and soon others began developing more elaborate conceptual frameworks for PCK (e.g., Grossman, 1990; Magnusson et al., 1999; Park & Oliver, 2008). Unfortunately, rather than clarifying research directions, it is possible that these different schools of thought about the nature (and development) of PCK in science education began hampering progress in the field, and in time led to calls for consensus around the conceptualisation of PCK (Abell, 2008).

In 2016, based on the earlier work of Gess-Newsome et al. (2015), Carlson et al. (2019) repositioned PCK in a new model of teachers' professional knowledge for teaching science. Building on the existing PCK components of earlier models, the Refined Consensus Model (RCM) for teaching science (Carlson et al., 2019) introduces three differentiated realms of PCK that inform understanding of potential sources and/or mechanisms for the development of science teachers' PCK. These realms include collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK). According to the RCM, cPCK exists within the larger science education communities that researchers and teachers belong to. Pre-service, as well as in-service, teachers become aware of cPCK through their immersion in the wider science education community during university-based teacher education and beyond, where they are exposed to and experience use of various curricular and teaching documents and resources and engage in interactions with other teaching professionals. They begin developing, amongst other forms of knowledge, a unique and personal form of PCK termed pPCK, which over time is increasingly informed by the teachers' experiences of classroom teaching. pPCK becomes a major intellectual resource that enables science teachers to think and perform as a teacher, both on explicit and tacit levels (Alonzo et al., 2019). In its centre, the RCM explains that during the act of teaching an individual teacher uses a process of pedagogical reasoning (involving decision-making) to manifest aspects of his/her pPCK as ePCK during the plan-teach-reflect (teaching) cycle (Alonzo et al., 2019). Therefore, teaching practice becomes a forum for knowledge exchange and PCK development, and pedagogical reasoning is the mechanism by which this exchange and development occurs. The RCM indicates that knowledge exchanges across the two realms can lead to changes in both pPCK and ePCK.

Delving into the central ePCK realm of the RCM, Alonzo et al. (2019) identify two distinct plan-teach-reflect cycles - a macro cycle focused on whole lesson planning, teaching and retrospective reflection; and a micro cycle within the teach phase of the macrocycle that features in-the-moment teaching decisions made during classroom instruction. In the micro cycle, ePCK guides interpretation (noticing and reflecting) of teaching situations that arise during the lesson and planning decisions and actions in response to those moments. Using these cycles, Alonso et al. (2019) argue that ePCK is related to a teacher's planning (ePCKp), teaching (ePCKt), and reflecting (ePCKr).

The RCM anticipates that ePCK is linked to pPCK in complex ways and testable inferences can be drawn about these links. Practical teaching experiences (e.g., during university-based teacher education programs) are important means of individual PCK development (Grossman et al., 2009; Alonzo et al., 2019) since teaching practice requires pedagogical reasoning to enact PCK and reflect upon those experiences (Loughran, 2019). Thus, these interactions between pPCK and ePCK constitute a link between a teacher's teaching experiences and her/his PCK development that is accessible to research. However, there are presently no conclusive overviews on the actual developmental mechanisms between PCK and teaching practice that have been studied in the science education literature (Gess-Newsome et al., 2017; Aydin et al., 2013).

This present study focuses on the interaction of ePCK and pPCK to refine and elucidate our understanding of links between PCK and teaching practice, and to flesh out the anticipated links in the RCM. It carries out a closer inspection of teaching practice and developmental mechanisms by presenting a systematic literature review of studies that investigated, in some form or another, links between PCK and teaching practice.

RESEARCH QUESTIONS

Based on the findings of Chan and Hume (2019), this study explores in greater depth how PCK and teachers' professional practice potentially interact. First, this study summarises two aspects of the reviewed studies to evaluate the representativeness of the review and to give an overview of the dissemination of theoretical PCK models.

(1) What is the research context of the studies (research foci, methods, framework)?

Second, the study addresses two further research questions to identify features of the interplay between science teachers' PCK and teaching practice. RQ 2 remains within the conceptual framework of the RCM, while RQ 3 ventures an exploratory look 'outside' the framework and attempts to relate these findings back to the RCM.

(2) What role did teaching experience (pPCK) and teachers' pedagogical reasoning in the teaching cycle (ePCK) play in promoting PCK development?

(3) What effects of interplay between PCK and teaching practice did researchers discuss and how do they relate to knowledge exchanges between the realms of pPCK and ePCK?

METHOD

To search the field of science teacher education for studies related to PCK and teaching practice, a systematic literature review following the approach taken by Bennett et al. (2007) was conducted. First, keyword searches in research databases (e.g., ERIC, PsychINFO, web of science) were implemented according to the goals of this study, using the search terms 'PCK', 'practice', 'pedagogical reasoning', 'STEM', and the STEM subjects to retrieve an exhaustive list of potentially relevant studies. The identification of suitable articles included peer-reviewed research articles for science teachers' PCK from 1986, when PCK was first conceptualised, to the end of 2018. Using standardised quality criteria, all studies were screened by reading the titles and abstracts.

To analyse the RQs in relation to the theoretical framework of the RCM, all studies were processed in a procedure that involved: (1) Identifying relevant segments in the abstract and full text of the papers. (2) Coding (inductive and/or deductive coding) by a first rater who was well acquainted with the RCM (first author). This rater developed a coding manual comprising categories and definitions for the categories. (3) Recoding subsets of the studies by an independent second rater (third author), which was done on the basis of the developed coding manual. (4) Calculating interrater agreement as a measure of interrater agreement that is corrected for chance (Cohen's κ).

RESULTS

Evaluating Method

The initial search yielded N=881 articles (212 ERIC, 94 PsycInfo, 525 WoS, and 50 peDocs). The abstracts of all these articles were read to identify the included articles, which resulted in a total of N=246 studies for the review. In the screening phase that followed, the remaining articles were read in detail and N=97 studies were selected for inclusion in the final systematic literature review. The interrater agreements for all RQs can be considered substantial or better (Landis & Koch, 1977) (Interrater Reliability: $\kappa_{[RQ1]}$=.95 | $\kappa_{[RQ2]}$=.91 | $\kappa_{[RQ3]}$=. 79).

Framework of studies (RQ1)

The included studies were conducted in multiple countries across six continents. Pre-service teachers, novice teachers and experienced teachers with more than five years of teaching experience were subjects in the selected studies. The majority of the studies used experienced teachers to study PCK in relation to teaching practice (N=42), followed by pre-service teachers (N=14). Amongst grade levels, most data were collected from secondary school teachers (N=55). In 12 studies, both primary and secondary school teachers were examined. Sample sizes of N=1 to N=118 were present in the study selection, but only 4.1% of the studies had a sample size of more than 100 teachers, while 76.3% had less than 10 participants. Most studies involved science teachers (N=30), followed by chemistry (N=27), biology (N=22), mathematics (N=16), physics (N=15), elementary science (N=4), and earth science (N=4) teachers. Space science, engineering, and science and technology were the least studied subject domain in the studies (N=1 each). N=17 studies used one single type of data source, N=21 used two types, N=33 used three types, and N=26 used four or more types of data sources. Predominantly qualitative methods were used.

In line with Chan and Hume (2019), the analysed studies were divided into two groups, one comprising studies that conceptualised PCK using integrative PCK models and the other using transformative models of PCK. The first group (N=9; 9.3%) considered PCK to be an integration of different knowledge categories, while the second group (N=88; 90.7%) conceptualised PCK as an independent and unique knowledge category resulting from a transformation of other knowledge forms. Almost a third (N=30) of the second group who viewed PCK as a transformed knowledge form used the Magnusson et al. (1999) PCK model and its five unique components as a conceptual framework to guide their studies. N=36 studies were identified that did not refer to any PCK conceptualisation, whether integrative or transformative.

Role of personal PCK and enacted PCK in promoting PCK development (RQ2)

In order to summarise interactions regarding past teaching experience and pedagogical reasoning during teaching, we looked in the reviewed studies for evidence of teachers' reasoning related to decision making while planning, teaching, or reflecting on/during actual lessons. We found no study in this review examined teacher's pedagogical reasoning explicitly – those studies that did discuss reasoning referred exclusively to students' reasoning rather than that of teachers. Therefore, therefore the review yielded little information about interactions between pPCK and pedagogical reasoning while teaching.

To investigate links in the literature between PCK development and teaching experiences in greater depth, we used the RCM conceptualisation of the teaching cycle (comprising the macro and micro cycles) as an analytical framework for interpreting how the reviewed studies investigated ePCK. This approach allowed us to account for most concepts in the plan-teach-reflect cycle that were investigated in the reviewed studies and how these concepts were investigated in relation to the macro and/or micro cycles. Most of the studies focused on the entire teaching cycle, although researchers examined the cycle in different ways. N=63 studies refer to at least one part of the macro cycle. In authentic classroom situations, only N=18 studies attempted to draw (or infer) conclusions about teachers' reasoning on the micro level (all on the teach part of the cycle), while N=17 of which appeared to use at least one reference to the macro level. On the micro level, only planning and reflecting were analysed in simulated situations. As a means of exploring in what ways researchers attempted to capture the teaching cycle parts via data gathering approaches, we crossed the teaching cycles with the methods used (from RQ1).

As already identified in RQ1, the majority of the studies uses qualitative methods of data collection. With the exception of lesson planning (N=41) and written reflections (N=22), which capture important dimensions of the teachers' pedagogical reasoning, the studies use methods that attempt to capture the teaching cycle on a macro level (semi-structured interview, that is: N=70; classroom observation: N=48; or reflective stimulated recall interviews: N=13). On a micro level, planning and reflecting were only analysed in simulated situations, whereas teachers' micro ePCKt was examined and analysed in real classroom situations and more frequently than micro ePCKp and ePCKr. At least N=23 of the N=84 studies on macro ePCKr were concerned with drawing conclusions about the micro ePCKt. Appropriate conceptual tools for capturing teachers' pedagogical reasoning during the teaching cycles seem to be Content Representations (CoRes) for macro planning, Pedagogical and Professional-experience Repertoires (PaP-eRs) for reflection during classroom observations or interviews during guided macro reflection. Stimulated Recall Interviews seem to be beneficial to capture parts of the micro teaching cycle.

In summary, all studies showed that more experienced teachers with more developed pPCK performed better in PCK tests and also better during classroom practice (plan-teach-reflect). In addition, methods for measuring PCK and PCK development seem to be well elaborated for small samples. However, in studies investigating PCK development it is mostly explicit learning opportunities (e.g., workshops, interventions, internships) or teachers' experiences that are taken into account, and those concerned with PCK development as a result of pedagogical considerations in the plan-teach-reflect cycle on a micro or macro level are rare.

Interplay of PCK components and practice (RQ3)

Figure 1 displays a summary of the effects of interplay between PCK and teaching practice, as discussed by at least two studies. All concepts (terms) in the research context of PCK and teaching practice were organised into four groups for clarity. (1) PCK components - not specified whether integrative or transformative, (2) PCK levels within the RCM, (3) pedagogical reasoning as it relates to the teaching cycle, and (4) other concepts discussed in studies that are not specifically related to PCK. If implications, in the sense of cause and effect or if-then statements, were discussed in the studies, then these relationships were illustrated in Figure 1 using arrows.

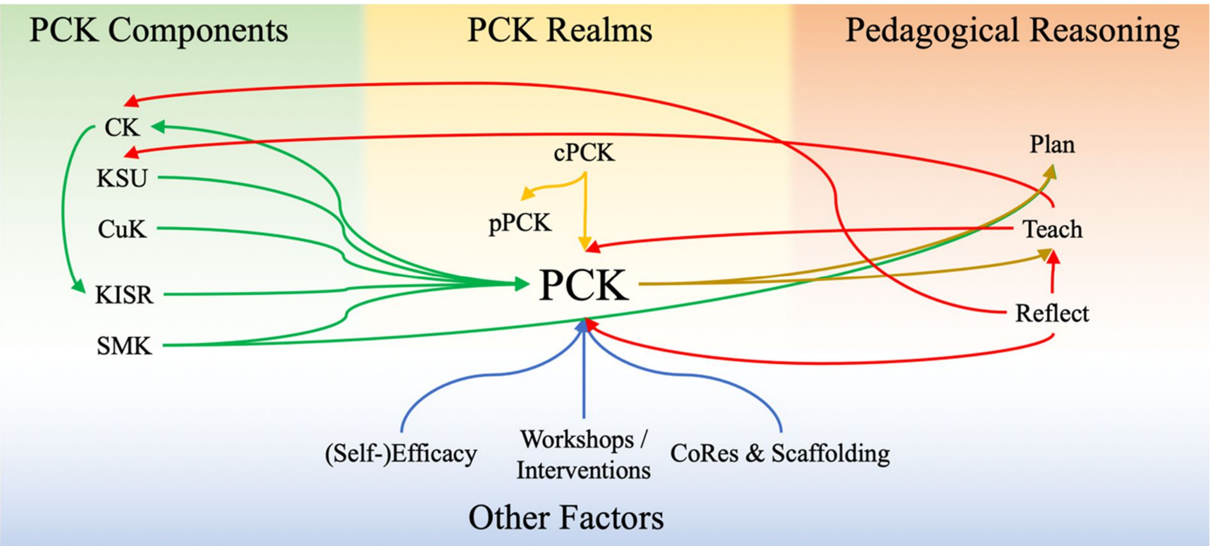

Figure 1. Map of discussed effects in the field of science teachers' PCK and their teaching practice.

In the N=97 studies dealing with PCK and teaching practice, N=11 studies directly identify effects of PCK (components) on teaching practice. Of those studies, N=6 studies (e.g., Demirdöğen et al., 2016) found that PCK (in generic terms) has a positive effect on aspects of teaching practice, while in the other N=5 further studies specific PCK components were found to have positive effects on teaching practice (e.g., Boesdorfer & Lorsbach, 2014). For teaching in a classroom situation, SMK/CK is considered essential by N=2 studies (e.g., Friedrichsen et al., 2009).

Teaching in class is often (N=12 studies) identified as facilitating development of PCK components (e.g., van Driel et al., 2002). A substantial proportion of the studies (N=11, and N=10, respectively) found reflection (e.g., Park & Oliver, 2008) and workshops and interventions (e.g., Nilsson & Vikstrom, 2015) resulted in positive effects on various PCK components. N=22 studies found teachers' interaction with the education community and/or colleagues (cPCK) as another aspect of practice that had positive effects on PCK.

Since a total of 112 positive effects on PCK and PCK development could be identified in 97 studies, it can be summarised that more pronounced or better networking of PCK components by teachers in their practice seem to have a greater impact on science teachers' PCK and its development.

DISCUSSION

This study sought to characterise and synthesise research featuring science teachers' PCK and their teaching practice to advance our understanding of the development of applicable and situation-adequate PCK. We were able to identify that no consistent PCK model is used across the studies even if most used scaffolds (e.g., Magnusson et al.,1999; Park & Oliver, 2008) might be conceptualized with the help of the RCM of PCK. Our findings indicate that existing studies related to PCK and teaching practice used predominantly qualitative methods for analysing the relationships between PCK and teaching practice. Many researchers engage in data triangulation to grasp these complex constructs such as PCK and teaching practice.

We argue the findings from this review suggests the RCM of PCK acknowledges and facilitates research that addresses the networking of PCK components in classroom teaching, since it explicitly links PCK and teaching practice by depicting the teaching cycles (plan-teach-reflect) and pedagogical reasoning at its core as classroom manifestations and/or generators of PCK. Using the RCM as a guide, this study identified that all reviewed studies attended to at least one aspect of the teaching cycle in their research of PCK and teaching practice. In addition, particular means of linking PCK and practice were found using research tools that focus on PCK in the planning, teaching, or reflecting aspects of the cycle. Data collection tools were often used that attempted to elaborate rationales for teachers' actions, resulting in aspects of the teaching cycle being addressed in different ways. It is notable that imbalances exist between studies investigating realistic and simulated teaching situations on the one hand and the micro and macro teaching cycles on the other. Most realistic teaching studies refer to a macro level of the teaching cycle, while the few studies that refer to a micro level typically investigated simulated situations (e.g., in stimulated recall interviews). In summary, these findings show that teachers' past experience and teaching actions (pPCK and ePCK) and pedagogical reasoning do appear to be closely interwoven and interconnected. We argue these findings suggest the interplay of networked PCK components with teachers' practical actions represents teachers' pedagogical reasoning as it manifests in teaching cycles.

The analysis of the discussed effects of interactions between PCK and practice indicates that there is agreement in the literature that pronounced or rich PCK (e.g., teachers who scored highly in PCK measurement) or (networked) PCK components (e.g., teachers who scored highly in CK, PK, and/or KSU performance-tests or showed multiple interacting knowledge bases in interviews) are beneficial for effective teaching practice (based on verifiable evidence from sources such as classroom artefacts, students interviews, or observations). Furthermore, teachers' self-influencing factors (e.g., their interaction with the science education community and/or their pedagogical reasoning) seem to be as effective for PCK and PCK development as external factors (e.g., workshops/ interventions). Based on these findings, it might be worthwhile to investigate science teachers' PCK development from a community of practice (CoP) perspective (as discussed for example by Polizzi et al., 2016) when considering the role of teacher connectedness to their professional community. Analyses regarding RQ3 suggest that the implications of findings from the reviewed studies are multidimensional. Broad implications (like the positive effects of well-developed PCK components on PCK and teaching practice) are more often discussed, while specific or consistent implications are only indirectly considered as part of comprehensive effects.

IMPLICATIONS AND FUTURE DIRECTIONS

The RCM of PCK provides a suitable lens for the investigation of the more concrete relationships that are implied from this investigation of the interplay between PCK and practice. Two groups of influences on PCK arising from teaching practice can be identified: first, teachers' interactions and participation in their teaching community and second, self-influencing factors that are independent of his/her professional community and only affect a single teacher. In sum, many of the reviewed studies argue that PCK is strengthened by teaching practice through (1) one's own planning, teaching, and reflection that is activated and sustained by pedagogical reasoning, and (2) interactions with colleagues and community. It remains to be evaluated which PCK components, if any, are most closely related to classroom performance.

Limitations to our findings arise from the conceptual ambiguity associated with PCK in the literature and teaching practice. Research on teacher beliefs and motivational constructs might present further important insights into effective professional development programs that foster relevant competencies for teachers. To deepen understanding of the relationship between PCK and practice, we recommend that PCK components and realms (as in the RCM) need to be investigated in relation to each other, with due consideration given to amplifiers and filters and the role of pedagogical reasoning in knowledge exchanges with and between realms of PCK. This review also revealed that, as in most PCK and practice research, there is a lack of quantitative research (Wilson et al., 2019), which may provide more evidence of tangible links and estimates of effects size to enhance qualitative links. In addition, established refined methods may allow an examination of PCK development in relation to pedagogical reasoning. Focused and quantitatively verifiable analyses of the interrelationships between the individual components are needed to strengthen understanding, and a unified framework model of PCK (like the RCM) would be very helpful for this.

REFERENCES

Alonzo, A., Berry, A., & Nilsson, P. (2019). Unpacking the Complexity of Science teachers' PCK in Action. Enacted and Personal PCK. In: A. Hume, R. Cooper, & A. Borowski (Hg.): Repositioning Pedagogical Content Knowledge in Teachers' Professional Knowledge. Singapore: Springer, 271–286.

Aydin, S., Demirdogen, B., Tarkin, A., Kutucu, S., Ekiz, B., Akin, F. N., Tuysuz, M., Uzuntiryaki, E. (2013). Providing a set of research-based practices to support preservice teachers' long-term professional development as learners of science teaching. In: Science Education 97 (6), 903–935. https://doi.org/10.1002/sce.21080.

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., , Klusmann, U., Krauss, S., Neubrand, M., Tsai, Y. (2010). Teachers' Mathematical Knowledge, Cognitive Activation in the Classroom, and Student Progress. In: American Educational Research Journal 47 (1), 133–180. https://doi.org/10.3102/0002831209345157.

Bennett, J., Lubben, F., & Hogarth, S. (2007). Bringing science to life. A synthesis of the research evidence on the effects of context-based and STS approaches to science teaching. In: Science Education 91 (3), 347–370.

Berliner, D. C. (2001). Learning about and learning from expert teachers. In: International Journal of Educational Research 35, 463–482.

Boesdorfer, S., & Lorsbach, A. (2014). PCK in Action: Examining one Chemistry Teacher's Practice through the Lens of her Orientation Toward Science Teaching. International Journal of Science Education, 36(13), 2111–2132. https://doi.org/10.1080/09500693.2014.909959.

Carlson, J., Daehler, K., Alonzo, A., Barendsen, E., Berry, A., Borowski, A., Carpendale, J., Chan, K., Cooper, R., Friedrichsen, P., Gess-Newsome, J., Henze- Rietveld, I., Hume, A., Kirschner, S., Liepertz, S., Loughran, J., Mavhunga, E., Neumann, K., Nilsson, P., Park, S. et al. (2019). The Refined Consensus Model of Pedagogical Content Knowledge. In: A. Hume, R. Cooper, & A. Borowski (Hg.): Repositioning Pedagogical Content Knowledge in Teachers' Professional Knowledge. Singapore: Springer.

Chan, K. K., & Hume, A. (2019). In: Repositioning Pedagogical Content Knowledge in Teachers' Professional Knowledge. Singapore: Springer.

Demirdöğen, B., Hanuscin, D. L., Uzuntiryaki-Kondakci, E., & Köseoğlu, F. (2016). Development and Nature of Preservice Chemistry Teachers' Pedagogical Content Knowledge for Nature of Science. Research in Science Education, 46(4), 575–612. https://doi.org/10.1007/s11165-015-9472-z.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. Journal of Research in Science Teaching, 46(4), 357–383. https://doi.org/10.1002/tea.20283.

Gess-Newsome, J. (2015). A model of teacher professional knowledge and skill including PCK. Results of the thinking from the PCK summit. In: Amanda Berry, Patricia Friedrichsen, & John Loughran (Hg.): Re-examining pedagogical content knowledge in science education. October 2012, Colorado Springs, USA, … PCK Summit, a working conference. 1. publ. New York, NY: Routledge (Teaching and learning in science series).

Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. M. (2017). Teacher pedagogical content knowledge, practice, and student achievement. In:

International Journal of Science Education, 1–20. https://doi.org/10.1080/09500693.2016.1265158.

Grossman, P. L. (1990). The making of a teacher: Teacher knowledge and teacher education. Professional development and practice series. New York, NY: Teachers College Press.

Grossman, P., Compton, C., Igra, D., Ronfeldt, M., Shahan, E., & Williamson, P. W. (2009): Teaching practice. A cross-professional perspective. In: Teachers College Record 111 (9), 2055–2100.

Hattie, J. (2003). Teachers Make a Difference, What is the research evidence? In: Australian Council for Educational Research (ACER) ACEReSearch (2003): Building Teacher Quality: What does the research tell us? - Conference Archive, Melbourne, Australia.

Landis, J. R. & Koch, G. G. (1977). The measurement of observer agreement for categorical data. In: Biometrics. 33, 1977, S. 159–174.

Loughran, J. (2019). Pedagogical reasoning: the foundation of the professional knowledge of teaching. Teachers and Teaching, 25(5), 523–535. https://doi.org/10.1080/13540602.2019.1633294.

Magnusson, S., Krajcik, J. S., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In: J. Gess-Newsome, & N. G. Lederman (Hg.): Examining pedagogical content knowledge. The construct and its implication for science education. Dordrecht: Kluwer Academic, 95–132.

Nilsson, P., & Vikström, A. (2015). Making PCK Explicit—Capturing Science Teachers' Pedagogical Content Knowledge (PCK) in the Science Classroom. International Journal of Science Education, 37(17), 2836–2857. https://doi.org/10.1080/09500693.2015.1106614.

Park, S., & Oliver, J. S. (2008). Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK). PCK as a Conceptual Tool to Understand Teachers as Professionals. In: Research in Science Education 38 (3), 261–284. https://doi.org/10.1007/s11165-007-9049-6.

Polizzi, S., J., Coyle, W., Lundquist, K., & Rushton, G. (2016). Exploratory Social Network Analysis of Science Teacher Leaders' Communities of Practice. Conference: National Association for Research in Science Teaching. At: Baltimore, Maryland.

Sadler, P. M., Sonnert, G., Coyle, H. P., Cook-Smith, N., & Miller, J. L. (2013). The Influence of Teachers' Knowledge on Student Learning in Middle School Physical Science Classrooms. American Educational Research Journal, 50(5), 1020–1049. https://doi.org/10.3102/0002831213477680.

Shulman, L. S. (1987). Knowledge and Teaching: Foundations of the New Reform. In: Harvard Educational Review 57 (1), 1-22.

Shulman, L. S. (2001). Appreciating good teaching. A conversation with Lee Shulman by Carol Tell. In: Educational Leadership 58 (5), 6–11.

van Driel, J. H., Jong, O. D., & Verloop, N. (2002). The development of preservice chemistry teachers' pedagogical content knowledge. Science Education, 86(4), 572–590. https://doi.org/10.1002/sce.10010.

Wilson, C. D., Borowski, A., & van Driel, J. H. (2019). Perspectives on the Future of PCK Research in Science Education and Beyond. In A. Hume, R. Cooper, & A. Borowski (Eds.), Repositioning Pedagogical Content Knowledge in Teachers' Professional Knowledge (pp. 289–300). Singapore: Springer.

THREE DIMENSIONS OF INQUIRY IN PHYSICS EDUCATION

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It is well established that many challenges need to be considered to address student interest and participation in science. While all of the science disciplines face challenges engaging students, it is particularly pronounced in the physics context for a multitude of reasons including shortages of qualified physics teachers, unconscious biases and perceptions of being difficult, to name just a few. Students often consider physics as irrelevant and are not motivated to study at upper secondary or tertiary level. However, physicists view physics as the fundamental discipline for further studies in science and technology and consider physics education as critical to empowering individuals and societies to thrive in our ever-changing complex world. This paper discusses the key findings of the Three Dimensions of Inquiry in Physics Education (3DIPhE) project which involved seven partner organizations and over one hundred in-service teachers of physics from four European countries (Slovenia, Belgium, Ireland and Poland). This paper discusses the key findings from three inquiry levels considered in this project, namely:

- *Inquiry Based Learning approaches to support student learning in physics,*
- *Practitioner inquiry of teachers inquiring into their classroom practices,*
- *Inquiry processes in collaborative professional learning communities of teachers*

Keywords: Inquiry Based Learning, Practitioner Inquiry, Professional Learning Community

INTRODUCTION

The modern world is increasingly dependent on exact, natural and technical sciences, thus there is a growing need to attract people who would associate their future and professional career with the development of these areas of life. One of the eight key areas of competence indicated in EU Key Competences (2018) is to provide basic education in natural and exact sciences. Since these are areas closely related to experience and practical work, special emphasis should be put on developing practical research skills, basing teaching on experiments and specific references to everyday life in motivating and teaching them. The benefits of using innovative learning and teaching approaches to enhance student learning in science are significant – students develop their conceptual understanding alongside developing the key skills and competences they need to live and thrive in our complex society. Such approaches serve to influence student's attitudes towards science and increase their appreciation of the value of science in society. Inquiry based learning (IBL) is an approach to learning and teaching physics that is gaining popularity, as it has proven the efficiency in gaining new knowledge, comprehension as well as retention (Sokolowska, 2018). Despite decades of dissemination of the IBL method, it is still not very representative during the science lessons, because, among others, teachers are not particularly convinced of its effectiveness and feasibility of using it in a school time-and-space regimen. To encourage teachers to implement the IBL method, the 3DIPhE project proposed a new strategy for IBL workshops to support teachers developing their IBL teaching skills and giving teachers a deep insight into the spirit of the method.

There is a widespread consensus that for teacher professional learning to be successful it needs to take place over an extended period of time, needs to be valued by teachers and should focus on the learning needs of their students. The Three Dimensions of Inquiry in Physics Education (3DIPhE, 2017-2020) project adopted a "generalistic" approach. The inquiry learning approach was extended to other dimensions, from students to teachers that formed professional learning communities of teachers (PLCT), and to teachers' coaches also called facilitators. The general framework of the scientific method, from formulation of the problem, designing the inquiry approach, collecting evidence, drawing conclusions, and presenting results was adopted and slightly adapted to practitioner inquiry (PI) of teachers and to practitioner inquiry of coaches. However, while the approach was generalized to different dimensions, the focus remained the IBL in physics education, that was, physics teachers inquired their IBL classes, and coaches focused on IBL in physics and PIs connected to it in PLCTs. Finally, an overarching concept of inquiry was applied in educational design research that inquired the processes across the project. The project 3DIPhE was active from September 2017 until August 2020 and involved seven partners from Slovenia, Belgium, Ireland and Poland who met regularly for more than two years with physics teachers from different schools in PLCTs, co-created many IBL units with them, developed protocols for supporting formulations of inquiry questions, collecting evidence, drawing conclusions, but also to support an open and friendly atmosphere in these PLCTs. The key learning and findings from the 3DIPhE project are shared in an e-book with four volumes (De Lange, 2020; Lovatt, Grimes & McLoughlin, 2020, Peeters, 2020; Sokołowska, 2020). The findings of the 3DIPhE project across three different inquiry levels in physics education are discussed in the following sections, namely:

- Inquiry by students who use the inquiry-based learning (IBL) approach to learning physics.
- Practitioner Inquiry (PI) of teachers inquiring the processes in their classroom.
- Inquiry processes in professional learning communities of teachers (PLCTs)

METHODOLOGY

Given the complex nature of the 3DIPhE project, Educational Design Research (EDR) was selected as the methodology used to inform, structure and elicit learnings across and between all inquiry levels (Lovatt, Grimes & McLoughlin, 2020). EDR, stemming from the 'family' of design research, addresses educational problems in real-world settings. It is a problem-oriented approach that focuses on reflection and cycles in order to achieve the most efficient solution (McKenney and Reeves, 2019). EDR is the act of interacting systematically with the subject of study and taking the learnings from that to improve practice. EDR has two primary goals, developing knowledge and developing solutions. Like other research approaches, it aims to develop scientific knowledge, but it also strives to develop interventions in practice. EDR extends theoretical knowledge through data collection and analysis embedded in the cyclic development of a solution to the problem being tackled. The nature of these solutions can be educational products, processes, programs or policies. While there are several definitions and descriptions of EDR, there is common agreement on the essential aspects, and common features appear in both the descriptions of design research, design-based research and educational design research. Plomp's (2013) description of EDR as "...the systematic study of designing, developing and evaluating educational interventions as solutions for complex problems in educational practice, which also aims at advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them" succinctly describes the key ideas that most descriptions of EDR are based upon.

INQUIRY BASED LEARNING TO ENHANCE PHYSICS EDUCATION

IBL is an active learning method in which students, in order to develop knowledge or find solutions (e.g. to discover trends, measure quantities of objects or quantities related to phenomena, find out the limits etc.), follow a scientific method used by researchers in science studies, reflected in the IBL cycle (Figure 1). IBL emphasizes the students' role in the learning process in which they are encouraged to explore the scientific issues, ask questions, and share ideas. Instead of memorizing facts and rules students discover them by doing. Unlike traditional teaching, inquiry-based learning is student-centred, consequently leading students to gain more and more independence in learning. The teacher's role is to support students in their learning process, and not to reply solely on direct instruction. Redefinition of the teacher's role in the IBL requires a new strategy for teacher education, both pre-service and in-service. Teachers need to gain new skills through active engagement in the IBL process, both as learners and facilitators of the learning. Such a two-side perspective makes the teachers enter into the spirit of the method, makes them aware of subtle details of implementation and enables them to perceive the benefits of this learning approach. In order to encourage teachers to implement the IBL in their daily practice, it is necessary to show them examples of good practice and evidence provided by other practitioners, as well as collected from the literature about the benefits for students' learning outcomes (Sokołowska, 2018), opportunities for development of interest, motivation and positive attitudes towards science careers (e.g. Kanter& Konstantopoulos, 2010), as well as chances to achieve better results by students usually doing poorly in science (e.g. Marx et al., 2004).

During 3DIPhE workshops with in-service teachers the IBL method was introduced first by sharing 'good' IBL examples collected from coaches and other teachers as members of PLCTs. By implementing the examples in their own classes, teachers could practice the IBL method principles, develop their positive attitude towards the IBL and their self-confidence in conducting the IBL cycle (Figure 1) in an accurate manner (Sokołowska, 2020). Following these examples, the teachers could adapt the existing IBL materials to the specific curricula or the needs of their students. However, such a path enabled teachers, in a sense, to come only halfway to developing their sense of ownership in teaching the IBL. To master their competences in the IBL method teachers needed to experience the IBL spirit in a more rigorous, deepened approach to the method. They needed to start to create the IBL material by themselves from scratch. However, they were not left alone in this process, since that might result in many doubts, early-stage discouragement and dropping the demanding IBL method. Such an opportunity of a group work arose in PLCTs, where teachers were supported by other teachers, making the same journey of developing the IBL teaching skills.

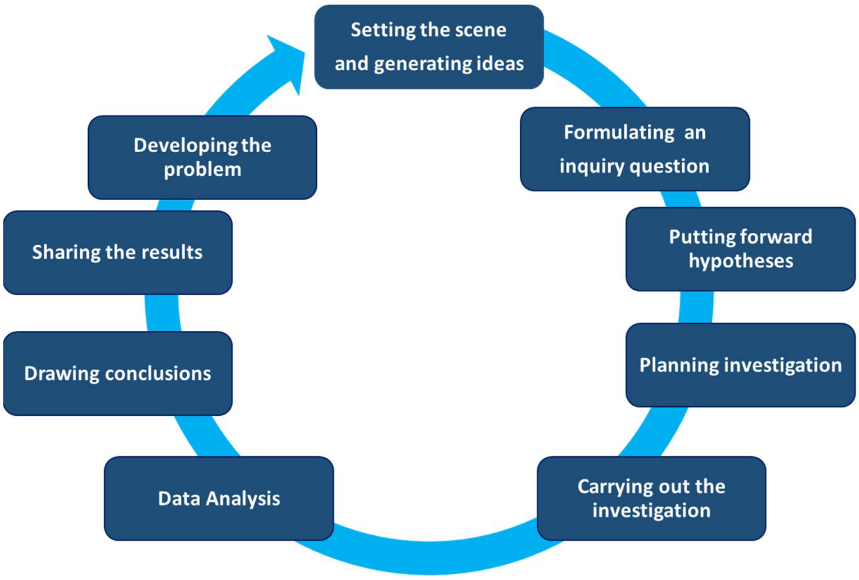

Figure 1. Inquiry Based Learning Cycle (Sokołowska, 2020).

Two approaches to introducing and developing teacher's IBL teaching skills were adopted. The first was intended for teachers with very little or no experience in teaching through IBL. For them the introduction to the IBL method was necessary, based on a sequence of intensive activities in exploring existing IBL materials. During a few workshop meetings teachers took on the roles of students and experience the IBL activities, following the material introduced by the coach. Subsequently, some teachers started the second sequence of workshops in an advanced format. Preferably, teachers started their pilot implementations of the IBL method in their classes somewhere between the first, introductory part of the course and the second, advanced part. In such a way they gained experience from two perspectives, which was beneficial for their development when they started workshops at the advanced level. Teachers already experienced in the IBL method might deepen their practice by participating from the beginning in the advanced part.

During the advanced sequence of workshops teachers took part in two types of activities. They continued their experience of the ready-to-use IBL learning units during the workshops when they again took on the roles of students. At the same time, during each meeting they also participated in workshops, in which they practiced one IBL teaching skill at a time ((1) Brainstorming, (2) Formulating a research question, (3) Design of the learning unit plan, (4) Design of IBL assessment tools), playing alternately the roles of teachers - unit designers and the roles of students. During the last meeting of each sequence of the course on developing the IBL teaching skills, PLCT members were also asked to reflect individually on their IBL practice in their own classes. For that the Self-reflection Tool for Teachers, designed in the Fibonacci project (Carulla, 2012) was used.

PRACTITIONER INQUIRY IN PHYSICS TEACHER EDUCATION

Teachers are continuously faced with many challenges that impact their teaching. However, finding out systematically what works in one's professional practice is often not regarded as part of a teacher's role. Teachers must be facilitated and encouraged to develop an inquiry stance about their own teaching practice. Their inquiry is about their profession, their practice, their daily work with students. This inquiry leads to a lot of learning for teachers and is referred to as 'practitioner inquiry'. Practitioner Inquiry (PI) is a form of professional learning defined as the systematic intentional study by teachers on their own practice (Cochran-Smith, 1993). The teachers (practitioners) engage in systematic reflection and act for change by asking questions ("wonderings"), gathering data to explore their inquiries, analysing the data, making evidence-informed changes in their practice, and sharing their learnings with others (Dana and Yendol-Hoppey, 2014).

During the 3DIPhE project the partners recognized several 'stages' during a PI cycle, as illustrated in Figure 2 (De Lange, 2020). However, it is important to consider this inquiry cycle not as a linear process but more as an ongoing process that must be used in a flexible way depending on teachers' needs. Conducting a PI can be done by an individual teacher. However, there is a lot of evidence that the process of improving of students' learning has the most impact if it is carried out as part of a collaboration.

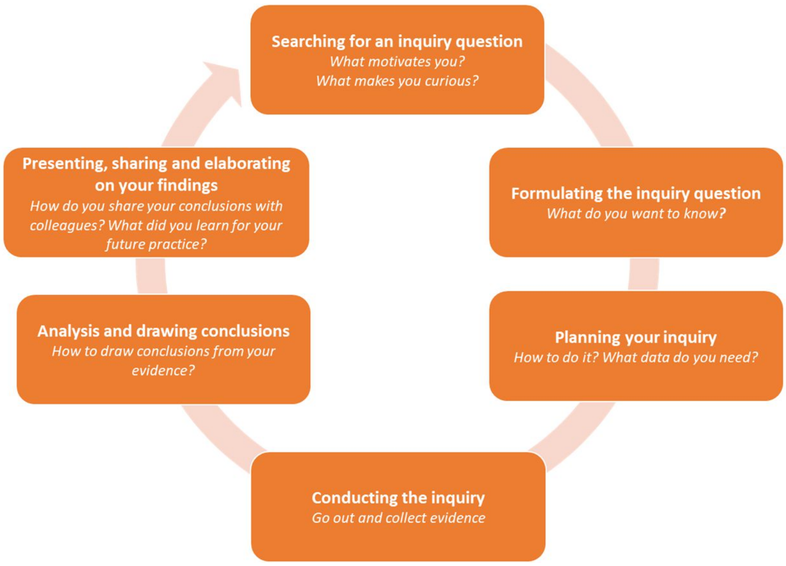

Figure 2. Practitioner inquiry cycle adopted in 3DIPhE project (De Lange, 2020).

In the 3DIPhE project, several groups of teachers worked in professional learning communities of teachers (PLCTs) on a topic/question that is related to IBL in class. Both the teacher (through PI) and student (through IBL) use very similar skills like generating ideas, asking questions, developing hypotheses, planning inquiries, gathering data and evidence, analysing, and making conclusions, working collaboratively and presenting/sharing/elaborating results. In the 3DIPhE experience, these two dimensions of inquiry, IBL and PI, reinforce each other by conducting PI in the context of IBL. Though it is not a necessity, the project partners experienced an added value of bringing the two together. By making PI more specific in the context of IBL, you give teachers direction and focus and, at the same time, amplify their teaching methodology of IBL.

The 3DIPhE project designed a professional development course for teachers that incorporates the six stages of the PI cycle and course implementation is structured around this PI cycle (Peeters 2020). How long a stage will take and what the exact actions are for each stage will depend on context and organization. However, there are some shared learnings that are essential, and form the design principles for the 3DIPhE course. Every stage should incorporate the following aspects

- Building a professional learning community
- Facilitating Practitioner Inquiry
- Promoting Inquiry Based Learning
- Reflection

FACILITATING REFLECTIVE LEARNING: BUILDING PROFESSIONAL LEARNING COMMUNITIES

Dana and Yendol-Hoppey (2019) defines a professional learning community as "a group of teaching professionals who meet regularly to learn from practice through structured dialogue and engage in continuous cycles of inquiry". The last part of this description refers to evidence the teachers need to provide for their learnings. Hord (1997) defines these as "... a place where teachers inquire together into how to improve their practices in areas of importance to them, and then implement what they learned to make it happen". This teacher learning is only valuable if their students show improved results. Both ideas taken together is proven to be extremely powerful, as shown by the Hattie ranking of "252 Influences and effect sizes related to student achievement", in which the newly studied influence "Collective teacher efficacy" was ranked at number one (Hattie, 2017). The pursuit to become a better teacher is indeed a lot more interesting, more motivating, richer, more sustainable, and more efficient if this takes place in a group of peers: other teachers, colleagues that share this ambition. If in each context a group of teachers has this insight, they can become a PLCT and have a lot of professional fun.

In the 3DIPhE project PLCT's were established (built) as a strategy to valorise and improve all learnings of all members of the PLCT. These members were in general physics teachers that were motivated to complete their own PI. 3DIPhE project partners, being experts in physics and STEM education, were guided in building PLCT's of groups of teachers according to a structured strategy. Using the framework of educational design research all learnings of facilitators of PLCT's have been collected, discussed, and captured and eventually led to the development of a course on how to coach a PLCT of physics teachers.

Focusing on the facilitator's role, some key learnings reported by the 3DIPhE partners for designing PLCTs are:

- The facilitator must have an open mind and even prepared to stretch some ideas
- The facilitator has a leading role: the PLCT facilitator is a central person in the community. They plan and organises the workshop. An effective facilitator will be able to use different styles when needed and has the capacity adapt and engage all to be a real leader. Some of the characteristics of such a leader: they can inspire the PLCT members, they can motivate, they have a vision on the effectiveness of working in

PLCTs, they can take decisions, they can discuss, argue, negotiate, find solutions, compromise between members of the PLCT, etc.

- The facilitator is engaged on the content and on the process.
- Facilitators should have good social skills like communication, creativity, positive thinking, high expectations, they should feel and pick up the team spirit within the PLCT and act accordingly, supportive, and at the same time truthful, providing quality feedback even when things do not evolve as desired, emphatic, paying attention to all members, remain focused on the goals of the group, and many more.
- One of the main competences of the facilitator in a PLCT is to make a planning for the entire inquiry cycle, for example, a whole school year: what is the main focus of the different workshops during a year, the timing, keep up motivation and speed.

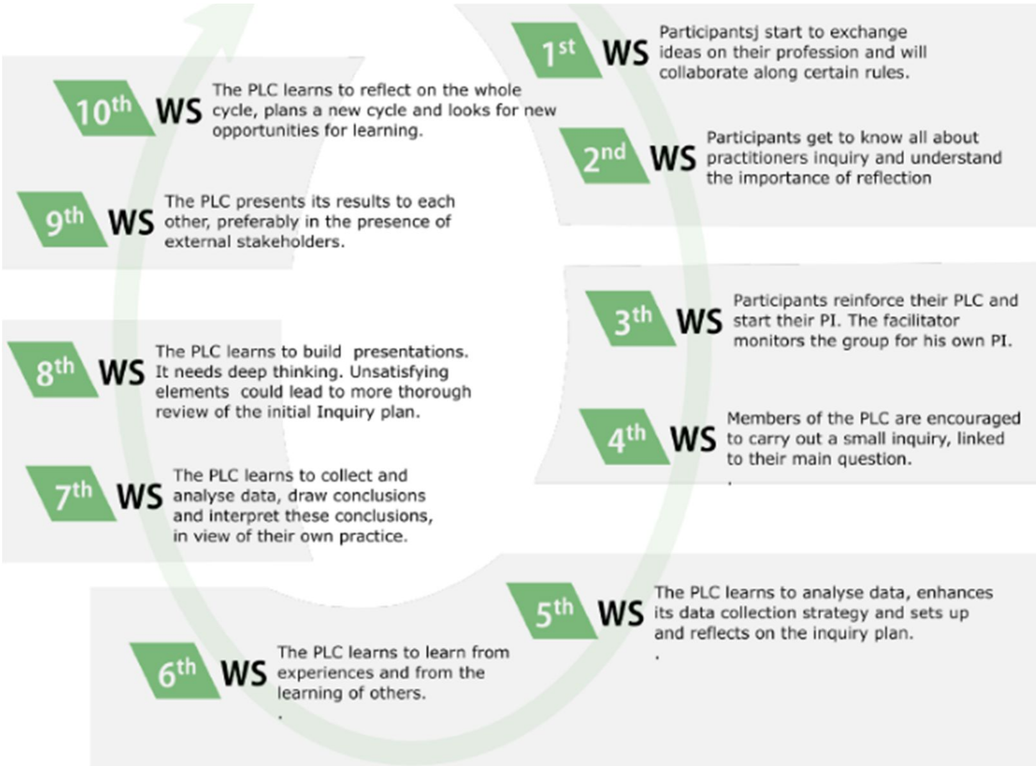

Figure 3. 3DIPhE guide for organizing ten PLCT workshops (Peeters, 2020).

These key learnings from the 3DIPhE experiences of organizing PLCTs have been used to prepare a guide for organizing a series workshops by a competent facilitator, e.g. an example with a series of ten workshops is illustrated in Figure 3 (*Peeters, 2020).* Prior to the first workshop, the purpose and organisation of the PLCT were considered, i.e., context, strategies to motivate, practical issues, all ideas that were needed to not only start with a PLCT, but also to guarantee its success. Then for all planning all subsequent workshops, “Why”, “How” and “What” questions were considered in detail, often enriched by several alternative approaches and experiences expressed by 3DIPhE partners. The “Why” question was often inspired by the teacher’s motivation and determination to have achieve better students learning. The “How” question very often referred to strategies that enhance collaboration, reflection and dialogue among members of the PLCT, through so-called protocols. The “What” question is highly determined by the phase of the sequence, the teachers' input and needs and feedback and reflections. Throughout the whole sequence, guidelines were also provided to inform the facilitator conducting their own PI.

DISCUSSION AND CONCLUSIONS

The project 3DIPhE was active from September 2017 until August 2020 and involved seven partners from Belgium, Ireland, Poland, and Slovenia, who met regularly for more than two years with physics teachers from different schools in PLCTs, co-created many IBL units with them, developed protocols for supporting teacher carrying out their own PI as part of a local PLCT. Two dimensions of inquiry (PI and IBL) were linked but additional learnings were derived from a third dimension of inquiry considered in this project, namely examining inquiry processes in professional learning communities of teachers. During the project, over one hundred in-service teachers of physics and indirectly over one thousand students taught by these teachers from across these countries participated in this study. The overall learnings and recommendations of the 3DIPhE project were derived from a synthesis of each project partners' evaluation of their second iteration of PLCTs as well as partner's responses to a final survey.

While there were cultural and structural differences in the partner countries regarding education systems and models of professional learning, there were many common challenges faced by teachers which included: limited access to equipment for doing experiments in the school; limited time to prepare experiments before the lesson; an overloaded curriculum and lack of student motivation. The structure of the workshops in each country was different as they were designed around the availability and needs of the teachers. In some cases, teachers attended during their holidays, at weekends or directly after a full day teaching. In some contexts, regular short workshops were held while in others spaced out full day workshops were used and in others clustered full day workshops were provided.

A core goal of the 3DIPhE project was to promote the sustainable use of IBL in the classroom and the usability and sustainability of teacher education resources and programmes developed through previous projects. While many educational projects have a significant short-term impact, they fail to create a sustainable change in teacher's classroom practice. Increasing teacher's motivation is expected to have a long-lasting sustainable impact on their classroom practice (Timperley, 2011). Therefore, the approach adopted by the 3DIPhE project to influence teacher's motivation to use inquiry approaches was to support teacher's working as a PLCT to carry out their own PI (Timperley et al. 2007, Dana and Yendol-Hoppey, 2014).

During the project, six teachers went through two sequences of the workshops on development of the IBL teaching skills. Nevertheless, observations of these teachers during the IBL workshops and their opinions expressed in focus group discussions revealed that the format of a two-stage and two-sided approach gave them a much better insight into the IBL method and gave them much more self-confidence in using the method than the traditional approaches of learning the IBL only by following the-ready-to-use materials. Even teachers, who initially thought they had some experience in IBL implementation in their own classes, admitted that they really appreciated the revealing idea of going step by step throughout the entire IBL cycle using a series of protocols developing skills in teaching by inquiry. Teachers emphasized a great role of the interaction with other PLCT members on self-reflection on their own materials and development of a critical-friend attitude towards other teachers' work. We believe that the format of the IBL courses for teachers proposed in the 3DIPhE project not only serves the development of the IBL teaching skills, but also gives the deep insight into the spirit of this method.

Without effecting the teachers' ownership (which is very important in PI), the partners identified it was important to promote IBL in an indirect way during a PLCT. This can be done though using appropriate examples of IBL as inspirations, and discussing problems faced by teachers while implementing IBL and how they feel when using IBL in class. In this way, teachers become motivated to choose IBL related inquiries themselves. This steering towards IBL should be carried out systematically. Other suggestions include modifying existing protocols from previous PI experiences, discussing IBL principles on regular basis with PLCT members and raining inquiry problems. Key learnings (which are called design principles) for the PI course were collated during two iterations of PLCTs across four countries, namely:

- All workshops incorporated the three pillars inquiry - fostering PLCTs, doing PIs and supporting use of IBL in the classroom
- Always keep in mind the learning of the students, so inquiry questions, data collection, … must be related to this goal (more specific IBL).
- the agenda and timeline must be structured and flexible.
- Don't overload workshops/course
- Small changes are the best.
- Share, extend and elaborate on key learnings and findings.

Inquiry for learning was the central focus of the 3DIPhE project and this inquiry happened at the student, teacher and partner levels. This paper presents the design and implementation of the 3DIPhE project, which was evaluated using an EDR approach over a three-year period. This approach allowed the project partners to systematically investigate how and where learning occurred throughout the project, in terms of

- IBL approach to students learning physics.
- PI by teachers inquiring into their classroom practice.
- Inquiry processes in a collaborative PLCT of teachers.

The key learnings and recommendations of the 3DIPhE project can be used to influence teacher's motivation to use inquiry approaches and support teacher sustained teacher professional learning and are openly shared in an e-book with four volumes (De Lange, 2020; Lovatt, Grimes & McLoughlin, 2020, Peeters, 2020; Sokołowska, 2020).

ACKNOWLEGMENTS

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REFERENCES

3DIPhE Project (2017-2020). *Three Dimensions in Physics Education Project,* ERASMUS+, KA2. http://3diphe.eu/

Carulla, S.B. (ed.) (2012). *Tools for Enhancing Inquiry in Science Education*, 40-43. http://fibonacci.uni-bayreuth.de/resources/resources-for-implementing-inquiry.html

Cochran-Smith, M., & Lytle, S. L. (Eds.). (1993). *Inside/outside: Teacher research and knowledge.* Teachers College Press.

Dana, N. F., & Yendol-Hoppey, D. (2019). *The reflective educator's guide to classroom research: Learning to teach and teaching to learn through practitioner inquiry*. Corwin

Dana, N. F., & Yendol-Hoppey, D. (2014). *Teacher inquiry defined. The Reflective Educator's Guide to Classroom Research: Learning to Teach and Teaching to Learn through Practitioner Enquiry.* Third Edition. Thousand Oaks: Corwin, 5-28

De Lange, J., (2020). *Practitioner inquiry in the context of inquiry-based learning, Volume 2*, In Čepič M. (Ed.) 3DIPhE e-book, University of Ljubljana, http://www.3diphe.si/e-book/

EU Key Competences (2006). EU Key Competences for Lifelong Learning (2018), https://op.europa.eu/en/publication-detail/-/publication/297a33c8-a1f3-11e9-9d01-01aa75ed71a1/language-en

Hattie, J. (2017). *Hattie Ranking: 252 Influences and Effect Sizes Related to Student Achievement*, https://visible-learning.org/hattie-ranking-influences-effect-sizes-learning-achievement/

Hord, S.M., (1997). *Professional Learning Communities: Communities of Continuous Inquiry and Improvement,* https://sedl.org/pubs/change34/plc-cha34.pdf

Kanter D.E. & Konstantopoulos S. (2010). The Impact of a Project-Based Science Curriculum on Minority Student Achievement, Attitudes,and Careers: The Effects of Teacher Content and Pedagogical Content Knowledge and Inquiry-Based Practices, *Science Education, 94,* 855-887

Lovatt, J., Grimes, P. & McLoughlin, E. (2020). *Educational Design Research for Teacher Professional Learning, Volume 4,* In Čepič M. (Ed.) 3DIPhE e-book, University of Ljubljana, http://www.3diphe.si/e-book/

Marx R.W. et al. (2004). Inquiry-Based Science in the Middle Graders: Assessment of Learning in Urban Systemic Reform, *Journal of Research in Science Teaching*, 41(10), 1063-1080.

McKenney, S., & Reeves, T. C. (2019). *Conducting educational design research*. Routledge.

Peeters, W., (2020). *Building Professional Learning Communities, Volume Three,* In Čepič M. (Ed.) 3DIPhE e-book, University of Ljubljana, http://www.3diphe.si/e-book/

Plomp, T. (2013). Educational Design Research: An Introduction. In Plomp, T., & Nieveen, N. (Eds.), *An Introduction to Educational Design Research*. Enschede, The Netherlands: SLO Netherlands Institute for Curriculum Development.

Sokołowska, D. (2018) *Effectiveness of Learning Through Guided Inquiry*. In Sokołowska D., Michelini M. (Eds.) *The role of laboratory work in improving physics teaching and learning* (243-255). Cham: Springer.

Sokołowska, D. (2020). *Inquiry based learning to enhance teaching, Volume 1,* In Čepič M. (Ed.) 3DIPhE e-book, University of Ljubljana, http://www.3diphe.si/e-book/

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2007). T*eacher professional learning and development: Best evidence synthesis iteration (BES)*. Auckland, New Zealand: University of Auckland https://www.educationcounts.govt.nz/publications/series/2515/15341

Timperley, H. (2011) *Realizing the Power of Professional Learning*, Open University.

UNDERSTANDING TEACHER IMPLEMENTATION OF BIOECONOMY ACTIVITIES THROUGH THE LENS OF EXPECTANCY VALUE THEORY

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Through a USDA funded grant, the Sustainable Bioeconomy Program, an interdisciplinary educational innovation was designed to stimulate high school students' career interest and to foster increased diversity in bioeconomy industries in the south-eastern US. This qualitative study investigated the motivations underlying teachers' decisions to implement the project's bioeconomy-focused lessons in their classrooms. Teachers' online course forum responses and post-course interviews were analyzed and coded using a priori task value constructs from Expectancy Value Theory to understand teachers' thinking about planned implementation and then their enactment of classroom lessons. After coding, teachers were put into high, medium and low enactment groups. Teachers with the lowest level of enactment expressed the highest cost and lowest percentage of utility for themselves. Teachers who had the highest level of lesson enactment described the highest level of the lessons' utility for students and the lowest level of cost to themselves. Teachers in the medium enactment group perceived the highest level of utility teacher and a medium level of cost. These preliminary findings suggest that higher lesson implementation is based on teachers' inherent interest, a focus on the value of the lessons for their students, and a reduced focus on the personal costs to themselves.

Keywords: Expectancy value theory, Teacher professional development, Bioeconomy

INTRODUCTION

Biobased product employment (excluding biofuels) grew 17% from 2014 to 2016 and contributed $459 billion to the U.S. economy (Golden et al., 2018). In conjunction with such growth, there is a need to develop the workforce in bioenergy, bioproducts, and the bioeconomy (EISA, 2007). However, STEM experiences can vary greatly between students; socio-economic factors, geographic region, racial background, and gender influence course persistence and future careers (Alegria & Branch, 2015; Andersen & Ward, 2014; Brown et al., 2016). Schools designated as high poverty tend to have fewer teachers who are certified in their content areas, fewer advanced courses offered in STEM subjects, and higher turnover than do wealthier schools (Darling-Hammond & Hammond, 2015). Rural schools also face geographic isolation and limited access to university-provided programs, equipment, and resources (Goodpaster et al., 2009).

THEORETICAL FRAMEWORK

The Expectancy Value Theory of Achievement Motivation (EVT; Eccles, 2009) demonstrates empirically how individual's expectancies, ability beliefs, and values directly affect their choices, performance, effort, and achievement. Other influences are socializers (e.g., parents, teachers) and one's interpretations of previous life experiences. This study uses one part of the framework, task value (Eccles & Wigfield, 1995), to understand teachers' thinking about the value they hold for the intervention activities. Task value has four major components: "attainment value, intrinsic value or interest, utility value, and cost" (p. 216). These task values were used to understand how teachers weighed the relative costs versus values when they decided whether and why to implement lessons or other materials from the teacher professional development project.

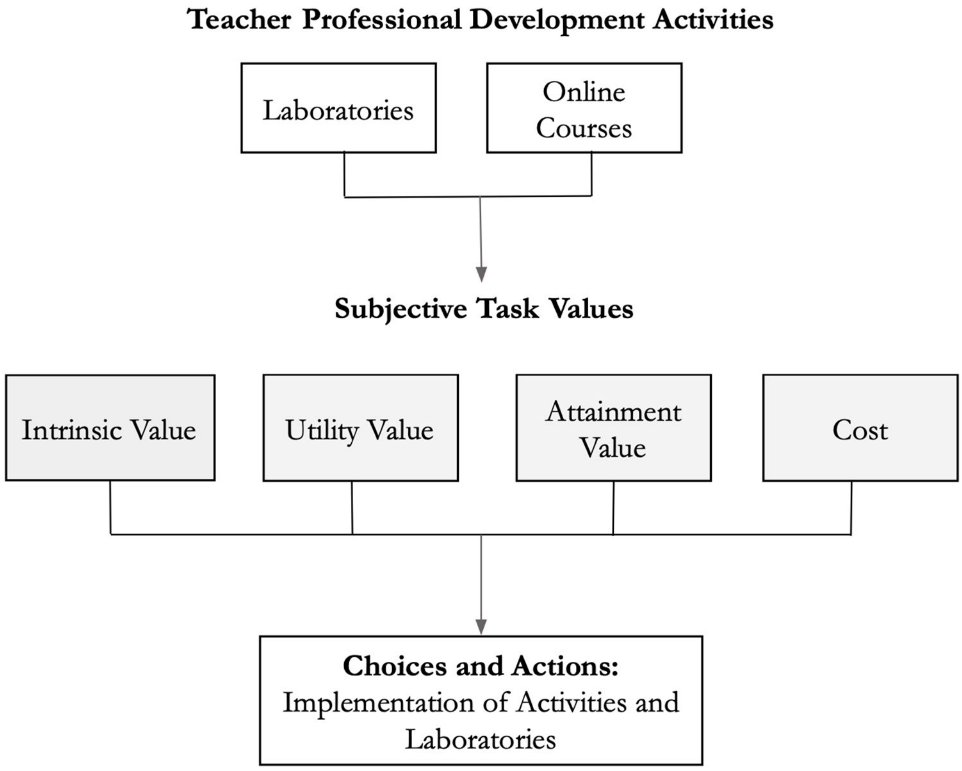

Figure 1. Teacher Professional Development Activities linked to Subjective Task Value Constructs.

RESEARCH QUESTIONS

1. How and to what extent did teachers implement what they learned into their practices?
2. How did teachers perceive the relative costs of the coursework and the classroom implementation aspects of the TPD and did these differ by implementation level?
3. What, if any, is the relationship between teachers' task values and their lesson enactment?

METHODS

Research Design

This qualitative pilot study (Creswell & Creswell, 2018) investigated the underlying reasons for teachers' decisions to implement project lessons in their classrooms, using task value constructs from EVT.

Context

The Sustainable Bioeconomy Program (all names are pseudonyms) was an interdisciplinary collaboration between a College of Education and a College of Natural Resources at a research university in the south-eastern US. Funded by the US Department of Agriculture, it was designed to stimulate high school students' career interest and to foster increased diversity in bioeconomy industries through an educational innovation. Twenty high school teachers from ten counties in Eastern North Carolina were originally selected to participate in 2-3 online graduate level bioeconomy courses and to gain experience with 17 bioeconomy laboratories and activities over a three-year period. Participation in summer workshops gave teachers hands-on experiences with laboratories and lessons, and they selected which labs they wanted to implement and were provided all of the needed equipment and supplies. These experiences and support provided teachers with the tools to provide their rural, diverse students in lower income high schools experiences with hands-on laboratories and to promote career pathways in the bioproducts and bioenergy industry.

Data Collection and Analysis

For this pilot study, 16 teachers were organized into implementation groups, which was blind to the coders. For the school year implementation, teachers were asked to enact at least two lessons with their students.

Teachers' post-course interviews and three class forum responses, totaling approximately 187 pages of double-spaced transcripts, were analyzed and coded using a priori task value constructs from Expectancy Value Theory. The construct of Utility value was split into two categories after beginning coding, to delineate whether the teacher viewed the course content as useful for their classes and/or their own career path (UT) or directly useful for their students (US). Teachers' expressions of interest and enjoyment in learning new content was coded as Intrinsic (I). Those which described appreciation of new knowledge as a citizen, confidence in doing the labs, or as positive for their rural/farmer community were coded as Attainment (A). Cost (C) was coded for instances when teachers expressed concerns about the time and effort required, student ability, or lack of confidence. In order to standardize the values, we converted the raw numbers into percentages by taking an individual's number of codes for UT, US, I, A, and C and dividing them by the total number coded for that individual. Every teacher's value and cost data were compared to their lesson enactment.

FINDINGS

How and to what extent teachers incorporated what they learned into their practices

The activities that teachers implemented were weighted as high effort activities and low effort activities. High effort activities included new labs or labs from the teacher professional development that they modified for their classrooms, teacher professional development activities, and bringing students on related field trips. These activities were multiplied by 2 for a weighted value. Lower effort activities included doing a related demo, related lab from previous year, using teacher professional development examples, curriculum night, and teacher conference participation. These activities were multiplied by 1. Weighted totals were calculated for teachers based on self-reported enactment from interview data. Implementation was categorized as Low (0-3), Medium (4-6), High (7+), as seen in Table 1.

Table 1. Teachers' weighted implementation.

Implementation	Participant	High Effort Activity (x2)	Low Effort Activity (x1)	Weighted Total
Low	111	0	0	0
Low	105	0	1	1
Low	120	1	0	2
Low	107	0	2	2
Low	106	1	1	3
Medium	114	2	0	4
Medium	118	2	0	4
Medium	103	3	0	6
Medium	112	3	0	6
Medium	110	3	0	6
High	115	5	0	10
High	104	4	2	10
High	117	5	1	11
High	121	5	1	11
High	102	6	0	12
High	113	7	2	16

From the analysis of the teachers' self-reported data, 5 teachers were classified at a low level of implementation, 5 teachers were classified as a medium level of implementation, and 6 teachers were identified at a high level of implementation. From the data, it was found that there were differences in which kind of labs and activities teachers used in the implementation groups. The Low group typically did no new labs and either used examples or added one activity to their current teaching practices. Teachers in the Medium group typically did 2 new labs and sometimes one new activity. The teachers in the High group most often did 2 new labs and also added 3 new class activities, as seen in Table 2.

Table 2. Lesson enactment type by teacher implementation group.

No. of Teachers	Lesson Enactment	High Effort Activities	Low Effort Activities
5	Low	33%	67%
5	Medium	100%	0%
6	High	84%	16%

How teachers perceived the relative costs of the coursework and the classroom implementation aspects of the TPD and whether they differed by implementation level

Costs were divided into Courses and Classroom implementation, and subcodes were assigned for each group, as seen in Table 3. All of the teachers expressed the most concerns (costs) related to the online courses. All of the teachers had the fewest concerns (costs) related to classroom implementation. The High implementation group expressed the fewest classroom implementation costs.

Table 3. Cost subcodes for Course and Classroom implementation.

Cost Sub-Codes	Example for Courses	Example for Implementation in Classroom
Curriculum issues	Not in curriculum; not relevant; not designed for their students	Wouldn't be able to use material from the online course in earth science.
Teacher Response – Content	Nothing new/novel; math was too hard; had been a while since I wrote a paper	Online course content was too heavy for students.
Teacher Response – Affective	Sometimes it was frustrating when I didn't get it.	Didn't like it.
Student Abilities	Too difficult for students.	Students lacked attention span; above their reading level; lack of student interest
Logistical – Teacher Professional Circumstances	Teaching responsibilities required too much time to focus on online courses more	Delayed arrival of equipment/materials; moved schools; lab too long; cyberattack; trouble with parents to do research
Logistical – Teacher Personal Circumstances	Time; family obligations	
Online course design	Not seeing other people; not able to learn from others; held to timing of others' posts	

From the analysis, all of the teachers expressed the most concerns (costs) related to the online courses. All of the teachers had the fewest concerns (costs) related to classroom implementation, and the High implementation group expressed the fewest classroom implementation costs (Table 4). With implementation, teachers had the highest frequency of costs associated with Curriculum Issues and Student Abilities. For the online courses, teachers expressed greater costs for Content Response and Affective Response (Table 5).

Table 4. Percent of cost statements by subcategories for different teacher implementation levels.

Implementation Level	Online Class Costs	Classroom Implementation Costs
Low	77.4%	22.6%
Med	81.6%	18.4%
High	86.7%	**13.3%**

Table 5. Types of implementation and course costs by teacher implementation levels.

Implementation Costs						
Group	**Curriculum Issues**	**Response – Content**	**Response – Affective**	**Student Abilities**	**Logistical – Teacher Professional Circumstances**	
Low	**6**	1	2	**7**	3	
Medium	**6**	1	2	**1**	8	
High	**1**	0	1	**6**	5	
Online Course Costs						
Group	**Curriculum Issues**	**Response – Content**	**Response – Affective**	**Logistical – Teacher Professional Circumstances**	**Logistical – Teacher Personal Circumstances**	**Course Design**
Low	1	**6**	**25**	0	2	5
Medium	2	**12**	**18**	9	9	7
High	2	**22**	**16**	1	4	11

The relationship between teachers' task values and their lesson enactment

For each level of enactment, teachers' costs and values were totaled and calculated as a percent (Table 6). All of the teachers described the usefulness of the PD to themselves. The Low implementation group was 3.0 times more likely to talk/write about Cost related to online coursework or implementing lessons than were the teachers in the High implementation group. The teachers in the High group were 1.6 times as likely to talk about the Attainment value and 1.8 times as likely Utility value for Students than the Low implementation group.

Table 6. Teachers' task values by enactment level.

No. of Teachers	Lesson Enactment	Utility Teacher	Utility Student	Intrinsic	Attainment	Cost
5	Low	25.6 %	11.4%	21.7%	11.9%	**29.4%**
5	Medium	29.5%	15.2%	22.2%	11.5%	21.7%
6	High	26.4%	**20.5%**	24.7%	**18.7%**	9.7%

Limitations

For this study, several factors need to be considered: 1) Transitioning to remote learning during Covid may have negatively impacted lesson implementation, 2) The sample size was small, the population of teachers could be unique, and the study was 1-2 years in duration, 3) If we had asked different questions or used a different analytical framework, we might have come to different conclusions, and 4) We made the choice to have 3 groups, low, medium and high - other groupings would have given different results.

CONCLUSIONS

These preliminary findings indicate that although the teachers participated in the same professional development, with the same level of financial and material supports, there was differential implementation of lessons. It is our belief that teachers might have implemented more activities and lessons if there had been better support through the program structural supports, such as visiting schools on lesson days. Our study suggests that teachers' task values and their perceptions of the cost(s) influenced their enactment of the new lessons. The "magic" combination for highest implementation with our teachers was high personal interest, high attainment value (which is tied to identity; Eccles & Wigfield, 1995), high utility value for students, and low perceived costs. We found promise in applying aspects of the Expectancy Value Framework to help us understand teachers' beliefs and values that contributed to teachers' motivation to implement lessons following the same professional development. From this study, recruitment for PD with teachers ought to consider using essay prompts that could better indicate which teachers are likely to implement new lessons. We also suggest having teachers explain the decisions underlying what they chose for their teaching video submission and use this to ascertain and select teachers whose explanations focus on the value for their students.

From the teacher interviews and forum posts, we also identified a need for more relevant and appropriate online courses for teachers. In this program, teachers took online courses with undergraduate students at the university, and consequently, the courses didn't closely match the needs of teachers. In future projects, it will be ideal to design specific courses for teachers, such as MOOCs. In addition, issues of diversity, equity and inclusion did not resonate for teachers. Though teachers were primarily selected from high-needs schools with diverse populations, these topics were absent from their class forum posts and interview transcripts. We suggest revising the course materials to better stimulate thinking about DEI, rural, and ability issues for teachers.

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REFERENCES

Alegria, S. N., & Branch, E. H. (2015). Causes and consequences of inequality in the STEM: Diversity and its discontents. *International Journal of Gender, Science and Technology, 7*(3), 321–342.

Andersen, L., & Ward, T. J. (2014). Expectancy-value models for the STEM persistence plans of ninth-grade, high-ability students: A comparison between Black, Hispanic, and White students. *Science Education, 98*(2), 216–242.

Brown, B. A., Henderson, J. B., Gray, S., Donovan, B., Sullivan, S., Patterson, A., & Waggstaff, W. (2016). From description to explanation: An empirical exploration of the African American pipeline problem in STEM. *Journal of Research in Science Teaching, 53*(1), 146–177.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE.

Darling-Hammond, L., & Hammond, R. (2015). *Teaching in the flat world: Learning from high performing systems.* Teachers College Press.

Eccles, J. S. (2009). Who am I and what am I going to do with my life? Personal and collective identities as motivators of action. *Educational Psychologist, 44*, 78-89.

Eccles, J. S., & Wigfield, A. (1995). In the mind of the actor: The structure of adolescents' achievement task values and expectancy-related beliefs. *Personality and Social Psychology Bulletin, 21*(3), 215–225.

Energy Independence and Security Act (EISA), Public Law 110-140. (2007). https://www.govinfo.gov/content/pkg/BILLS-110hr6enr/pdf/BILLS-110hr6enr.pdf

Golden, J.S., Handfield, R. B., Daystar, J. S., & McConnell, T. E. (2018). *An economic impact analysis of the U.S. biobased products industry: A Report to the Congress of the United States of America Update*. A Joint Publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University.

Goodpaster, K. P. S., Adedokun, O. A., & Weaver, G. C. (2009). Teachers' perceptions of rural STEM teaching: Implications for rural teacher retention. *Rural Educator, 33*(3), 9–22.

TEACHER RESIDENCY PROGRAM: CONTRIBUTIONS AND LIMITS TO THE SCIENCE TEACHERS PROFESSIONAL DEVELOPMENT

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In this article, we present the contributions and limits of a formative experience developed in the Teacher Residency Program (TR) scope with two resident teachers of the Natural Sciences area in an application school. We emphasize that the TR is situated as a teacher professional induction program, implemented in 2019 at the Federal University of Juiz de Fora, being one of the few programs of this nature existing in Brazil. In this sense, describing the trajectory built with the residents and reflecting on the process and its formative implications is of fundamental importance for the memory and evaluation of that program and bringing contributions to the field of research on teacher education. We realized a focus group (FG) with the residents at the end of the program, which was conducted from a semi-structured script, in which we sought to explore the motivation of them to participate in the TR and the contributions and limits of this program to their professional development. Concerning the contributions of the TR to their professional development, the residents pointed out that the TR made it possible to expand the initial training, providing differentiated experiences, which were categorized in the following contributions: i) interdisciplinary experience; ii) experience of different teaching styles and practices; iii) experience of collaborative work, with supervisors and other residents; iv) experience of research at school; v) experience of inclusive education; vi) experience of fieldwork and practical classes. The experiences valued by the residents reaffirm the importance of the dimension of immersion and on-site training. The experience of research at school and the didactic and academic production fostered by the collaborative research are linked to the dimensions of authorship, collaboration, training through language and reflection, reaffirming the teacher's identity as a producer of knowledge.

Keywords: Continuing professional development, In-service Teacher Training, Collaboration.

INTRODUCTION

Teacher training, more than simply a topic, is a social problem of the greatest relevance nowadays, especially in the Brazilian context, marked by discontinued policies, the devaluation of the profession, and little social discussion regarding its concrete social value in contemporary times, as well as on the foundations of teacher training and associated practices, as announced by Gatti and collaborators (2019).

In line with Marcelo (2009), we consider the concept of teacher professional development (DPD) as the one that best fits the conception of the teacher as a teaching professional, since it emphasizes the teacher's learning and development process rather than his/her training process, demarcating a differentiation with training based on courses that do not establish a relationship with professional practices. In this way, we understand teacher training as a *continuum*, from which the constitution of knowledge and professional identity occur in an idiosyncratic and procedural way, though it occurs through clearly differentiated phases: in the experience as a student, in the initial training, in the period of initiation to teaching and continuing education;

it is continuous learning and involves a variety of learning formats (Gatti *et al*, 2019; Marcelo & Vaillant, 2017; Nóvoa, 2019).

Marcelo (2009) systematized an emerging perspective of teacher professional development (TPD), guided by the following concepts: i) the active construction of knowledge by teachers; ii) recognition of TPD as a long-term change process; iii) contextualization in teachers' practices; iv) reconstruction of school culture; v) the view of the teacher as a reflective practitioner; vi) the conception of the TPD as a collaborative process and vii) flexibility of training paths.

In the same direction, Gatti and collaborators (2019) carried out a synthesis of the discursive consensus that has been built by the field of research on teacher education, highlighting and describing the following aspects: i) reflection on the articulation of theory and practice; ii) the valorization of the investigative posture; iii) the approximation between training institutions and the school; iv) valuing the construction of learning communities; v) teaching conceived as a professional activity based on a solid repertoire of knowledge; vi) the importance of training teachers for social justice; vii) the importance of considering the beliefs and knowledge that teachers have about teaching and learning in training.

The systematization carried out by the aforementioned authors has common points, as they emphasize reflection, collaboration, teaching practices and the production of knowledge by teachers. But they are also complementary, especially regarding teacher training aimed at promoting social justice, which has also been highlighted by Zeichner (2011).

The research on teacher education in Brazil has pointed out one of the major problems of training in the country due to the excessively theoretical nature of the initial teacher education courses and their departure from schools' reality (Gatti *et al*., 2019). In addition, the professional induction of teachers, which is when novice teachers start their activities in schools, is something that needs greater attention from public policies, managers and trainers, given the crucial importance of this period for training and education (Nóvoa, 2019). According to Nóvoa (2019), the first years as beginning teachers are the most decisive in the professional teaching life, since they mark, in many ways, our relationship with students, with colleagues and with the profession, being the most important time in our constitution as teachers and in the construction of our professional identity.

To solve the problem of the departure of the teachers training from schools' reality, has been the subject of several initiatives, one of which is the teacher residency programs, which have been carried out for more than a decade in Brazil under different circumstances and conceptions, involving both initial and continuing teacher education (Faria & Diniz-Pereira, 2019).

What is in common between the diverse experiences and projects of residency in education is the idea of immersion in the field of professional practice, based on in-service training, which implies a link between the resident and the schools intensively and systematically, under the supervision of highly ethical and professionally qualified teachers, bringing them closer to medical residencies.

In 2018, the Federal University of Juiz de Fora (FUJF) created a Teacher Residency Program (TR), characterized as a teacher professional induction program, at the postgraduate level, aiming to improve Basic Education teachers' training based on the development of teaching skills *in loco*. The aim is to complement the education received in initial training with experience in a school environment of recognized excellence. This environment is João XXIII Application School (AS) of FUJF. The program lasts 12 months and has a workload of 2880 hours of activities during the year, representing 60 hours a week on an exclusive dedication basis, with a scholarship being offered, enabling conditions for training and immersion in school. The TR's target audience is newly graduated teachers (up to three years), and entry takes place through a selection process.

The activities proposed for such a program involve three areas: i) teaching; ii) performance in administrative-pedagogical sectors and iii) academic production, which requires participation in graduate courses, study and/or research groups, and the development of a Teacher Education Work (TEW), which consists of an academic-related product to teaching practice, in the form of research and/or proposition of educational action plans, interventions, projects or pedagogical resources. In the first year of TR, 2019, eleven scholarships were offered, distributed among the following areas: Human Sciences (2), Natural Sciences (2), Mathematics (1), Language (2), Arts (2), and Pedagogy or Superior Normal (2). In this article, we will focus on the trajectory of the Natural Sciences residents, whose guidance was carried out by the authors in collaboration.

Based on documentary analysis of the FUJF's Teacher Residency project and resolution, Callian and Magalhães (2019) identified five formative dimensions considered essential for teacher training in contemporary times: i) immersion, ii) authorship, iii) collaborative networks and communities, iv) training through language and v) reflection. However, the authors emphasize that this "does not guarantee that the practices are linked to them; however, making them explicit and analyzing them makes the concepts more visible and can lead us to reformulate the practices that are in progress" (Idem, p. 182).

We understand that reflecting on the trajectory built with the residents and its formative implications is of fundamental importance for evaluating and improving that program. Thus, this action research's central aim was to identify the contributions and limits of the TR developed since 2019 for the FUJF (Brazil) to the continuing professional development of the two Natural Sciences residents.

METHODOLOGY

This research was developed from the theoretical-methodological perspective of collaborative action research (Ibiapina, 2008), which was chosen for associating two dimensions of research in education that we consider fundamental: the production of knowledge and the continuing education of teachers, enabling the realization of studies and proposal intervention based on practical situations, which combine theory, practice, research, reflection and action based on collaborative work among teachers to transform schools into critical communities of teachers who problematize, think and reformulate practices with a view to professional emancipation. According to the author, collaborative action research starts from three basic conditions: the study is triggered from a specific social practice that can be improved; it is carried out taking into account the spiral of planning, action, observation, reflection, new action; it is preferably developed collaboratively.

The two residents of the Natural Sciences area have degrees in Chemistry and Biological Sciences and both have master's degrees as well. They are identified in this article as CR and BR, respectively. At our first orientation meeting, we discussed an initial proposal for the Teacher Education Work (TEW), based on the school's demand for science curriculum restructuring. We proposed to carry out collaborative action research, aiming at building a more integrated curriculum, articulating contends of Biology, Chemistry, and Physics, seeking meaningful learning of the central concepts of sciences. From then on, the residents were gradually integrated into the teaching, extension, and research activities that we developed at Application School and started to work with us in classrooms, in pedagogical meetings, in the orientation of interns, in collective projects and commissions, integrating our study group.

In order to know the residents' perspectives on the training and guidance process carried out in the teaching residency program, we held a focus group (Gatti, 2012) at the end of the program, that was conducted from a semi-structured script, in which we sought to explore their motivation to participate in the TR and the contributions and limits of this program to their professional development. The focus group lasted 90 minutes and was recorded in audio and video. Data analysis was performed by content analysis (Bardin, 1977).

RESULTS AND DISCUSSION

From the analysis of the focus group, we highlight as a central aspect of the residents' motivation to participate in the program the offer of the scholarship, which enabled them to articulate work and training, since its value overlaps the teacher's initial salary. According to them:

> *"The scholarship is very tempting" (BR)".*
>
> *"We can finish graduation, participating of the continuing teacher education to work on what we like with a decent remuneration" (CR).*

In this way, the offer of the scholarship plays a fundamental role in enabling in-service training and the immersion of residents in the school reality, contributing to the appreciation of the teaching profession, which is urgent in the Brazilian scenario (Gatti, 2019).

Concerning the contributions of the TR to the professional development, the residents pointed out that the program made it possible to expand their initial training, providing differentiated experiences, which were explored throughout the focus group, thus mapping the following contributions: i) interdisciplinary experience; ii) experience of different teaching styles and practices, adopted by the different monitored teachers during the TR; iii) experience of collaborative work, with supervisors and other residents; iv) experience of research at school, expanding previous experiences with academic research; v) experience of inclusive education; vi) experience of fieldwork and practical classes.

To this extent, the main contribution of the TR expressed by the residents is related to the experiences that it provided due to the immersion process that characterizes the program. Immersion in school, made possible by TR, therefore, has a central role in the articulation between theory and practice, which has been considered a gap in teacher training (Gatti et al. 2019; Nóvoa, 2019), enabling reflection and production of knowledge by the resident teachers.

Among the variety of experiences acquired in the TR, the residents highlighted the training in inclusive education, which permeated the entire course, from the study for the selection test to the subject of inclusive education and the experiences fostered in the Application School, since at the initial training this issue had not been addressed. The TR's focus on inclusive education, which represents the AS' concern to guarantee the learning of all students and which has recently materialized through the creation of a special education sector, is in line with the concept of teacher training focused on social justice (Gatti, 2019; Zeichner, 2011).

They also highlighted the opportunity to participate in the planning and monitoring of scholar visits to different spaces of non-formal education in and outside the city, that have contributed to the cultural enrichment of the students and also the teachers. In this way, Nóvoa (2017) defends the importance of the offer of a solid cultural and academic formation to the teachers.

The residents also emphasized the interdisciplinary and collaborative work that they experienced with the other residents, the supervisors, and other AS' teachers, corroborating the presence of the collaborative dimension identified by Callian & Magalhaes (2019) in the FUJF Teacher Residency project. In addition to these different experiences, according to the residents, TR provided them: academic production, due to the production of articles, abstracts for congresses, book chapters, and the TEW, providing reflection and research on teaching practices and also the production of knowledge by teachers, that is a fundamental aspect of their professional development (Marcelo, 2009; Gatti, 2019; Nóvoa, 2017).

Besides, they considered the opportunity and encouragement for the continuity of training promoted by the TR important, since both intend to continue the training process and the reaffirmation of professional identity as teachers of basic education in the public system. In this degree, the program has contributed to the identity constitution of beginning teachers, fundamental in the period of professional induction (Marcelo & Vaillant, 2017; Nóvoa, 2017, 2019).

In the field of science education, in addition to fieldwork and participation in collective projects, they called attention to the experience of experimental classes - which provided the expansion of the repertoire of practices, and also the opportunity to experience research at school, based on action-research developed with the supervisors, which according to CR, was encouraging to continue training after the TR, having been approved in the doctorate:

> *"I strongly believe that research at school was what moved me to have the courage to try the doctorate" (CR).*

Another differential of the TR and which is associated with the continuity of training is the academic production that it is generating (didactic materials, articles):

> "*These are opening paths, for example, CR passed the doctorate, the other residents who are finishing TR will try to get their master's degrees; and they certainly have a great chance of succeeding as all of this will add up" (BR)*.

In this way, TR stands out as a stimulus and real possibility to continue training:

> *"After you graduate and start working in teaching, it is difficult to reconcile continuing training with work" (CR).*

Regarding the limits of this experience and suggestions for a new edition, the following was pointed out: i) improve the experience in administrative-pedagogical sectors, with emphasis on insertion in teaching coordinations, which was not feasible; ii) excess of evaluative activities in the subjects organized in modules, which required a lot of time and effort, compromising immersion in other activities; and iii) different infrastructure and working conditions from the Application School, which does not match the reality of other public schools.

The mapping of the TR contributions made in this study shows the materialization of the five formative dimensions pointed out by Callian and Magalhães (2019): immersion, collaboration, authorship, reflection, and training through language. The experiences valued by the residents reaffirm the importance of the dimension of immersion, of on-site training. The experience of research at school and the didactic and academic production fostered by TR are linked to the dimensions of authorship, collaboration, training through language and reflection, reaffirming the teacher's identity as a producer of knowledge.

CONCLUSIONS

From the research, we apprehended that the central contribution of the TR was to provide the expansion and deepening of teacher education based on significant experiences involving: interdisciplinarity, collaborative work, field activities, inclusive education, and school research, which were constituted as meaningful experiences for both residents.

We believe that the Application School working conditions and pedagogical proposal, expressed in its Political Pedagogical Project, were fundamental to provide such experiences, highlighting the collective work projects, interdisciplinarity, and the school's growing commitment to inclusive education. On the other hand, Application School's differentiated infrastructure and working conditions, which places it in a very privileged position to other public schools in the country, constitute, according to the residents, as a training limit, since the practices held there that demand differentiated resources cannot be transposed, at least directly, to the other schools.

However, despite this reality, the TR meant for both of them the reaffirmation of their identity as teachers of basic education in the public system. Finally, it is important to highlight that the Teacher Residency Program has provided significant experiences also for us, supervisors, who had the opportunity to try new forms of teaching and collaborative work, to discuss and reflect on our practices and their implications.

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REFERENCES

Bardin, L. (1977). *L'Analyse de contenu* [Content analysis]. Paris, France: Presses Universitaires de France.

Callian, G.R. & Magalhães, T.G. (2019). Dimensões da formação docente no programa de formação continuada "Residência Docente" da UFJF: uma leitura inicial [Dimensions of teacher education in the continuing education program "Teacher Residency" at UFJF: an initial reading]. In: Magalhães, T. G.& Ferreira, C. S (Orgs.). *Oralidade, formação docente e ensino de língua portuguesa.* Araraquara: Letraria, 141-188.

Faria, J.B. & Diniz-pereira, J. E. (2019). Residência pedagógica: afinal, o que é isso? *R. Educ. Públ.* 28(68): 333-356.

Gatti, B. *et al*. (2019). *Professores do Brasil:* Novos cenários de formação [Teachers from Brazil: New training scenarios]. Brasília: UNESCO, 351p.

Gatti, B.A. (2012). Grupo Focal na Pesquisa em Ciências Sociais e Humanas. Brasília: Liber Livro.

Ibiapina, I. (2008). M.L.M. *Pesquisa Colaborativa:* Investigação, formação e produção de conhecimentos. Brasília: Liber livro Editora, 136 p.

Marcelo, C. (2009). Professional Development of Teachers: past and future. *Sísifo/Educational Science Journal*, (8):5-20.

Marcelo, C. & Vaillant, D. (2017). Políticas y programas de inducción en la docência en latinoamérica. *Cadernos de Pesquisa* 47(166): 1224-1249.

Nóvoa, A. (2019). Entre a formação e a profissão: ensaio sobre o modo como nos tornamos professores. *Currículo sem Fronteiras*, 19(1): 198-208.

Nóvoa, A. (2017). Firmar a posição como professor, afirmar a profissão docente. *Cadernos de Pesquisa*, 47(166): 1106-1133.

Zeichner, K. (2011). Teacher Education for Social Justice. In: Margaret R. Hawkins. *Social Justice Language Teacher Education*. Bristol: Blue Ridge Summit: Multilingual Matters, 7-22.

AFFORDANCES OF ONLINE PROFESSIONAL LEARNING

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In the United States, the Next Generation Science Standards (NGSS) include a focus on computational thinking. Similarly, The Framework for Science Education for Responsible Citizenship in the European Union emphasizes a shift from STEM to STEM. Both frameworks highlight the need for science education to mirror professional practice, which increasingly involves computing. As such, we focus on how elementary school teachers learned about computing in an online professional development.

Keywords: Teacher professional development, technology in education and training, science education

INTRODUCTION

Increasingly, professional scientific practice demands engagement with computer science, as evidenced by fields like computational biology, bioinformatics, and computational statistics. There is also a growing recognition that K-12 science education needs to reflect professional scientific practice more closely. In the United States, the Next Generation Science Standards explicitly identify computational thinking as key scientific practices for learners. Similarly, The Framework for Science Education for Responsible Citizenship in the EU identifies the need to integrate across STEM disciplines and to include the arts in science learning. For computational thinking to become a practice that is taken up in K-12 classrooms, teachers must understand what computational thinking is and how to integrate it within scientific practice. There is a real concern with how to train pre- and in-service teachers in computing, so they can engage and support students in computing in ways that mirror professional scientific practice. In this paper, we report on an asynchronous online professional development designed to assist upper elementary teachers in integrating computational thinking with science education concepts related to circuitry.

Asynchronous online professional development is one of the more promising possibilities to provide computer science and computational thinking training for pre- and in-service teachers (Fishman et al., 2013). Professional development offered in an online format has similar affordances to in-person professional development (Fishman et al., 2013), but also includes unique affordances not present in face-to-face professional development. Asynchronous online professional development allows teachers to skip, review, and complete material at their own pace, providing opportunities for coaching and expert support, greater content mastery, and reflection.

Background

Effective professional development has seven key characteristics (Darling- Hammond et al., 2017): It focuses on content, incorporates active learning, supports collaboration, uses models of effective practice, provides coaching and expert support, offers opportunities for feedback and reflection, and is of sustained duration. By providing professional development that is content focused, teacher learning is situated within their own classroom contexts. This is especially important for areas like science and computing where there is discipline-specific content and pedagogy that needs to be covered. Teachers also need opportunities, through active learning, to engage in the kinds of learning they will be engaging their students in, and to collaborate with one another and share ideas. Further, by providing models of effective lesson plans, teachers are able to clearly understand what best practices look like within a specific domain. Coaching and support is delivered one-on-one to focus on the needs of individual teachers within the professional development setting. This individualized support is augmented through opportunities for feedback and reflection, which help teachers to grasp a vision of what expert practice looks like within the specific disciplinary and curricular content. Finally, effective professional development must be sustained enough in duration that teachers have "adequate time to learn, practice, implement, and reflect upon new strategies that facilitate changes in their practice" (Darling-Hammond et al., 2017, p.vi).

In recent years, there has been a growth in the development and delivery of online professional development, especially during the COVID-19 pandemic, but more research is needed to understand the affordances of online professional learning in disciplinary contexts (Fishman et al., 2013). In this paper, we focus on the need for time for reflection and the provision of coaching and extra support in effective professional development. During conventional face-to-face professional development, coaching and extra support is available, but can be limited. Such individualized instruction may be limited because teachers receive all instruction as a group first, and facilitators regulate and schedule time for activities during the professional development. A need to get through large quantities of content and a constrained time frame may not allow for sufficient opportunities for individualized coaching and extra support or enough time for teachers to reflect on what they have learned sufficiently to know what they still do not understand.

METHODS

Context & Participants

The Elementary STEM Teaching Integrating Textiles and Computing Holistically (ESTITCH) professional development provides teachers (grades 3-6) with the skills and knowledge to carry out the ESTITCH curriculum within the classroom. Centered around the themes of immigration, migration, and forced relocation, the ESTITCH curriculum integrates computer science and computational thinking into existing science, social studies and language arts teaching standards through electronic textiles (e-textiles) projects. E-textiles combine craft materials and sewing practices with sewable, programmable electronic components, including a microcontroller and a variety of sensors and actuators.

Teachers had access to the ESTITCH online professional development in the Canvas learning management system for two months. The online course provided opportunities for content acquisition and pedagogical knowledge development, with participants making and programming each of the three e-textiles projects described below. Facilitators also offered office hours via Zoom, to provide additional support, particularly with troubleshooting and debugging e-textiles projects.

The e-textiles projects are carefully sequenced so that the skills developed in one project build to the next project. The first project was a programmable paper circuit timeline based on a work of children's literature included in the ESTITCH curriculum. The second was an e-textile quilt square that replicated quilt patterns used to assist formerly enslaved peoples navigating the Underground Railroad. Lastly, teachers created a programmable quilt square connected to a meaningful moment in their lives (see Figure 1).

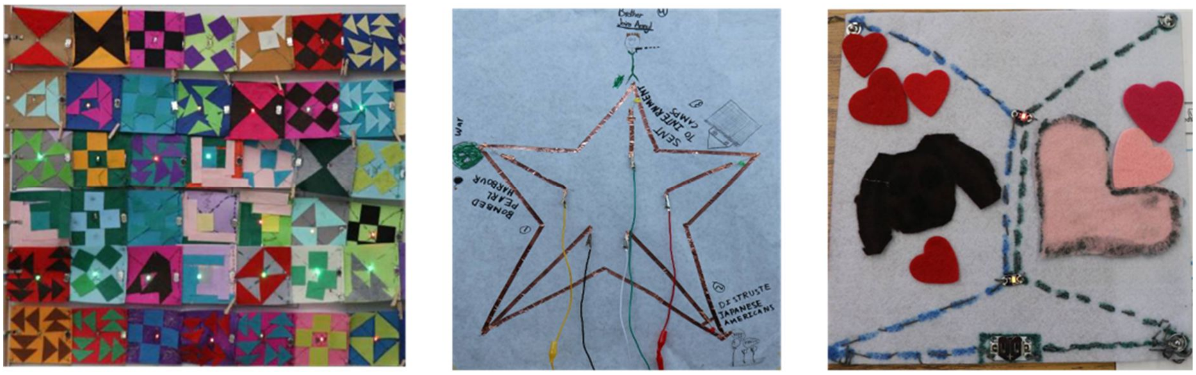

Figure 1. ESTITCH freedom quilt squares, paper circuit timeline, and meaningful moments projects.

Recruitment for the online professional development was conducted across the state of Utah. Of 27 teachers who enrolled in the professional development, 23 completed the training. Prior teaching experience ranged from no experience to several years of experience within the same grade. Notably, several of the teachers who signed up also taught in their native language in dual-language immersion programs. Teachers who participated in the professional development included native speaking Mandarin and Portuguese immersion program teachers.

Data Collection & Analysis

We performed exit interviews with each teacher to gather information about their expectations coming into the professional development, their experiences during the professional development, and how they thought professional development experiences would aid them with computer science and computational thinking instruction in the classroom. We also conducted a post-survey inquiring about teachers' experiences with the online professional development. For this paper, we focused on analysis of teacher reflective exit interviews concerning their experiences during the PD. We used emergent thematic coding to examine the interviews (Braun & Clarke, 2006; Nowell et al., 2017). First, we read the transcripts of all teacher interviews as a corpus of data, immersing ourselves in them as one might immerse themselves in a novel. Then, we went back and conducted an initial coding of the data, identifying important sections of the interview transcripts and labeling them. Through subsequent rounds of thematic coding, we refined our codes and identified patterns in our data. One set of codes dealt with the affordances of online professional development and we delve into those findings here.

FINDINGS

Our findings highlight the learning affordances provided to elementary teachers by the online asynchronous format. We found that the online asynchronous format provided time for coaching and extra support. Teachers utilized the online format in many ways to optimize their learning; however, our analysis revealed two affordances that are unique to the online asynchronous format: time and space to review material.

Time and Space to Review

Some teachers remarked that the online format of the professional development was difficult and that they would have preferred a face-to-face training. However, several teachers appreciated the online asynchronous format because it allowed differentiation in many ways. Because of the asynchronous nature of the professional development, teachers did not worry about keeping pace with other teachers, as they would have in a traditional professional development. Teachers also had sufficient time to review and master difficult content, as well as to reflect on their experiences to prepare for classroom implementation. One teacher commented:

> I really liked being able to kind of take my time to process it. 'Cause when in the face to face it, it was kind of a lot of information and stuff and packed into, you know, a few days. And I really liked being able to read the articles, mark 'em up, process it, think about. And I would even sometimes stop after the video and create something for my classroom, right from what I was learning. And, for back- for back when we go back to school, and then come back to it [the course material]…that was really powerful (Interview, 7/28/20).

The online asynchronous professional development afforded more time for teachers to review materials, work at their own pace, and even stop instruction and to work on creating artifacts for the classroom while instructions were still fresh. Teachers also leveraged the digital space to review other teachers' discussion posts. Posts by other teachers provided tricks for working with the e-textiles materials and provided a compendium of possible mistakes encountered by the teachere when working on their projects, mistakes likely to be encountered by students in the classroom.One teacher remarked:

> You know, some of [the projects] work, some of them don't work. And so, it was nice to just … read everybody's comments and stuff and that's why it doesn't work for students or, Oh, I understand. And so then when I went back and did some of the projects over, it works so much smoother, so I could like take it back to my students and say, this is what you need to do.

In this teacher's comment, we see how the online discussion forum provided an opportunity for reflection at the teacher's own pace but with the benefit of the group's collective wisdom about making the e-textiles projects in the ESTITCH curriculum. The online format allowed teachers to create a shared forum and stored all the common problems teachers encountered. This shared forum provided opportunities for reflection, as teachers were able to post, access, read, and find solutions to problems they were encountering. Teachers were able to access all the problems all other teachers encountered and the solutions, allowing teachers to more fully understand the computer science and circuitry content, to devise strategies to help students, and to prepare for teaching the ESTITCH curriculum in the classroom. Teachers even created new spaces outside of the PD to collaborate. For example, one teacher said, "So we just kinda did it together like that through texting or Face-timing each other and working through it and troubleshooting and stuff like that" (Interview, 07/24/20). In this way, teachers' participation in the online professional development was more sustained than it would have been in a one week, in-person professional development.

DISCUSSION

Online PD was able to provide comparable, and in some cases better experiences than in-person PDs, aligning with arguments some scholars make in favor of the online format (Fishman et al., 2013). According to teacher interviews, the ESTITCH online professional development was able to provide enhancements beyond a face-to-face professional development in relation to the seven aspects of effective professional development identified by Darling-Hammon and colleagues (2017). First, the online asynchronous format allowed teachers to delve deeply into the content of the ESTITCH curriculum, especially in areas they did not understand. Teachers were able to make and, in some cases, remake the three e-textiles projects in the ESTITCH curriculum until they solidly grasped the circuitry and computer science concepts involved. This was supported by the online discussion forums, which provided a compendium of possible problems and their solutions. These forums provided teachers opportunities to reflect not only on their own learning, but also on what might happen during classroom implementation. The asynchronous portion of the professional development provided the most affordances allowing teachers to pace their progress, and review professional development materials and community posts to gain greater mastery and understanding of computer science and science content and pedagogies. Additionally, the professional development allowed time for teachers to gain greater insights into troubles students my encounter, providing teachers with strategies effectively convey computer science principles and plan for classroom application. Despite not meeting in-person, teachers were able to create connections with other teachers and receive help from one another and facilitators when needed. In many cases, these interactions extended beyond the time bounds of a one-week, face-to-face professional development, contributing to the sustained duration of interactions.

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REFERENCES

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*, 77-101. DOI:10.1191/1478088706qp063oa

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

Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., & Edelson, D. C. (2013). Comparing the Impact of Online and Face-to-Face Professional Development in the Context of Curriculum Implementation. *Journal of Teacher Education*. https://doi.org/10.1177/0022487113494413

Gal-Ezer, J., & Stephenson, C. (2010). Computer science teacher preparation is critical. *ACM Inroads*. https://doi.org/10.1145/1721933.1721953

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Cambridge, MA: The MIT Press.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International Journal of Qualitative Methods*, *16*(1), 1-13. https://doi.org/10.1177/1609406917733847

COASTRO CITIZEN SCIENCE PROJECT: CONTRIBUTIONS TO TEACHING PRACTICES, ATTITUDES, AND BELIEFS TOWARDS SCIENCE

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Attitudes and beliefs towards science are key factors for changing teachers' professional practices. However, structuring teaching professional development practices, considering all these domains, is as challenging as making its effects reach students. To respond to these challenges, CoAstro: @n Astronomy Condo emerged. This citizen science project intended, among other aspects, to understand how changing teachers' attitudes and beliefs influenced their teaching practices and affected the school community. To this end, nine primary teachers, without initial science training, were engaged in astronomy research, led by five astronomers and also engaging five science communicators.

Individual interviews and a focus group were carried out. Teachers were asked about their attitudes and beliefs and how the project changed their practices and influenced the school community. Data analysis was made using data categories defined previously.

The CoAstro's results reveal that the teachers' engagement in astronomy research led to changes in their attitudes (interest and proactivity; understanding and use of scientific knowledge) and beliefs (about astronomers' work and the way science is built) towards astronomy. Those changes led to teaching practices modifications in terms of methodologies and resources used, and collaborative work with peers.

The CoAstro project allowed us to understand how participation in citizen science projects, and the appropriation of learning outcomes, can contribute to teachers' professional development, specifically related to their needs and the needs of their schools, impacting on the surrounding school community.

Keywords: Teaching Practices, Science Education

CONTEXT

The term citizen science (CS) refers to public engagement in different stages of scientific processes. CS can easily create a win-win context: it attracts more researchers to science communication and, on the other hand, allows the public to participate directly in scientific processes (Riesch & Potter, 2014).

In addition to the advantages of CS to scientific research, this method also has powerful educational and science communication outputs. Accomplishing science communication goals is, indeed, one of the most common purposes of citizen science, pointed out by scientists and citizen science project managers (Burgess et al., 2017). Indeed, the advantages of associating science communication and science education have long been known (Walker et al., 2018), namely through CS projects (Gray et al., 2012) helping to bridge the gap between scientific research and science education (Gilbert et al., 2011).

Thus, engaging teachers in CS processes is a natural path enhanced by the "school effect" and the "teacher effect" in students (Gilbert et al., 2011; Heafner, 2019), but also in their families and the surrounding school community. This multiplier effect of influences that the school allows is unique and highly positive. Therefore, it is in this synergistic context of science education, science communication, and scientific research in astronomy that CoAstro emerges.

COASTRO: @N ASTRONOMY CONDO

CoAstro is a citizen science project which, during one school year (2018/2019), had the participation of five astronomers (from the Instituto de Astrofísica e Ciências do Espaço – IA), nine primary school teachers, and five science communicators (these belonging to the Porto Planetarium – Ciência Viva Center – PP-CCV).

CoAstro was organized in two major stages: (i) the engagement of primary school teachers, with the Research Group on the "Origin and Evolution of Stars and Planets" at IA; (ii) the engagement of teachers, astronomers, and science communicators into astronomy education activities for the school community.

Teachers' engagement in astronomy research

In the first CoAstro stage, teachers could choose between two scientific projects: "Stars" and "Planets". The "Stars project" aimed to analyse standard stellar spectra to allow the determination of the composition of 57000 stars and the characterization of their brightness, using Data Release 2 from the European Space Agency (ESA) – GAIA Mission. Using Python's coding program, the "Planets project" aimed to develop a planetary transit video (a video as a planet passes in front of a star). That task was necessary to analyse of light curves to signal the presence of potential exoplanets: planets outside of the Solar System. The main features of the two scientific projects are summarized in figure 1.

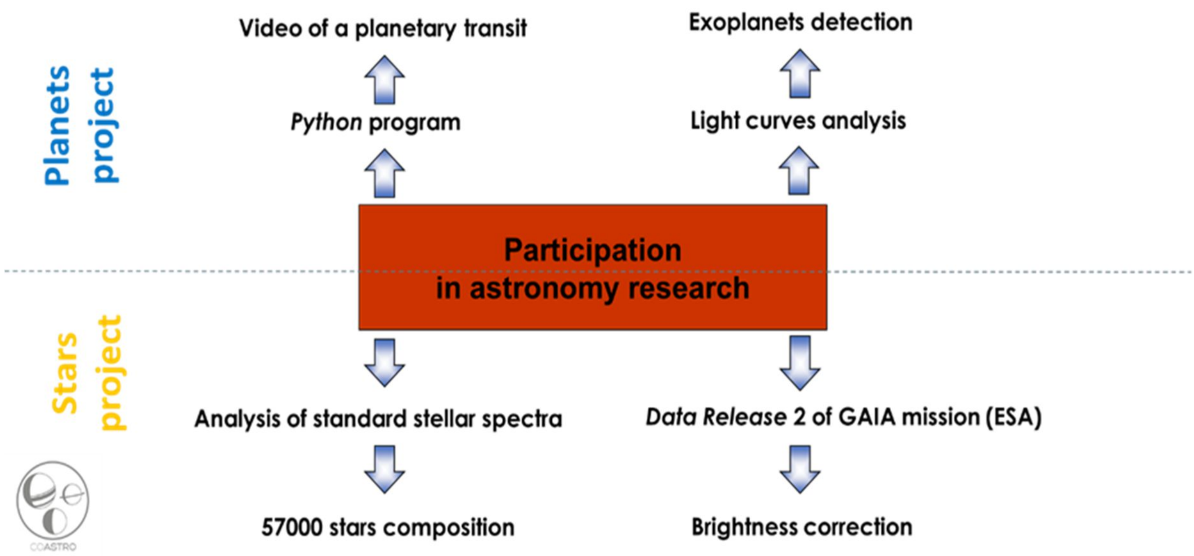

Figure 1. Astronomy research tasks.

This stage culminated with the presentation to the school community of the astronomy research results carried out with teachers' participation.

Astronomy education activities for the school community

This stage included astronomy education carried out in the school community (figure 2). It started with 25 hours of in-person teacher training, based on an extensive astronomy activities kit. This teacher training and all the work done in the first CoAstro's stage (2.1) allowed teachers to build astronomy education initiatives. So, starting from the specific context of their schools (it's potential and limitations), teachers freely devised a way to engage their school communities effectively. Astronomers and science communicators supported the implementation of these activities.

Figure 2. Examples of CoAstro´s educational activities.

METHODS

Considering that participant's attitudes toward science are an essential condition for understanding and engagement with science (Oliveira & Carvalho, 2015), we aimed to know the CoAstro teachers' knowledge (Costa et al., 2020), scientific attitudes, and beliefs (Costa, 2021), and understand how those aspects influenced teaching practices and affected the school community.

To do so, we conducted a qualitative investigation, specifically a case study with nine primary school teachers (eight females and one male, with an average age of 44.8 years), with no initial training in science.

We used an interview survey, document analysis, and participant observations (table 1).

Table 1 – CoAstro techniques and instruments of data collection.

Technique	Instrument	Data collected
Interview survey	Interview scripts	Attitude towards science and epistemological beliefs
Document analysis	Records produced by the participants	Type of activities carried out; their scope; target audience
Observation	Observation records (field notes)	Relevance of participating in CoAstro

We choose to e-mail the interview script and receive the answers the same way. Whenever necessary, the participants were contacted, by e-mail, to clarify doubts from the preliminary analysis. A focus group with all teachers followed the interview. Based on the interview objectives, an analysis framework was produced with categories and subcategories (table 2), from which the content analysis of the interviews was made.

Table 2 – Categorization structure of the interview.

Category	Subcategory
A. Teachers' attitudes towards science	A1. Interest and proactivity A2. Understanding and use of scientific knowledge
B. Teachers' epistemology beliefs	B1. Amoral B2. Creative B3. Developmental B4. Parsimonious B5. Testable B6. Unified
C. Teachers' educational practices	C1. Planning C2. Communication C3. Quality

	C4. Nature of the work C5. Coverage / scope C6. Effects
D. Effects on the school community	D1. Awareness of science D2. Enjoyment D3. Interest D4. Opinion

The following section summarizes the CoAstro´s main results in each analysis categories.

RESULTS

As a citizen science project, CoAstro had scientific research outputs. Indeed, we identified the teachers' contribution as a step in determining the composition of 57000 stars and the characterization of their brightness. We also identified teachers' contribution as a step to the validation and consequent publication, in Monthly Notices of the Royal Astronomical Society, of the first discovery and characterization of a planet identified by Planet Hunters TESS (a citizen science platform to detect exoplanets). However, in the present paper, we look to the CoAstro outputs on its second stage (the engagement of teachers, astronomers and, science communicators into astronomy education activities for the school community).

Despite the teachers' initial difficulties with the astronomy research tasks required, they were dazzled by the experience and relevance to their personal and professional development.

Regarding attitudes towards astronomy, we found that CoAstro played a very relevant role in promoting or expanding interest in this science to enhance its learning. Thus, the project contributed to awareness, pleasure, and interest in astronomy, albeit with varying degrees of depth. At the same time, the understanding and the usage of this science have increased. CoAstro reinforces the scientific belief in the: i) science creativity, interdisciplinarity, and amorality; ii) scientific knowledge validation process. So, in CoAstro attitudes and beliefs changed due to the teachers' engagement in astronomy research, but also due to the horizontal interpersonal relationships established and to the co-design of the project by the participants: astronomers decided the best way to engage teachers in astronomy research, and teachers decide the best way to use astronomers in their educational activities with the school community.

With CoAstro, there were changes in teaching practices in terms of methodologies, resources, and dynamics of collaborative work with peers. Indeed, teachers carry out astronomy education activities with their students (and other school community members) and beyond the curricular imperative and structure. Thus, teachers started to structure initiatives in an inquiry-based learning framework, which moved to an eminently interdisciplinary nature. They also promoted exhibitions and lectures. All those initiatives were clearly supported by the resources made available by astronomers and science communicators.

With other teachers, the increased motivation for the practices (because they better master the concepts and processes of astronomy) and the quality of those practices were evident and noticed by the students and led to a greater appreciation of their work by the school community. CoAstro stimulated collaborative work with teachers' peers.

So, CoAstro had huge educational effects on students, and all the school community. That in terms of awareness of science, and science enjoyment, interest, understanding and opinion.

CONCLUSION

CoAstro demonstrates the greater relevance that CS projects can have if they add educational goals in addition to the scientific goals. Indeed, schools are suitable environments to flow scientific results and processes with efficiency and agility. Thus, CoAstro contributed to: the school opening to families, but also to the families opening to school; scientific research and astronomy communication opening to lay public, but also for the public to be open to scientific research and science communication. CoAstro seems to stem last-longing public effects and reach audiences that would hardly ever be engaged with astronomy. What has just been described was made possible due to the participation of teachers in CS who, after changing attitudes and beliefs towards astronomy, changed their teaching practices and how they collaborate with their peers.

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REFERENCES

Burgess, H. K., DeBey, L., Froehlich, H., Schmidt, N., Theobald, E. J., Ettinger, A. K., HilleRisLambers, J., Tewksbury, J., & Parrish, J. K. (2017). The science of citizen science: exploring barriers to use as a primary research tool. *Biological Conservation, 208*, 113-120.

Costa, I. A., Morais, C., & Monteiro, M. J. (2020). CoAstro: @n Astronomy Condo - Development of teachers´ knowledge of astronomy through a citizen science project. International Technology, Education and Development Conference, Valencia.

Costa, I. A. M., Carla; Monteiro, Mário João (2021). CoAstro: @n Astronomy Condo – Teachers' Attitudes and Epistemological Beliefs towards Science in a Citizen Science Project. In M. Carmo (Ed.), *Education Applications & Developments VI - Advances in Education and Educational Trends Series* (pp. 66-75). inSciencePress.

Gilbert, J. K., Bulte, A. M., & Pilot, A. (2011). Concept development and transfer in context-based science education. *International Journal of Science Education, 33*, 817–837.

Gray, S. A., Nicosia, K., & Jordan, R. C. (2012). Lessons learned from citizen science in the classroom. *Democracy and Education, 20*(2), 14.

Heafner, T. L. (2019). Teacher effect model for impacting student achievement. In M. Khosrow-Pour (Ed.), *Pre-Service and In-Service Teacher Education: Concepts, Methodologies, Tools, and Applications* (pp. 433-449). IGI Global.

Oliveira, L. T. d., & Carvalho, A. (2015). Public Engagement with Science and Technology: contributos para a definição do conceito e a análise da sua aplicação no contexto português. *Observatorio (OBS*), 9*(3), 155-178.

Riesch, H., & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science, 23*(1), 107-120.

Walker, M., Nelson, J., Bradshaw, S., & Brown, C. (2018). *Teachers' engagement with research: What do we know? A research briefing*. https://educationendowmentfoundation.org.uk/public/files/Evaluation/Teachers_engagement_with_research_Research_Brief_JK.pdf

PCK OF PRE-SERVICE AND IN-SERVICE TEACHERS IN RELATION TO THE USE OF DRAWINGS

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The purpose of the study is to assess how the pedagogical content differs between pre-service teachers and in-service teachers. The drawings that teachers draw on the board to illustrate their interpretations in human biology lessons at the lower secondary level were analyzed. The respondents studied the professional illustrations and then redrew them as they would present them to the students and recorded their interpretation on video. The analysis showed that in-service teachers were more systematic in their interpretation, more likely to connect their speech to already acquired knowledge, and used fever terms. However, both groups of respondents have successfully transformed the original drawing into the suitable form. A difference between pre-service and in-service teachers was found in the interpretation, because pre-service teachers followed a text from a textbook to a great extent, while in-service teachers tried to explain the topic in their own words.

Keywords: pedagogical content knowledge, pre-service teacher education, training and development

THEORETICAL BACKGROUND

Pedagogical content knowledge

Future teachers' training focuses mainly on knowledge of the field of study and the competencies they need in their professional life. Pre-service teachers face two key questions throughout their studies in teacher training faculties: 'What to learn?' (the issue of selecting educational content) and 'How to teach?' (problem of transferring subject content, use of teaching methods and forms, etc.). The second question concerns the choice of curriculum, especially form and level of knowledge transformation, and is still in the interest of didactics, researchers, and teachers. In this case, we can talk about the so-called pedagogical content knowledge (PCK).

Shulman (1987) defined PCK as a special form of content knowledge that goes beyond knowledge of a given subject to the level of curriculum knowledge. PCK is a connection between content-related knowledge and pedagogy and is actually a level to which the teacher understands how individual topics are organized, represented, and adapted with respect to different levels of knowledge, skills, and interests of students (Shulman 1987, p. 8). Magnusson et al. (1999) expanded Shulman's definition of PCK and defined four basic components: 1) goals for teaching the topic, 2) level of understanding of the topic by students, 3) teaching strategies chosen for teaching the topic, and 4) ways to assess whether students understand the topic. These components are universal and appear in the professional pedagogical literature, and are often mentioned in the training of future teachers as well (Berendsen & Henze, 2019).

Pedagogical content knowledge (PCK) develops over time and through experience. Teachers learn how to teach specific content in particular ways to improve student understanding and enable them to acquire knowledge and key competencies (Loughran, Berry & Mulhall, 2012).

Concerns have emerged in European countries, as well as in the United States, whether the training of pre-service teachers and in-service teachers' professional development are able to successfully prepare teachers with the good pedagogical content knowledge they would need to improve their own teaching practices (Gess-Newsome et al., 2011). Researchers and educational policy makers agree that a higher level of PCK leads to quality teaching, which improves student outcomes (Baumert et al. 2010; Schmidt et al., 2007). Therefore, teacher training in many countries has started to focus mainly on developing an understanding of pedagogical content, and a large number of studies have also addressed this issue. However, few studies have examined how PCK directly affects teacher teaching activities (Barendsen & Henze, 2019).

Drawings and their use in teaching

Drawing can be understood as a tool that is suitable for creating personal knowledge, especially through creative problem solving (Rybska, 2016). Drawing is also important from the point of view of science, which requires data recording, so that it is possible to obtain an overview and formulas (Katz, 2017). Drawing itself can often be more comprehensible and effective than long verbal descriptions (Katz, 2017), and in many cases drawing can be used as a suitable alternative to verbal expression (Patrick & Tunnicliffe, 2010).

In the literature, we encounter five reasons why drawing should be recognized in addition to writing, reading, and speaking as a key element in science education: 1) drawing increases student involvement; 2) drawing develops visual literacy and helps to create new and at the same time support current knowledge; 3) comprehension is often associated with visual models; 4) drawing can be considered as an effective learning strategy that helps to organize students' knowledge and understanding; 5) thanks to drawing, students are able to think in a clear and concrete way, and they are able to better exchange and clarify meanings between peers (Ainsworth, Prain & Tytler, 2011, 2011). Drawings are often used in teaching as a supplement to oral interpretation; however, their processing is also influenced by the level of teacher's pedagogical content knowledge.

METHODOLOGY

Aim and research question

The aim was to assess the extent to which respondents were able to create a simplified version of the complex professional illustrations intended for eighth graders. Differences were observed between pre-service teachers who have only minimal experience in practice but were familiar with detailed and up-to-date knowledge in the field of human biology, and in-service teachers who have experience with didactic transformation from their teaching. The research question was 'How does knowledge of pedagogical content differ with respect to the use of drawings in human biology lessons between pre-service and in-service teachers?' Differences in the drawings were also analyzed.

Sample and data collection

There were 22 pre-service biology teachers (19 women, 3 men) in the master's study program focused on biology education and four in-service biology teachers (only women) with different lengths of practice (teacher 1: 4 years; teacher 2: 5 years; teacher 3: 11 years; teacher 4: 24 years). Ten illustrations selected for drawing were taken from textbooks of medical physiology, somatology, and functional anatomy. Specifically, we used illustrations representing the structure of the heart, tooth, spinal cord, kidney, neuron, ear, eye, skin, bone, and reflex arc.

Each student received selected illustrations retrieved from professional publications and tried to transform them appropriately into a form corresponding to the cognitive level of eighth graders. Due to covid-19 lockdown, data collection was not carried out in the form of inspections in the classes, but in an alternative on-line way. Based on the detailed instructions, the respondents recorded their interpretations and sent them to the researchers together with the scanned drawings.

Data analysis

The data obtained were evaluated using specific criteria established in advance. First, the drawings were analyzed from a content point of view. It was observed which concepts are drawn and described in comparison to the original illustration, whether some concepts were included in addition, or whether some concepts were missing. The respondent's interpretation itself was also evaluated. We focused on specific aspects of the interpretations of the respondents with stress put in professional terms. Finally, we also observed whether the respondent mentioned the functionality of a given part of the human body in the interpretation. The analysis was carried out by two independent researchers. Subsequently, their conclusions were compared, and in case there was not a consensus, another person, a biology didactic, who was not directly involved in the research was invited.

Although we have already evaluated all the drawings, we decided to present only one selected drawing, namely the drawing of the heart.

RESULTS

The first step was a simplified analysis of five selected textbooks that are used in human biology teaching in Czech schools (Tab. 1). According to predetermined criteria, it was monitored whether they contained selected illustrations, how they are processed and presented, concepts related to them, etc. This analysis was also essential to compare how respondents follow the text of the textbooks in their interpretation.

Figure 1 shows the structure of the human heart. This illustration was taken from a script for university students (Machová, 2006) and used to investigate the level of didactic transformation of pre-service and in-service teachers.

Table 1. Results of the simplified analysis of five textbooks.

Drawn and described sections of the heart	Selected textbooks				
	1	2	3	4	5
Superior vena cava	yes	yes	yes	yes	yes
Inferior vena cava	yes	yes	yes	yes	yes
Aorta	yes	yes	no	yes	yes
Pulmonary artery	no	yes	yes	yes	yes
Right atrium	yes	yes	no	yes	yes
Right ventricle	yes	yes	no	yes	yes
Left atrium	yes	yes	no	yes	yes
Left ventricle	yes	yes	no	yes	yes
Pulmonary veins	yes	yes	no	yes	no
Pulmonary valve	no	yes	no	yes	yes
Tricuspid valve	no	yes	no	yes	yes
Mitral valve	no	yes	no	yes	yes
Aortic arches	yes	no	yes	no	no
Septum	yes	yes	no	no	no
Pericardium	yes	no	no	no	no
Coronary veins	no	no	yes	no	no
Coronary arteries	no	no	yes	no	no

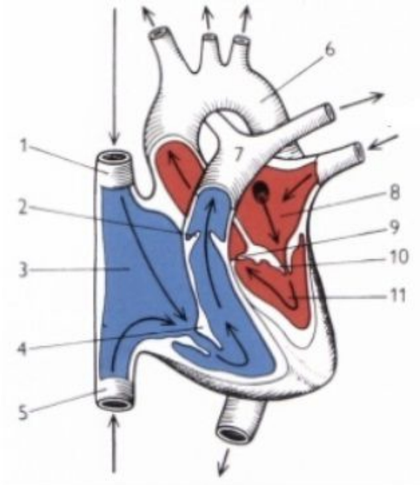

Figure 1. Original illustration retrieved from script for university students (Machová, 2006).

Legend: number 1 – 5 represent selected textbooks of human biology for lower secondary school: **1:** Černík, Martinec & Vodová (2015, p. 28, fig. 40); **2:** Navrátil & Ševčík (2017, p. 37, fig. 4.5); **3:** Dobroruka et al. (2010, p. 101, fig. unnumbered); **4:** Žídková et al. (2018, p. 43, fig. 23); **5:** Vaněčková (2007, p. 69, fig. unnumbered).

Only one pre-service teacher chose a black and white drawing, and she shaded part of the heart with oxygenated blood (Fig. 2). When discussing the created drawings, this method was described as rather confusing. All other respondents used the traditionally used representation of oxygenated blood with red and blood without oxygen with blue.

The realization itself was interesting, too (Tab. 2), three of the pre-service teachers drew the picture in advance and then commented it, and one pre-service teacher tried to interpret and describe the picture at the same time.

Table 2. General aspects of pre-service teachers' (S) and in-service teachers' (T) drawings and interpretations.

Student / Teacher	Colors	Processing of drawing	Used captions (number)	Correctness	Length of interpretation
S1	yes	parallel with interpretation	yes (5)	yes	1:57
S2	yes	drawn beforehand	yes (14)	no	2:14
S3	yes	drawn beforehand	yes (12)	no	2:30
S4	no	drawn beforehand	yes (14)	yes	3:26
T1	yes	preprinted	yes (9)	yes	5:26
T2	yes	preprinted	yes (9)	yes	1:31
T3	yes	parallel with interpretation	yes (9)	yes	6:55
T4	yes	parallel with interpretation	no (0)	yes	4:12

It is a little surprising that three of four in-service teachers used pre-printed or projected illustrations (Fig. 4). During the discussion, the teachers stated that they normally do it because they have more time to better clarify the function and structure of the heart. One of the in-service teachers (T2) had labels directly on the pre-printed picture. According to her opinion, students cannot take notes from her speech. Teacher 1 gave the students a pre-printed picture, but it contained numbers, which were preceded by captions, which were also written by the teacher. In the end, the pupils should color the illustration with red (part with oxygenated blood) and blue (part with non-oxygenated blood) colors.

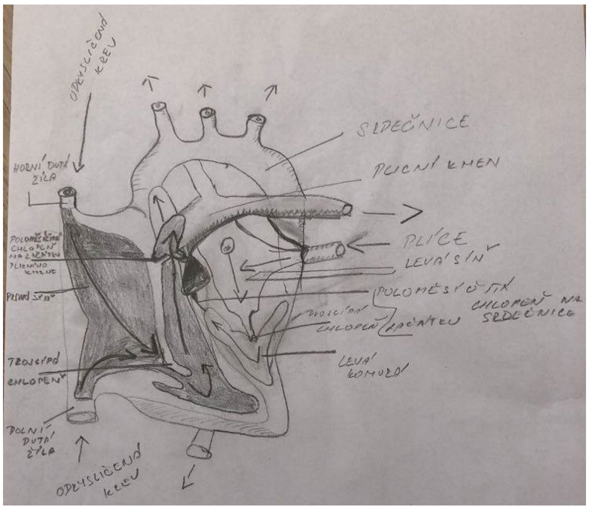

Figure 2. Drawing performed by pre-service teacher (S4).

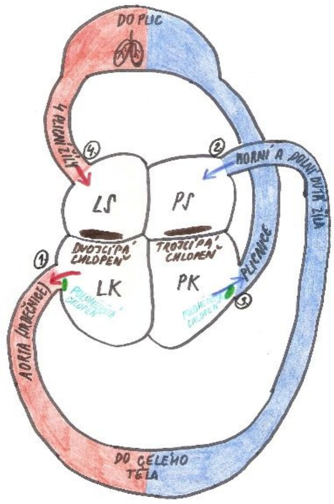

Figure 3. Drawing performed by the pre-service teacher (S3)[17].

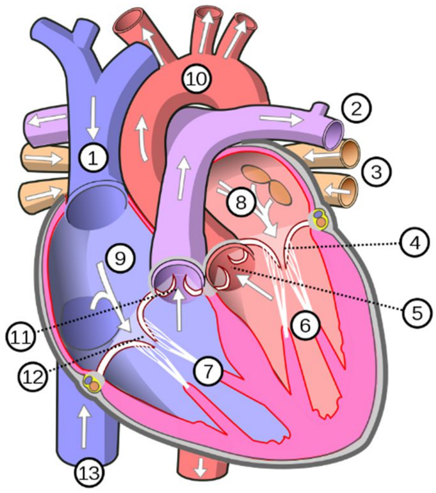

Figure 4. Preprinted illustration used by in-service teacher (T1)[18]

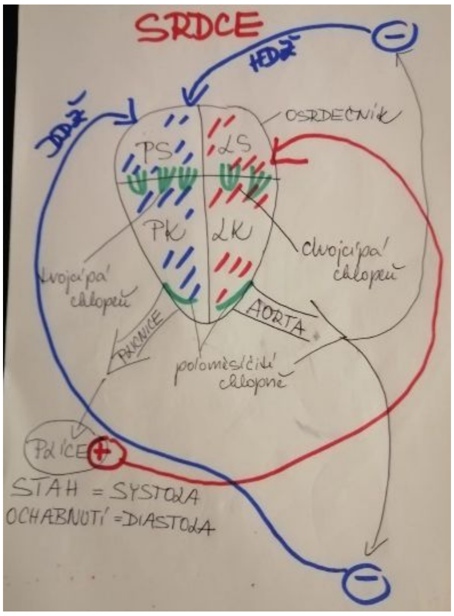

Figure 5. Drawing performed by the in-service teacher (T3)[1]

In terms of assessing the correctness of the drawing and interpretation, it was found that two pre-service teachers had side-flipped drawings (Fig. 3). They forgot about the so-called anatomical position of the human body, so they determined the left part of the heart as the right part and vice versa. Teacher 1 notified this fact in her interpretation, and she also added

[17] The letters used in the picture are Czech abbreviations for the following parts of the human heart: LS – left atrium, PS – right atrium, LK – left ventricle, PK – right ventricle

[18] Retrived from Wikimedia Commons (https://commons.wikimedia.org/w/index.php?curid=1399394; CC BY-SA 3.0, author MesserWoland).

mnemonics to remember the difference between ventricles and chambers. Teacher 3 supplemented her interpretation by diastole and systole, including an explanation of their principle and the connection with heart activity (Fig. 5).

All in-service teachers explained the function of the valves, only one of the pre-service teachers did so, and the rest of pre-service teachers mentioned the valves in their interpretation without explanation of their purpose. When compared to the text of the textbooks, it was found that pre-service teachers strongly followed the text from one of the textbooks (in some cases almost literally), while the in-service teacher formulated the interpretation according to themselves. All respondents used a comparison of heart size with a clenched fist. In general, pre-service teachers also used a greater number of terms than in-service teachers. During discussion about number of terms pre-service used argument that they learnt these terms too. In-service teachers tried to describe some professional terms in other words, not to introduce another new term or to liken it to other knowledge that students already had.

Table 3 compares the drawings created with the original illustration in relation to the concepts drawn and described. The pre-service teacher (S1) drew and described only a small part of the descriptions in the scheme of the construction of the heart, but all the basic terms were mentioned in his interpretation.

Table 3. Detailed analysis of heart structure drawings – terms described in comparison with the original illustration (see Fig. 1).

Drawn and described sections of the heart	Author of the drawing							
	S1	S2	S3	S4	T1	T2	T3	T4
Superior vena cava	no	yes	yes	yes	yes	yes	yes	no
Inferior vena cava	no	yes	yes	yes	yes	yes	yes	no
Aorta	no	yes	yes	yes	yes	yes	yes	no
Pulmonary artery	no	yes	yes	yes	yes	yes	yes	no
Right atrium	yes	yes	yes	yes	yes	yes	yes	no
Left atrium	yes	yes	yes	yes	yes	yes	yes	no
Left ventricle	yes	yes	yes	yes	yes	yes	yes	no
Pulmonary valve	no	yes	yes	yes	yes	no	yes	no
Mitral valve	no	yes	yes	yes	yes	no	yes	no
Tricuspid valve	no	yes	yes	yes	yes	no	yes	no
Extra terms (in comparison to the labels in the original illustration):								
Right ventricle	yes	yes	no	yes	yes	yes	yes	no
Pulmonary veins	no	yes	no	yes	yes	no	no	no
Septum	no	yes	yes	yes	no	yes	no	no
Pericardium	no	yes	yes	yes	no	no	yes	no

The term septum appears in the interpretation of one in-service teacher (T2), although in her drawing there was no description; in a similar way a pericardium can be registered in the interpretation of an in-service teacher (T3) and three pre-service teachers (S2, S3, and S4). The pre-service teacher (S3) did not include the description of the right ventricle and pulmonary veins, although both terms were mentioned in the explanation. This confirms a strong analogy with the original illustration of the heart structure taken from Machová (2016), where these sections of the human heart also miss.

CONCLUSION AND DISCUSSION

It is not surprising that teachers generally proceeded systematically in their interpretation, more related their interpretation to what students should already know, and more explained the function of individual parts of the human heart. Pre-service teachers very often followed the text in the textbook, while in-service teachers interpreted the content in their own words.

If pre-service teachers should acquire an appropriate level of PCK, they need the assistance of a supervisor during their training at university, but especially during pedagogical practice in schools (Halim et al., 2010). One of the possible ways to develop PCK is the implementation of action research, in which the pre-service teacher would cooperate with a didactic and especially with an in-service teacher (Halim et al., 2010). Such supervision, however, must be carried out by experts who are able to reflect on different teaching styles and think critically about the content, but also about the pedagogical dimension (Jordan, Phillips & Brown, 2004). As part of the pedagogical practice of pre-service teachers, feedback should be provided immediately after the lesson, preferably from an expert from the university as well as a teacher from practice. If feedback is to be relevant and promote the understanding of the nature of PCK in pre-service teachers, it is essential that supervisors themselves are able to reflect their abilities (Feldman, 2005).

It can be said that all the respondents did successful didactic transformations of the illustration that they adapted to the age of the pupils. However, the content part deserves greater simplification, especially for pre-service teachers. It turned out that their interpretation contained a large number of terms. In-service teachers reduced this number and generally used fewer terms. It should not be forgotten that two pre-service teachers made a fundamental mistake in their drawings, which could lead to the development of misconceptions about students in the future.

According to Bektaş (2015), some pre-service teachers had fixed misconceptions related to the content of the subject and mainly did not have sufficient knowledge in relation to the pedagogical component, i.e., they do not know the appropriate methods and forms of teaching or methods of assessment. Pre-service teachers subsequently stated that they prefer to use traditional methods and forms of teaching to overcome this lack of experience in teaching specific topics (Bektaş, 2015). Of course, errors related to the field content are a problem, but the lack of pedagogical skills is a major obstacle for the future teaching profession and especially for the application of innovative approaches.

As already mentioned in the theoretical background, there are studies that show that there is a correlation between the PCK of the teacher and the effectiveness of his teaching and the student results. For this reason, it is necessary to focus on PCK and include it as an essential component of pre-service teacher education programs, as well as professional development programs, in order to prepare teachers more effectively (van Driel & Berry, 2019; Schmelzing et al., 2013).

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REFERENCES

Ainsworth, S., Prain, V., & Tytler, R. (2011). *Drawing to Learn in Science*. *Science*, *333*(6046), 1096–1097. https://doi.org/10.1126/science.1204153

Barendsen, E., & Henze, I. (2019). Relating Teacher PCK and Teacher Practice Using Classroom Observation. *Research in Science Education*, *49*, 1141–1175. https://doi.org/10.1007/s11165-017-9637-z

Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., Klusmann, U., Tsai, Y. M. et al. (2010). Teachers' mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal*, *47*, 133–180. https://doi.org/10.3102/0002831209345157

Bektaş, O. (2015). Pre-service Science Teachers' Pedagogical Content Knowledge in the Physics, Chemistry, and Biology Topics. *European Journal of Physics Education*, *6*(2), 41–53.

Černík, V., Martinec, Z., & Vodová, V. (2015). *Přírodopis 8: biologie člověka pro základní školy* [Biology 8: Human biology for primary schools]. SPN.

Dobroruka, L. J., Vacková, B., Králová, R., & Bartoš, P. (2010). *Přírodopis III pro 8. ročník základní školy* [Biology III for 8th grade of primary school]. Scientia.

Feldman, A. (2005). *Enhancing the practice of physics teachers: Mechanisms for the generation and sharing of knowledge and understanding in collaborative action research*. Research report. University of Massachusetts Amherst.

Gericke, N., Hudson, B., Olin-Scheller, Ch., & Stolare, M. (2018). Powerful knowledge, transformations and the need for empirical studies across school subjects. *London Review of Education, 16*(3), 428–444. http://dx.doi.org/10.18546/LRE.16.3.06

Gess-Newsome, J., Cardenas, S., Austin, B. A., Carlson, J., Gardner, A. L., Stuhlsatz, M. A. M., Wilson, C. D. et al. (2011, April). *Impact of educative materials and transformative professional development on teachers' PCK, practice, and student achievement*. Paper presented at the NARST Annual Meeting, Orlando.

Halim, L., Meerah, T. S. M., & Buang, N. A. (2010). Developing pre-service science teachers' pedagogical content knowledge through action research. *Procedia Social and Behavioral Sciences*, *9*, 507–511

Jordan, P., Phillips, M. & Brown, E. (2004). We train teachers: Why not supervisors and mentors? *Physical Educator*, *61*(4), 219–221

Kansanen, P., & Meri, M. (1999). The didactic relation in the teaching – studying – learning process. In B. Hudson, F. Buchberger, P. Kansanen, & H. Seel, H. (Eds.), *Didaktik/Fachdidaktik as Science(-s) of the Teaching Profession?* (pp. 107–116). Thematic Network on Teacher Education in Europe.

Katz, P. (2017). *Drawing for Science Education: An International Perspective*. Sense Publishers.

Klafki, W. (1997). Kritisk-konstruktiv didaktik. In M. Uljens (Ed.), *Didaktik: Teori, reflektion och praktik* (pp. 215–228). Studentlitteratur.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and Developing Science Teachers' Pedagogical Content Knowledge*. Sense Publishers, https://doi.org/10.1007/978-94-6091-821-6_2

Machová, J. (2016). *Biologie člověka pro učitele* [Human biology for teachers]. Charles University in Prague.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Kluwer.

Navrátil, M., & Ševčík, D. (2017). *Přírodopis 8: Biologie člověka pro 8. ročník* [Biology 8: Human biology for 8th grade]. Prodos.

Patrick, P. G., & Tunnicliffe, S. D. (2010). Science teachers' drawings of what is inside the human body. *Journal of Biological Education, 44*(2), 81–87. https://doi.org/10.1080/00219266.2010.9656198

Rybska, E. (2016). A model for conceptualizing drawing as a teaching-learning activity in biology education. *Edukacja Biologiczna, Środowiskowa*, *58*(1), 74–81.

Schmelzing, S., van Driel, J., Jüttner, M., Brandenbusch, S., Sandmann, A., & Neuhaus, B. J. (2013). Development, evaluation, and validation of a paper-and-pencil test for measuring two components of biology teachers' pedagogical content knowledge concerning the "cardiovascular system". *International Journal of Science and Mathematics Education*, *11*, 1369–1390. https://doi.org/10.1007/s10763-012-9384-6

Schmidt, W. H., Tatto, M. T., Bankov, K., Blömeke, S., Cedillo, T., Cogan, L., Schwille, J. et al. (2007). *The preparation gap: Teacher education for middle school mathematics in six countries. MT21 report*. Michigan State University.

Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–23.

van Driel, J., & Berry, A. (2019). Pedagogical content knowledge in preservice teacher education. In M. A. Peters (Ed.), Encyclopedia of Teacher Education Springer. https://doi.org/10.1007/978-981-13-1179-6_176-1

Vanečková, I. (2007). *Přírodopis 8 pro základní školy a víceletá gymnázia* [Biology 8 for 8th grade of primary school and lower-level of grammar school]. Fraus.

Žídková, H., Knůrová, K., & Karešová, P. et al. (2018). *Hravý přírodopis 8 pro 8. ročník ZŠ a víceletá gymnázia* [Playful biology 8 for 8th grade of primary school and lower-level of grammar school]. Taktik.

FOSTERING SELF-EFFICACY: ASTRONOMY EDUCATION PROFESSIONAL DEVELOPMENT

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In this qualitative study, we report on the effects an astronomy education professional development had on teachers' self-efficacy and confidence in teaching astronomy content. The data presented here is a subset of a larger dataset. Five in-service teachers participated in the 2019 iteration of the program. The data informing this paper stem from daily reflections, observations, focus group discussions, participants' presentations, and open responses from the follow-up survey; analysis followed a thematic process. The results show that while the participants initially felt a lack of confidence in teaching challenging astronomy content, the professional development program succeeded in enhancing teachers' self-efficacy in terms of content knowledge, including increased confidence to teach astronomy in schools.

Keywords: astronomy education, teachers' professional development, self-efficacy

INTRODUCTION

The interdisciplinary nature of astronomy comprises various cognitive processes, including spatial reasoning, imagination, and visualization (Eriksson, 2019), making it an intriguing area to study (Ampartzaki & Kalogiannakis, 2016). Students learn astronomy through an integrated STEM approach, including developing critical and computational thinking, handling complexity, and improving technical skills. Learning astronomy requires teachers' preparation and proper training (Panou & Violetis, 2018). Hence teaching astronomy courses out-of-field is the norm (Mizzi, 2013). Astronomy contents are not often the focus of teacher professional development (TPD) and certification (Brunsell & Marcks 2005; Bailey, Lombardi, Cordova, & Sinatra, 2017). Chastenay (2018) noted that lack of training and feeling incompetent to teach astronomy are the foremost reasons for encountering limitations and unwillingness to teach K-12 astronomy. The sense of less confidence to teach comes from unfamiliarity with concepts and difficulties in teaching the complex contents. Teachers who lack content knowledge are less likely to have strong self-efficacy beliefs, more likely to encourage students to memorize factoids, and may inadvertently promote alternative conceptions (Danaia & McKinnon 2007; Sadler, Coyle, Miller, Cook-Smith, Dussault, & Gould, 2010; Bailey et al., 2017). Teachers prepare students for the future; empowering them with content knowledge could translate to better-prepared students and make them enthusiastic about studying and contributing to the advancement of astronomy (Frost, 2012; Panou & Violetis, 2018).

This paper describes how a TPD focused on astronomy education impacted in-service teachers' self-efficacy. Specifically, the TPD presented here is organized for the science teachers to equip with tools and resources to have a comprehensive and applicable understanding of scientific contents and influence them to improve their practice.

Research Question

What are the in-service teachers' perceptions of self-efficacy related to an astronomy education professional development program?

THEORETICAL FRAMEWORK

This study is grounded in Bandura's work on self-efficacy (1977), defined as an individual's belief in their capacity to organize and execute the required action to achieve certain goals. Teachers' self-efficacy is their belief in planning, designing, and implementing lessons to accomplish desired learning outcomes (Skaalvik, & Skaalvik, 2010; Brígido, Borrachero, Bermejo, & Mellado, 2013). Catalano and Durkin (2019) stated that teachers with high self-efficacy could implement effective strategies, commit more to the profession, and be less likely to burn out. Self-efficacy is an essential factor for teaching, positively impacting students' achievement and behavior (Yoo, 2016). In addition, self-efficacy increases teachers' ability to make decisions and empowers them as leaders who positively influence students (Runhaar, Sanders, & Yang, 2010). Confidence includes self-efficacy as a determinant and refers to the belief that one can do what has to be done. Therefore, self-efficacy works as a stimulus to achieve the goal, attempt greater responsibilities, and fulfill the cognitive demand to increase confidence (Brígido et al., 2013; Komarraju & Nadler, 2013).

Brigido et al. (2013) reveals a significant relationship between science teachers' self-efficacy and the subject matter they teach. Science teachers who lack confidence and are anxious to teach complex science content experience low self-efficacy. On the other side, teachers educated with proper science content and teaching skills have a high level of self-efficacy (Catalano & Durkin, 2019). Yoo (2016) informed that gaining new knowledge is positively associated with enhancing teachers' efficacy. TPD is a process of improving the quality of teachers' teaching by increasing their professional confidence, sense of self-efficacy and enhancing leadership quality to reform the education system (Frost, 2012; Lumpe, Czerniak, Haney, & Beltyukova, 2012). TPD increases teachers' self-efficacy beliefs, a driving factor for the teaching practice (Peters-Burton et al., 2015). Lumpe et al. (2012) assert that TPD enhances teachers' self-efficacy significantly and positively correlates with students' attainment.

METHODOLOGY

This paper is based on qualitative data, specifically from in-service teachers, to explore and understand a central phenomenon: self-efficacy. The cohort of in-service teachers is considered a case; through a thematic analytic process, the researchers sought a holistic view and an in-depth understanding of phenomena (Braun & Clarke, 2006; Creswell, 2014). Data stem from essays, reflections, observations, focus group interviews (FGI), participants' presentations, and open responses to a follow-up survey. After transcription, data were iteratively coded in NVivo, identifying and analyzing the emerging themes.

Context

The 2-week astronomy education TPD was organized by the College of Education and Human Development and College of Science at the University of Texas, San Antonio, and incorporated NASA's Universe of Learning (UoL) content. The TPD included Subject Matter Experts

(SMEs) presentations (astrophysics, space exploration, ground and space telescopes, and the Future of Astronomy), hands-on activities, MicroObservatory (online sessions), field trips (McDonald Observatory, Scobee Education Center, and Witte Museum), Science Olympiad, and final presentations by participants.

Participants

Five of the participants were in-service teachers (three female; two male) from three different school districts serving students from diverse backgrounds. Their backgrounds are briefly described here, using pseudonyms for anonymity. STN, a biology major with 24 years of teaching experience, volunteered to teach astronomy and found astronomy to be a challenging subject matter. APS realized that she wanted to know more about astronomy and actively sought opportunities to add to her knowledge base. SAI was a novice teacher looking for opportunities to develop his astronomy teaching skills. NET, an elementary teacher, did not have previous experience teaching astronomy content and expressed a lack of confidence in understanding and teaching scientific concepts. She was dedicated to expanding her knowledge and translating what she learned into engaging lessons. TSJ had earned a biology degree but enjoyed being a physics teacher; he wanted to instill curiosity about astronomy in his students.

FINDINGS AND ANALYSIS

Motivations for Participation and Expectations

As part of the application process, teachers submitted an essay on how participation in the TPD would help them improve their teaching. Although not explicitly required to be reflective writings, in essence, these essays were written as such. Three of the five teachers mentioned difficulties with understanding and teaching astronomy content, including inadequate knowledge, which leads two of the teachers' lack of confidence and identified astronomy as a challenging topic to teach. However, two of them noted a deep desire and need for opportunities to expand their knowledge and skill. The teachers' responses revealed the causes behind feeling a lack of confidence to teach the astronomy content and their keen interest in improving their skills, which led them to apply in the workshop.

Acquisition of Knowledge and Gaining Confidence

Generally, participants noted that the content did not overwhelm them, and they were interested in learning more about astronomy. After sessions on stars and exoplanets, a participant wrote, "I have to say I do have a better understanding of the stars and their life cycle, how the planets formed, and general information about the galaxies." The participants mentioned how embedded visualizations and hands-on experiences helped them understand even more abstract content. As one participant put it, "Hands-on lessons help get a grasp on content knowledge, and you can see and hear other peoples' views. That is where the learning occurs because you will probably pick up an idea that you would not have thought of." As a specific example, although none of the teachers were familiar with the workings and differences between telescopes at the beginning of the TPD, they found learning about them interesting. One noted, "You got to see the logic behind why telescopes like those are constructed the way they are.

Because you got to explore each lens and what it does, individually first before putting it together."

Before the field trip to the McDonald Observatory, the participants were asked to write about their expectations. Their responses reflected their keen interest in seeing how the big telescopes work, how astronomers use the telescope to collect information, and how the night sky looks in an area without light pollution. The participants found the visit useful as they came to better understand the scientific underpinnings of telescopes and noted that they would take the new insights to their classrooms where the concept could be applied for both physics and astronomy. After a planetarium visit, teachers mentioned that they understood the night sky better. A participant wrote, "I understood a little bit more about the constellations since it was more visual, and that's more of my learning style." The stargazing history of ancient people similarly helped the teachers to understand astronomy as part of the human experience. As one of them noted, the visit to the museum helped recognize "Science is an evolving process," and this was a lens she would now share with students. In summary, after each part of the TPD, the teachers expressed growing confidence in understanding astronomy and in their ability to teach it.

Difficulties in Understanding Some Content

Dark Matter was a challenging topic for the teachers. They sought to understand the difference between dark and ordinary matter and encountered hurdles plotting associated data as a part of the activity. Three of the in-service teachers found this discussion conceptually difficult and expressed a sense of anxiety and frustration. One of them mentioned that not having a background in physics and astronomy caused substantive difficulties in making meaningful connections on this topic.

Teachers' Post-workshop Perceptions

Participants had to present their takeaways from the TPD in a presentation session. Two in-service teachers highlighted the in-depth understanding they acquired related to how telescopes work in their final presentations. In the follow-up survey, teachers were asked to write briefly about how their participation in the program might influence their future teaching. Three of the five teachers noted that they felt prepared content-wise to teach astronomy, and two of them stated they saw the benefit in their access resources, human and material, through the workshop. These responses stand in direct contrast to their perceived ability to teach astronomy before participating in the workshop.

DISCUSSION AND CONCLUSION

In-depth Knowledge

As evidenced in daily reflections and discussions, the teachers began the TPD with a tentative understanding of astronomy content and became more cognizant of each day. Before the TPD, they felt that their content knowledge was inadequate; the literature recognizes this and links it to teachers feeling intimidated, leading to instruction heavily reliant on memorization (Brunsell & Marcks, 2005; Bailey et al., 2017). Throughout the two weeks of the TPD, teachers increasingly made the science and the language of the field their own. By the time they presented on the last day, they had talked about astronomy and astronomy teaching confidently.

The findings are associated with the literature that links teachers' beliefs and depth of understanding to increase self-efficacy (Plummer, & Zahm, 2010; Brígido et al., 2013; Yoo, 2016). Lacking academic preparation, teachers feel unprepared and less confident to teach the astronomy content. The studies (Nadelson, Callahan, Pyke, Hay, Dance, & Pfiester, 2013; Wongsopawiro, Zwart, & Van Driel, 2017) stated that TPD is explicitly designed to help teachers construct new knowledge and improve their practice while enhancing self-efficacy. Self-efficacy can increase engagement with the topic and impact conceptual change.

Challenges in Understanding Advanced-level Content

The teachers' discussions and reflections related to Dark Matter, in particular, were evident in frustrations and anxiety. Although they were interested in the content and felt their students were interested in it, they noticed the topic was highly abstract and did not understand it well. Therefore, they expressed little to no confidence in their ability to teach this topic. A study review (Abell, 2013) asserted that teachers are less confident to explain the advanced level science contents. However, in-service teachers' interest in acquiring advanced astronomy content knowledge requires further research.

Improving Pedagogical Content Knowledge (PCK)

Teachers' response to the takeaways reflected their belief to improve their practice as they gained content knowledge and access the resources for teaching (Wongsopawiro et al., 2017). Hence, TPD improves content knowledge and stimulates teachers to enhance their pedagogical content knowledge (PCK). Shulman's (1986) study illustrated the fact of PCK that a teacher's quality of knowledge helps them improve their pedagogy. PCK is a cyclical process that refers to teachers' transformation, reflection, and evaluation of their practice to enhance their learning and skills. Teachers' belief in their capability is an essential factor for the effective execution of PCK to lead self-efficacy (Mizzi, 2013). Peters-Burton, Merz, Ramirez, and Saroughi (2015) noted that science teachers who participated in TPD reported having authentic science concepts, being more confident in teaching, and keen on learning more concepts. Teachers' positive attitudes to change and improve their PCK could significantly impact students' learning outcomes (Ertmer & Ottenbreit-Leftwich, 2010).

Empowering Science Teachers as Future Leaders

The five in-service teachers represented three school districts with diverse students' populations, including economically disadvantaged, non-educationally disadvantaged, section 504 students, English learners, students with disciplinary placements, dyslexia, and drop-out risk (TEA, 2021). STEM is an area of education where social justice warrants focused consideration as it pays scant attention to social aspects, especially social inequalities (Dimick, 2012). Professional development focuses on improving teachers' quality of teaching, but what is the next step? Barko and Putnam (1995) illustrated that teachers' knowledge significantly impacts decision-making. Teachers' beliefs reflected in their ability to adapt to change and their positive attitude toward expanding their knowledge (Ertmer & Ottenbreit-Leftwich, 2010).

Astronomy needs more exposure as an educational subject matter. It is a unique area that requires science processing skills to understand concepts. TPD can work as a catalyst for educational change by improving teachers' pedagogical content knowledge and boosting self-efficacy. Self-efficacy could be the stimulus to increase confidence to drive the teaching-learning process to instill an interest in students to astronomy at an early age to create the experts for the future.

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REFERENCES

Abell, S. K. (2013). Research on science teacher knowledge. In *Handbook of research on science education* (pp. 1119-1164). Routledge.

Ampartzaki, M., & Kalogiannakis, M. (2016). Astronomy in early childhood education: A concept-based approach. *Early Childhood Education Journal*, *44*(2), 169-179.

Bailey, J. M., Lombardi, D., Cordova, J. R., & Sinatra, G. M. (2017). Meeting students halfway: Increasing self-efficacy and promoting knowledge change in astronomy. *Physical Review Physics Education Research*, *13*(2), 020140.

Bandura A (1977). Self-efficacy: Toward a unifying theory of behavioral change. Psychol. Rev. 84: 191-215.

Barko, H., & Putnam, R. T. (1995). Expanding a teacher's knowledge base: A cognitive psychological perspective on professional development. In T. R. Guskey & M. Huberman (Eds.), *Professional development in education: New paradigms & practices* (pp. 35-66). New York: Teachers College Press.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101.

Brígido, M., Borrachero, A. B., Bermejo, M. L., & Mellado, V. (2013). Prospective primary teachers' self-efficacy and emotions in science teaching. *European journal of teacher education*, *36*(2), 200-217.

Brunsell, E., & Marcks, J. (2005). Identifying a baseline for teachers' astronomy content knowledge. *Astronomy Education Review*, *2*(3), 38-46.

Catalano, A., Asselta, L., & Durkin, A. (2019). Exploring the Relationship between Science Content Knowledge and Science Teaching Self-Efficacy among Elementary Teachers. *IAFOR Journal of Education*, *7*(1), 57-70.

Chastenay, P. (2018). To teach or not to teach astronomy, that is the question: Results of a survey of Québec's elementary teachers. *Journal of Astronomy & Earth Sciences Education (JAESE)*, *5*(2), 115-136.

Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.

Danaia, L., & McKinnon, D. H. (2007). Common alternative astronomical conceptions encountered in junior secondary science classes: Why is this so? *Astronomy Education Review*, *6*(2).

Dimick, A. S. (2012). Student empowerment in an environmental science classroom: Toward a framework for social justice science education. *Science Education*, *96*(6), 990-1012.

Eriksson, U. (2019). Disciplinary discernment: Reading the sky in astronomy education. *Physical Review Physics Education Research*, *15*(1), 010133.

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change: How knowledge, confidence, beliefs, and culture intersect. *Journal of research on Technology in Education*, *42*(3), 255-284.

Frost, D. (2012). From professional development to system change: Teacher leadership and innovation. *Professional development in education*, *38*(2), 205-227.

Komarraju, M., & Nadler, D. (2013). Self-efficacy and academic achievement: Why do implicit beliefs, goals, and effort regulation Matter? *Learning and individual differences*, *25*, 67-72.

Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International journal of science education*, *34*(2), 153-166.

Mizzi, D. (2013). The Challenges Faced by Science Teachers When Teaching Outside Their Specific Science Specialism. *Acta Didactica Napocensia*, *6*(4), 1-6.

Nadelson, L. S., Callahan, J., Pyke, P., Hay, A., Dance, M., & Pfiester, J. (2013). Teacher STEM perception and preparation: Inquiry-based STEM professional development for elementary teachers. *The Journal of Educational Research*, *106*(2), 157-168.

Panou, E., & Violetis, A. (2018). Teaching astronomy using monuments of cultural heritage: The educational example of "Horologion of Andronikos Kyrrhestes". *Sci. Cult*, *4*, 77-83.

Peters-Burton, E. E., Merz, S. A., Ramirez, E. M., & Saroughi, M. (2015). The effect of cognitive apprenticeship-based professional development on teacher self-efficacy of science teaching, motivation, knowledge calibration, and perceptions of inquiry-based teaching. *Journal of Science Teacher Education*, *26*(6), 525-548.

Plummer, J. D., & Zahm, V. M. (2010). Covering the standards: Astronomy teachers' preparation and beliefs. *Astronomy Education Review*, *9*(1), 010110.

Runhaar, P., Sanders, K., & Yang, H. (2010). Stimulating teachers' reflection and feedback asking: An interplay of self-efficacy, learning goal orientation, and transformational leadership. *Teaching and teacher education*, *26*(5), 1154-1161.

Sadler, P. M., Coyle, H., Miller, J. L., Cook-Smith, N., Dussault, M., & Gould, R. R. (2010). The astronomy and space science concept inventory: development and validation of assessment instruments aligned with the k–12 national science standards. *Astronomy Education Review*, *8*(1), 010111.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. Educational Researcher, 15(2).

Skaalvik, E. M., & Skaalvik, S. (2010). Teacher self-efficacy and teacher burnout: A study of relations. *Teaching and teacher education*, *26*(4), 1059-1069.

Texas Education Agency. (2021, May). *Initial Mathematics and Science Teaching Certificates by Certification Field and Grade Level 2016-17 through 2019-20.* https://tea.texas.gov

Wongsopawiro, D. S., Zwart, R. C., & Van Driel, J. H. (2017). Identifying pathways of teachers' PCK development. *Teachers and Teaching*, *23*(2), 191-210.

Yoo, J. H. (2016). The Effect of Professional Development on Teacher Efficacy and Teachers' Self-Analysis of Their Efficacy Change. *Journal of Teacher Education for Sustainability*, *18*(1), 84-94.

TEACHER LEARNING AS BOUNDARY CROSSING DURING INTERDISCIPLINARY COLLABORATION

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Professional development, teacher collaboration and availability of quality curriculum have been named as three important sources of support for teachers involved in the teaching of interdisciplinary curriculum. However, there is limited research on how these measures support teacher development in an interdisciplinary context. This study examines the learning potential of collaborative development of interdisciplinary curriculum in secondary schools in Singapore. In a researcher-initiated intervention, an English teacher and a science teacher collaborate in a teacher design team to plan and carry out a lesson that teaches students to critically read science news articles. A qualitative case study approach is adopted to examine the learning potential of the boundaries encountered by teachers in a researcher-initiated teacher design team. As the teachers negotiate the discontinuities they experience during these boundary encounters, their attempts at sense-making have the potential to give rise to learning opportunities. This learning potential is understood through four learning mechanisms that may be evoked at boundaries - identification, coordination, reflection and transformation. Qualitative content analysis of data collected from reflection logs, meeting transcripts and interviews of one case study found evidence of all four mechanisms describing learning opportunities in the areas of curriculum and pedagogical knowledge. Further analysis and comparison of boundary encounters across cases would surface aspects that promote boundary crossing. These findings could inform the design of teacher collaboration as a source of professional development in interdisciplinary contexts.

Keywords: Interdisciplinary teaching, teacher professional development, teacher collaboration

INTRODUCTION

Interdisciplinary approaches to teaching and learning are often promoted as a necessary means of preparing students to meet the challenges of an increasingly globalised world (e.g. OECD, 2019). However, such approaches are not common features in school curriculum, which is usually structured around discrete subjects. Teachers involved in planning and implementing integrated curriculum often face obstacles such as a lack of pedagogical and curriculum knowledge (Lam, Alviar-Martin, Adler & Sim, 2011). Evidently, inadequate teacher development is an impediment to the successful implementation of integrated curriculum. To address this issue, it has been suggested that there should be an availability of quality integrated curriculum, teacher collaboration and opportunities for professional development (Margot & Kettler, 2019). These three support measures for teachers can take place simultaneously. Teacher involvement in curriculum development and collaboration with other teachers have been reported to be key avenues of teacher learning (Voogt et al., 2011). If the effect of collaborative curriculum development on teacher learning can be demonstrated, the findings could shed light on practical considerations that facilitate the development of interdisciplinary programmes by teachers in schools.

Few studies have looked at the process of teacher learning in the context of developing integrated curriculum in a collaborative manner. In a report where English and science teachers collaborated to plan lesson resources for teaching students to critically evaluate science news media, McClune, Alexander and Jarman (2012) found preliminary evidence of the teachers learning from the process. The study reported in this paper builds upon the findings of McClune et al.'s (2012) study by examining the learning potential of collaborative curriculum development by English and science teachers in a researcher-initiated intervention in secondary schools in Singapore. Together with the researcher (author of this paper), one English and one science teacher form a teacher design team, a type of professional learning circle focused on the (re)design of curriculum (Handelzalts, 2009).

The theoretical approach adopted for the analysis of findings in this study is based on the observation that teachers who participated in interdisciplinary activities often reported learning arising from disciplinary differences (Grossman, Wineburg & Woolworth, 2001). Such differences are often regarded as obstacles for interdisciplinary endeavours, but they can also be opportunities for learning (Wenger, 2000). Since the differences between subjects can also be understood in terms of the boundaries between practices, the attempt to overcome these differences is a form of boundary crossing. According to boundary crossing theory, boundaries are defined as "socio-cultural differences that give rise to discontinuities in action or interaction" (Akkerman & Bakker, 2011, p. 139). When people encounter boundaries of an unfamiliar domain or practice, the act of crossing them opens up "new possibilities of meaning" (Wenger, 1998, p. 109). From the perspective of boundary crossing, teacher learning occurs at the boundaries of interdisciplinary collaboration. After identifying the boundaries, the teachers' attempts at negotiating the boundaries are then examined through the lens of four distinct learning mechanisms – identification, coordination, reflection and transformation (Akkerman & Bakker, 2011). The study is guided by the following research question and sub-questions.

What is the learning potential of teachers' boundary encounters in an interdisciplinary teacher design team?

a. What are the boundaries encountered by teachers in an interdisciplinary teacher design team?
b. What are the learning mechanisms evoked at the boundaries encountered by the teachers?

METHOD

A qualitative case study approach was used for this study. The research intervention was conducted at three secondary schools in Singapore, with a teacher design team (TDT) formed in each school. A TDT comprises an English teacher, a science teacher and the author of this paper taking on the dual role of a researcher and facilitator. Each TDT is analysed as a case. This paper reports on the findings of one of the three case studies.

The two teachers who participated in this research study taught at a secondary school that caters to students from Secondary One to Four (13 to 16-year-olds). The English teacher, Vanessa (pseudonym) had been teaching in the school for a decade. Previously, she taught Mathematics at another secondary school. The science teacher, Rachel (pseudonym) had also been teaching for a decade in the school. She had experience teaching English to Secondary One and Two students for the first five years of her career, before teaching solely Biology for the next five years. Both teachers agreed to the request of their respective heads of department to participate in the study.

The task given by the researcher to the interdisciplinary TDT was to collaboratively develop a lesson to teach students to critically read science news. To guide their planning of the interdisciplinary lesson, the teachers were provided with resources by the researcher. These resources included a learning intentions model developed by McClune and Jarman (2011) and samples of learning activities. The process of lesson planning began with the selection of learning objectives from the “science knowledge” and “literacy skills” domains of the learning intentions model. The teachers then proceeded to design learning activities for the students based on the selected learning objectives. Through a series of six meetings held over a period of seven months from April to November 2020, the TDT developed a teaching plan and accompanying teaching resources for an interdisciplinary lesson. The lesson was conducted during curriculum time in January 2021 for a Secondary Four English class regularly taught by Vanessa. For the interdisciplinary lesson, both teachers were present and co-taught the lesson that lasted for an hour each week for two weeks. The study concluded after post-lesson interviews (30 minutes each) were conducted with the teachers in February 2021.

Each TDT lasted for around 1.5 hours, and the total time taken for all six TDTs was around 8 hours. Data collected from the TDTs was in the form of audio-recorded TDT conversations and individual reflection logs that the teachers were asked to record in a digital template after each TDT session. The template contained a series of open-ended questions adapted from Melrink, Meijer and Verloop (2007), designed to probe the learning experiences of the teachers. The audio conversations and post-lesson interviews were transcribed verbatim and the digital logs were submitted to the researcher after each TDT session. There were three data sources obtained from each of the six TDT sessions, comprising one transcript and two teacher reflection logs. In addition, the teachers each wrote a post-lesson reflection log which was submitted to the researcher.

The material in the teacher reflection logs, TDT transcripts and interview transcripts was processed and analysed using qualitative content analysis (QCA). The foremost step in QCA is the development of a coding frame containing main categories and subcategories. In the context of boundary crossing, the categories were formulated such that they describe the boundary encounters of the teachers. A boundary encounter comprises two components – boundaries encountered by teachers (derived from research sub-question a) and learning mechanisms evoked by the boundaries (derived from research sub-question b). Correspondingly, the two main categories in the coding frame directly reflect these two components (see Table 1). The subcategories for the first main category were derived in an inductive manner from the teacher reflection logs using the steps of subsumption laid out by Schreier (2012). For the second main category, the subcategories are the four learning mechanisms of identification, coordination, reflection and transformation that could be evoked by boundary crossing.

Table 1: Coding frame used to identify boundary encounters.

Category	**Description**
Main category 1: Boundaries encountered by teachers	
Learning outcomes for critical reading of science news	Teachers are unfamiliar with learning outcomes for critical reading of science news.
Integration of science and English subjects	Teachers experience challenges in integrating science and English learning outcomes in terms of curriculum, pedagogy and assessment.
Science topic for interdisciplinary lesson	Teachers lack knowledge about the science topic selected for their interdisciplinary lesson.
Epistemiologies of science and English	Teachers encounter differences in how the disciplines of English and science view knowledge, in terms of its nature, source and scope.
Curricular practices of science and English	Teachers are unfamiliar with the curricular, pedagogical and assessment practices of another subject.
Working styles	Teachers encounter working styles that are unlike their own.
Knowledge of students' aptitude and inclinations	Teachers make incorrect assumptions about students' aptitude and inclinations with regard to tasks and activities during interdisciplinary lessons
Main category 2: Learning mechanisms evoked at boundaries	
Identification	Discontinuity between practices is identified, but not overcome. - A practice is (re)defined in terms of how it differs from another practice (othering). - Two practices are considered as different, but each is recognised for its own value and contribution (legitimising coexistence).
Coordination	Means and procedures are put in place that establish continuity between practices. - A communicative connection between diverse practices is established. - A person and/or a boundary object translates understandings between diverse practices. - Boundary permeability is enhanced without deliberate choice through changing roles or rituals. - Routines and procedures are established across boundaries.
Reflection	New perspectives are formed about own and others' practices. - As one's awareness and understanding of the boundary grows, they begin to form new perspectives (perspective-forming). - By connecting the knowledge of both practices, one's perspective takes the other perspectives into account (perspective-taking).
Transformation	In response to a problem, elements from different practices are combined to create a solution. - There is a confrontation with an area of inadequacy or problem that causes a reconsideration of current practices. - There is recognition of a shared problem space in response to the confrontation. - Features from different practices are combined to create something new. - The hybrid product is embedded in practice with the help of routines or procedures. - The integrity of the existing fields is maintained while being connected to a new hybrid field. - Continued collaboration at the boundary is carried out to maintain the transformation.

The application of the coding frame to the material in the reflection logs and TDT transcripts was carried out using MaxQDA software. Coding took place in two phases. During the trial coding phase, 30% of the data set was coded twice for the purpose of refining the coding frame. During the main coding phase, all the material in the reflection logs and relevant portions of the TDT transcripts and interview transcripts were assigned to the subcategories in the revised coding frame. After the main coding, the data segments from categories 1 and 2 were arranged according to boundary encounters. The data segments from different sources were aligned with one another to provide a detailed and in-depth description of each boundary encounter.

FINDINGS

The boundary encounters of the teachers in the TDT are grouped according to the domains or practices where the boundary crossing took place. The three boundary encounters that are detailed in this section are divided into two groups, as they either took place at the boundaries between English and science, or between subject-based and interdisciplinary curriculum. To address the research question, the description of each boundary encounter includes the context that gave rise to the enactment of the boundary, the boundary itself, and the learning mechanisms evoked at the boundaries. Examples of all four learning mechanisms are included across the three boundary encounters.

Boundary crossing between English and science subjects

Encounter 1: Making sense of epistemological differences

The first TDT session was a critical reading exercise where the facilitator asked the two teachers to give their critical take on two science news articles. They were also asked to describe how they would use the articles during their respective lessons. As some epistemological differences between English and science became apparent during the discussion, Vanessa went through the identification and reflection mechanisms in their effort to manage the discontinuity.

Identification and reflection mechanisms. The boundary between the two subjects that was evident in the different critical reading perspectives of the teachers was explicated by Vanessa in her reflection log:

> "I looked at how the information was presented in the article but Rachel based on what kind of information was given and how accurate it was, something that a language teacher would not know of…I realised that both of us were reading the articles critically but from different perspectives." [Vanessa's reflection log for TDT1, Apr 2020].

As she learned about an aspect of information analysis that she was not familiar with, she first distinguished the two critical reading perspectives (*othering*) by stating that she focused on language use in the article while Rachel looked at the nature and accuracy of the factual content. She then *legitimised coexistence* of both perspectives by recognising that although they are focused on entirely different aspects of the article, both are valid approaches of critical reading.

Subsequently, Vanessa built upon the identification mechanism to form a new perspective about the role of understanding factual content in her own language teaching:

> "I felt that if my students were able to discern the technical information, then they would be able to focus on how language in an expository writing is used to convey a purpose…the technical ideas and concepts even without the extensive jargon could prove to be a stumbling block to my students understanding the article, what more to understanding it with a critical lens." [Vanessa's reflection log for TDT1, Apr 2020]

After learning about the analysis of factual content from Rachel, Vanessa perceived that focusing on language alone was insufficient in teaching her students to read content-heavy articles with a critical lens. Since language teachers typically do not dwell on the accuracy of factual information in their teaching, Vanessa recognised that this lack of emphasis could negatively impact students' learning, particularly in the area of expository writing. Through the reflection mechanism (*perspective-taking*), she figured that students' language learning needed to be supported by their learning of factual content knowledge.

Encounter 2: A glimpse into the English classroom

A persistent discontinuity that arose from the lesson planning process was that the teachers were unfamiliar with the curricular practices of the subject that they do not teach. To overcome this boundary, the teachers took the initiative to share some of their classroom teaching material with each other.

Coordination mechanism. Although Rachel had experience teaching English, it was confined to the lower secondary levels and she had no exposure to English teaching at the upper secondary levels. This lack of experience caused Rachel to feel uncertain about the students' responses to the critical reading tasks that the TDT planned for them:

> "It was a bit difficult to visualise what Vanessa is talking about sometimes, because we are not very used to what the English department is doing. So I've had to clarify with her some of the things that I don't really understand, or maybe to ask whether we need to scaffold a bit more to make sure that the students know what they're supposed to do, because it's something that is new to us." [Transcript of interview with Rachel, Feb 2021].

After Vanessa granted Rachel access to her Secondary Four students' assignments in Google Classroom, the latter was able to gain an understanding of the skills that the students learned during English lessons:

> "…because we shared some resources, I got to see some of the things that they do in class. And she actually let me join Google Classroom. So, it's interesting to see the students' discussion, their daily work as well, which is quite similar to what we did for the critical response lesson… so it's quite eye-opening to see what the English department is doing." [Transcript of interview with Rachel, Feb 2021].

The online repository of students' work served to *translate* the meaning of the learning objectives of English for the science teacher, allowing her to observe similarities with a critical response lesson she had previously conducted for her biology students. Learning from the visual documentation of students' assignments helped Rachel to cross the boundary between the curricular practices of English and science.

Boundary crossing between subject-based and interdisciplinary curriculum

As the teachers were new to the collaborative development of interdisciplinary curriculum for the critical reading of science news, they faced uncertainties in approaching the integration of their subjects. Moreover, the English and science learning outcomes that they selected from the learning intentions model were confined to their respective subject domains. The teachers had to conceptualise their own approach of curriculum integration.

Encounter 1: Developing a hybrid pedagogy

Transformation mechanism. In the midst of the lesson planning process with Rachel, Vanessa was *confronted with a problem* that became more pressing as the teachers continually sought ways to integrate the learning outcomes from English and science:

> "I felt frustrated at times as I do not want this to be another typical English lesson on responding to texts critically. The students need to see that it is a collaboration between the science and English departments. I hope that with this, the students would begin to use the skills and strategies they have learnt in English to their other subjects when they come across information – that our students become even more discerning users/receivers of the language." [Vanessa's reflection log for TDT4, August 2020].

Vanessa wanted the interdisciplinary lesson to present an opportunity for her students to transfer their language skills to other subjects, but she still felt that the science aspect was not prominent enough for the transfer of learning to occur. Besides noting it down in her reflection log, Vanessa also expressed this concern during the fifth TDT meeting:

> Vanessa: So how do we put that, I mean, how, in the sense that when we look at a product, we will look at what they have given us or what they have delivered, we can see that they have understood that you know, that critical thinking and critical reading is not just about...it's not just an English skill, but it's a skill, it's a life skill that can be applied to other disciplines as well.
>
> Rachel: I was thinking if we want to do a hot-seating, Hot Seat activity right, because they are adopting different perspectives, but no matter what role they adopt, they have to provide evidence for whatever claim they make-
>
> Vanessa: Correct.
>
> Rachel: Could we maybe create some sort of note-taking template for them when they listen to the questions posed to the people in the hot seat? For the explanations, usually in science we use the Claim-Evidence-Reasoning structure. A thinking routine to get them to explain certain claims that they make.
>
> Vanessa: Like that, what it means is that we can actually use a science strategy in terms of the note-taking right…Then, you know, the moment we use the science strategy with an English...then maybe they will see 'Oh, actually, you know, we can use skills from other disciplines to help us to understand'. [TDT 5 transcript, Aug 2020].

In response to Vanessa's concern about the lesson being a predominantly English one, Rachel suggested a *problem space* where the science learning objectives could be tied to the English learning objectives through the learning tasks given to the students. Since they had decided to carry out a hot-seating activity where students in the "hot seats" took on the roles of different stakeholders in a discussion on the ethics of organ transplants, they could leverage on the activity to integrate the outcomes of English and science.

Rachel's idea of adopting the thinking routine called "Claim-Evidence-Reasoning" (CER) as a template to guide students' thinking was well-received by Vanessa as she viewed it as a "science strategy" that would signal to the students to apply their critical reading skills to another subject besides English. Moreover, the CER template could fulfil the dual learning objectives of English and science – students being able to give reasons for their stand about an issue, and students being able to use scientific knowledge as supporting evidence for their claims. As such, the CER template was a *hybrid* pedagogical tool for the interdisciplinary lesson.

DISCUSSION

The findings of this study present an effort to understand how teacher learning takes place in an interdisciplinary context. From the perspective of teachers' attempts at boundary crossing during interdisciplinary collaboration, it is evident that the teachers gained renewed insights about teaching practices both within and beyond their subject areas. Furthermore, the teachers devised a means of integrating learning outcomes from English and science through a pedagogical tool. For this interdisciplinary TDT, the learning opportunities for teachers included gains in curricular knowledge, changes in perceptions about student learning and increased understanding of the applicability of pedagogical approaches across subjects.

Although the learning took place in the context of planning for an interdisciplinary lesson, the varied nature of the learning and the connections the teachers made with their own practice raise the possibility that it can influence the teachers in their day-to-day work. However, as the longer-term effects of the interdisciplinary TDT are not within the scope of this research study, it cannot be ascertained if the learning of the teachers is sustained and/or translated into beliefs or practice.

This teachers in this case study participated voluntarily in a small-scale intervention that was not part of any school-mandated programme. In this regard, the study circumvented the administrative and logistical barriers typically associated with large-scale interdepartmental collaboration in a school setting. As the interdisciplinary lesson was a standalone one that was not part of the usual school curriculum, the teachers were not overly constrained by curricular and assessment requirements. While research on interdisciplinary teaching tends to highlight the factors that hinder its implementation, this research focuses on the rich learning potential of teacher collaboration in contexts where some of these barriers are largely absent, for example, where structure and support are already established for interdisciplinary school programmes.

Clearly, participation in an interdisciplinary TDT has given the teachers an opportunity to broaden their subject and professional knowledge, opening the doors to interdisciplinary thinking in the process. Such thinking is essential for the effective implementation of integrated curriculum (McPhail, 2018). If the opportunities for boundary crossing in interdisciplinary collaboration can be enhanced, then the likelihood of teacher learning would increase. As one of the cases in a multi-case study, the findings from the TDT reported in this paper will be compared with those from two other case studies to elucidate the features of interdisciplinary TDTs that promote boundary crossing. Based on these features, recommendations will be made regarding the design of interdisciplinary collaboration as a source of professional development for teachers.

REFERENCES

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research*, *81*(2), 132–169.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *Teachers College Record*, *103*(6), 942–1012.

Handelzalts, A. (2009). *Collaborative curriculum development in teacher design teams*. University of Twente.

Lam, C. C., Alviar-Martin, T., Adler, S. A., & Sim, J. B.-Y. (2013). Curriculum integration in Singapore: Teachers' perspectives and practice. *Teaching and Teacher Education*, *31*, 23–34.

Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: a systematic literature review. *International Journal of STEM Education*, *6*(1).

McClune, B., Alexander, J., & Jarman, R. (2012). Unexpected allies: Advancing literacy in a 'Science–English' cross-curricular context. *International Journal of Educational Research*, *55*, 66–78.

McClune, B., & Jarman, R. (2011). From aspiration to action: A learning intentions model to promote critical engagement with science in the print-based media. *Research in Science Education*, *41*(5), 691–710.

McPhail, G. (2017). Curriculum integration in the senior secondary school: A case study in a national assessment context. *Journal of Curriculum Studies*, *50*(1), 56–76.

Meirink, J. A., Meijer, P. C., & Verloop, N. (2007). A closer look at teachers' individual learning in collaborative settings. *Teachers and Teaching*, *13*(2), 145–164.

OECD. (2019). *Future of Education and Skills 2030: Conceptual learning framework*. Retrieved from http://www.oecd.org/education/2030-project/teaching-and-learning/learning/knowledge/Knowledge_for_2030_concept_note.pdf

Schreier, M. (2012). *Qualitative content analysis in practice*. Thousand Oaks, C.A.: Sage Publications Ltd.

Voogt, J., Westbroek, H., Handelzalts, A., Walraven, A., McKenney, S., Pieters, J., & de Vries, B. (2011). Teacher learning in collaborative curriculum design. *Teaching and Teacher Education*, *27*(8), 1235–1244.

Wenger, E. (1998). *Communities of practice: Learning meaning and identity*. Cambridge, UK: Cambridge University Press.

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*(2), 225–246.

COLLABORATIVE GROUPS & TEACHER PROFESSIONAL DEVELOPMENT: CONTRIBUTIONS FROM AN EXPERIENCE IN BRAZIL

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In this article, we present the results of collaborative action research, which aimed at fostering the professional development of a group of science teachers, based on critical reflection on teaching practices and approximation with the research carried out in the field of Science Education. The actions of the group were guided by discussions of articles related to teaching and reflection on their teaching practices, based on the production and video recording of didactic sequences using the reflective cycle proposed by Smyth (1989). The data sources for the research were the teachers' textual productions, the field diary, and the focus group carried out at the end of the process. Content Analysis was used to identify some evidence of the reflection and collaboration process. The data indicated that the process provided a movement of reflection and change concerning the role of the teacher from a transmitter to a mediator of the learning process; the approach to research in the education area, both from the perspective of critical "consumption" of its results and from the perspective of producers of knowledge, considering that teachers were simultaneously constituted as actors and authors of their practices, sharing them both with the community of teachers and with researchers. The collaboration among members was built throughout the process so that we identified all through the group's trajectory the progressive development of the forms of collaboration described by Little (1990), marked by growing levels of interdependence among teachers: i) storytelling and scanning for ideas, ii) aid and assistance, iii) sharing and iv) joint work.

Keywords: Collaboration, Reflection, Teacher Professional Development.

INTRODUCTION

In the last decades, many works have focused on teacher professional development (TPD) and the analysis of the processes of learning how to teach, given the importance of teachers in student learning (Darling-Haimond *et al*., 2017). According to Marcelo (2009), the TPD has been considered a collaborative and flexible long-term process of change for teachers, seen as practical-reflective, involving the active construction of knowledge contextualized in teaching practices and aimed at the reconstruction of school culture. In line with this perspective, we consider critical reflection on teaching practices, collaborative work among teachers, and the production and resignification of knowledge by them as fundamental to TPD.

According to Alarcão (2011), the reflective process involves a triple dialogue - with oneself, with others, and with the situation, to reach an explanatory and critical level. Freire (2007) highlights critical reflection on practice, allowing the critical consciousness to overcome naive curiosity. Both authors refer to reflection and consciousness levels about reality, valuing the systematization of knowledge, methodical rigor, and dialogue as strategies to move from a descriptive level that characterizes the naive consciousness to an explanative, argumentative, and transforming one, characteristic of critical consciousness (Freire, 2007). In this direction, Smyth (1989) proposes a sequence of four hierarchically organized actions (Smyth's cycle) to guide critical reflection on practice, as a means of professional development: describing (What do I do?), (b) informing (What does this mean?), (c) confronting (How did I come to be like this?), and (d) reconstructing (How might I do things differently?).

Several studies have pointed out the potential of the collaboration between teachers to their professional development (Bassoli, 2017; Darling-Hamond *et al*., 2017; Parker *et al*, 2021; Vescio *et al*., 2008; Vaillant, 2016) increasing the studies about what has been described in the literature as collaborative groups (Megid & Wasconcellos, 2015), communities of practice (Wenger, 1998) or learning communities (Parker *et al*., 2021). However, few studies have analyzed the collaboration meanings and forms and their relationships with the TPD. In this sense, Little (1990) distinguishes collaboration from artificial collegiality and describes four collaboration forms (storytelling and scanning for ideas, aid and assistance, sharing, and joint work), respectively relating them to increasing levels of interdependence among teachers.

Having the above perspectives outlined as a theoretical framework, as members of a research group focused on teacher education, we have encouraged the emergence of collaborative groups, composed of basic and higher education teachers, through a powerful partnership established with the Science Center of the Federal University of Juiz de Fora (Brazil). Such groups are understood as collaborative because they have the following characteristics that guide their *modus operandi*: voluntary participation, sharing of objectives, acceptance of the need to rethink their practice, and democratic decision-making (Megid & Wasconcelos, 2015).

In this work, we will discuss an experience with a collaborative group, which is circumscribed in a double movement: of training, through collaboration among teachers, and of research on this process, in which we seek to bring contributions to the questions: What are the contributions of the collaborative group to the participants' TPD? What is the role of collaboration (and its different forms) in the participants' TPD?

METHODOLOGY

This research was developed within the scope of the first author's doctoral process. The methodology used in the research was Collaborative Action Research (Ibiapina, 2008), which involves both training and researching on the process.

The collaborative group consisted of the authors of this work and four other teachers from basic education in the Natural Sciences field, mentioned in the research as Elza, Lisa, João, and Flávia. The group meetings were weekly, 3 hours long, totaling 27 meetings that occurred in the Science Center of the Federal University of Juiz de Fora, located in southeast Brazil.

The objectives of the training process, agreed with the teachers since the beginning of the process, were: to promote an approach to research in science education; to produce didactic sequences fomenting innovations in teaching based on research in science education; to stimulate critical reflection on teaching practices and the production of knowledge from research on the practice itself; to socialize the knowledge produced through the publication of a book and participation in scientific events.

The training process was organized in five phases described in the table below:

Table 1. Phases of the training process, duration, and developed actions.

Phase	Duration	Developed actions
1st	6 meetings	**First approximations between the members of the group and of these with the theoretical references:** discussions about the contexts in which teachers work, difficulties, conceptions and expectations, discussions of scientific articles, related to issues raised by teachers or researchers.
2nd	7 meetings	**Preparation of a project or teaching/research sequence:** Planning teaching sequences from the Science Technology and Society perspective (Karisan & Zeidler, Ramsey, 1993), considering the demands of the contexts in which teachers work. Travel to the city of São Paulo to get to know a model school and different non-school spaces for science education.
3rd	7 meetings	**Teachers in action in schools**: development of teaching sequences, which were video recorded.
4th	3 meetings	**Reflective analysis of the video recorded classes:** selection of the most significant episodes of the classes for the realization of Smyth's cycle (Smyth, 1989). Presentation to the group and collective discussion.
5th	4 meetings	**Sharing constructed knowledge**: production of communications in scientific events, book chapters, and experience reports.

Source: Survey data.

Data were collected through participant observation (which generated a field diary), video recordings of group meetings, interviews, focus group, and textual productions by teachers. The focus group, understood as a set of people selected and brought together by researchers to discuss and comment on a topic, which is the object of research, based on their personal experience (Gatti, 2012), was carried out after the end of the training process using a semi-structured script, in the Science Center. It had the participation of all members of the group and lasted approximately 2 and a half hours, being recorded in audio.

As a strategy to enhance critical reflection on pedagogical practices, we used the video recordings of the participating teachers' classes and their analysis based on the actions proposed by Smyth (1989): describing, informing, confronting, and reconstructing. After individual reflection, group discussions were held, expanding the reflective process. The data were analyzed using Content Analysis (Bardin, 1977).

RESULTS AND DISCUSSION

Based on the objectives of this research and the conception of TPD adopted, when reviewing the trajectory of the participating teachers, we found several indications of the TPD process triggered during the process with emphasis on: a critical reflection on practices, focus on learning, the curriculum, and the political-professional context; the search for change concerning the role developed in the classroom: from the transmitter of knowledge to that of the mediator; the production of knowledge based on reflection and research on the practice itself; (re) investment in the professional development process - understood as a long-term process that accompanies the entire teaching career - and the improvement of collaboration among teachers in this development process.

Critical reflection on the practice itself was the guiding axis of the group's actions, thus, we used several strategies to provide it, such as appreciation and problematization of experiences narrated by teachers, discussion of articles, recording of classes by teachers, and group discussion from Smyth's cycle, as well as text writing.

The development of critical reflection could be identified at different times, not only concerning the practice itself, but more broadly, considering the three axes of teaching action defined by Cachapuz and colleagues (2004): "epistemological axis", "learning axis", "curriculum axis", and also the political-professional axis (Bassoli, 2017).

We will highlight below some reflections triggered by Smyth's cycle on the role of teachers in the learning process since, from the analysis of their classes, they perceived inconsistencies between their discourses and their practices, when they are predominantly assuming the role of transmitters, rather than mediators.

> *"The research helped me support my practice, but also rethink it. Is my discourse consistent with my practice"*? (Lisa).
>
> *"I see myself reproducing the way I was taught: transmission-reception, and I see that my students are not participative subjects in their learning"* (Flavia).
>
> "*I realized from the filming that I was not exactly sure how to ask the questions"* (Elza).

According to Marcelo (2009), one of the characteristics of the TPD perspective is that "the teacher is considered a reflective practitioner, someone who has previous knowledge when accessing the profession and who is acquiring more knowledge from a reflection about his experience" so that the professional development activities "consist in helping teachers build new theories and new pedagogical practices" (p. 10-11). It was also pointed out by Carvalho and Gil-Pérez (2006) as a need for training Science teachers: "acquire the necessary training to combine teaching and didactic research."

In this way, it was possible to identify, throughout the process, the teachers' development of skills related to research on their practice - such as video recording of classes and conducting reflective cycles based on the actions proposed by Smyth (1989), as well as the development of skills related to the recording in written form and systematization of the results for their socialization. Also, it was possible to perceive in the teachers' discourse the appreciation and recognition of the importance of teachers' research, as well as the complexity and difficulties involved in the process of researching their own practice, as follows:

> "*With the participation in the group, it became clear to me, that although I read a lot, I was constantly seeking to master and improve the content that I didn't know how to research. There were some advances, I did not report the results, though.*" (Lisa).
>
> "*The discussions about the difficulties in the school environment, about how and what to teach and how to be teacher-researchers, made it possible for me to realize the importance (and the challenges) of researching my own practice, in order to contribute to the training of students. (...) It is important to highlight that this reflection became possible when I started to discuss and appropriate the literature on 'teachers as researchers', as well as when analyzing my classes through videos*" (Flavia).

Smyth's cycle initially allowed for individual reflection, but when it was shared with the group and systematized - as the teachers did when they wrote reports and chapters in a book (Bassoli, Lopes & Cesar, 2015), it favored a dialogue "with others", assuming an explanatory and critical level that allows "education professionals to act and speak with the power of reason" (Alarcão, 2011, p. 49). Thus, we realize the importance of theoretical frameworks for the reflection process, as expressed by Flávia, who demonstrates an alignment with the constructivist perspective, addressed throughout the process, and uses it as a parameter for analyzing her practice, confronting it.

> *"These video recordings, in addition to Smyth's cycle, proved to be powerful tools for analyzing my own practice, enabling me to become aware of some characteristics of my class that were not transparent to me (...). Thus, I do not allow this student to be participative, creative, nor do I offer support for him to build his own knowledge"* (Flávia).

In the same direction, João has used the theoretical references discussed in the group for the critical analysis of both the practice itself and its initial training, pointing out "the need to break with a series of paradigms, including the conception of neutral and unquestionable science and our vision of teaching and the role of the teacher" (João).

Thus, we understand that the training process provided an approach to research in education, contributing to the development of "teachers as researchers" (Roth, 2007), both from a perspective of critical "consumption" of its results and from a knowledge production perspective, considering that teachers were simultaneously constituted as actors and authors of their practices, sharing them both with the community of teachers and with researchers.

From the analysis of the group's trajectory, it was possible to understand that the collaborative character was procedurally being developed so that it was possible to identify along the group's trajectory (Figure 1) the development of forms of collaboration described by Little (1990): i) storytelling and scanning for ideas, ii) aid and assistance, iii) sharing and iv) joint work. In this sense, the development of these forms of collaboration was related to the deepening of interpersonal relationships, involving a growing professional interdependence among the group members, which evolved from narratives and exchanges of ideas towards joint work.

The first form of collaboration involves the exchange of informal experiences so that, in the construction of these stories, personal and social interests are often underlying. In our group, teachers' reports about daily occurrences in their schools were constant, especially in the initial moments of the meetings, sharing their anxieties and experiences with the other members of the group.

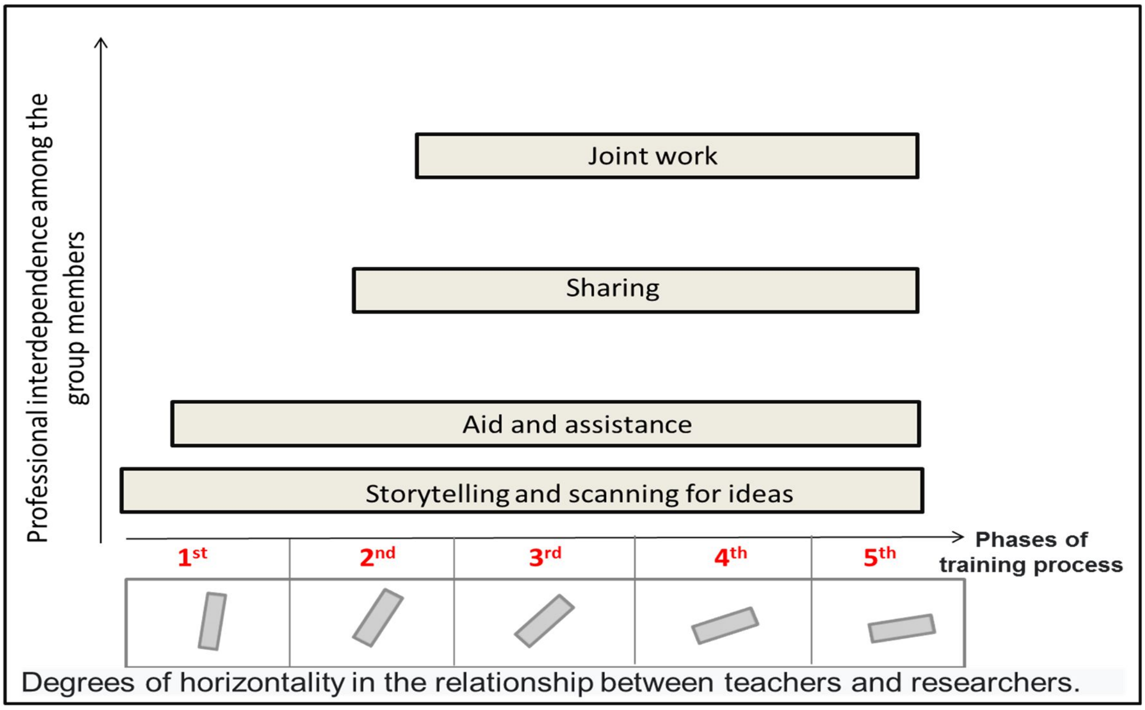
> *"I see clearly today, after our meetings, that continuing education is essential for a well-structured teaching practice, that* ***having someone to share our anxieties with helps us in our understanding of the school dynamics****".* (Lisa).

We agree with Louden (1992) that narratives are also configured as a form of reflection, relating to the first action proposed by Smyth (1989) in the DPD context, describing. However, we understand that they, by themselves, do not provide critical reflection, unless subjected to problematizing.

The second form of collaboration, "aid and assistance", was also valued by members of our group, as expressed below in Flavia's speech:

> *"From my participation in this first planning-action-reflection cycle, I found myself faced with numerous difficulties (...). However,* ***with the support of the group, I gradually overcame such difficulties*** *and developed a more critical view of my teaching practice"* (Flávia).

According to Little (1990), in many cases, help is provided according to a logic of technical rationality, usually from the specialist, who can be another, more experienced teacher. We realized during the first meetings (1st phase) this expectation towards us, authors. Therefore, we always seek to place ourselves in a position of non-centrality and non-authority concerning others, understanding that our role would consist of problematizing the narratives and actions to favor the explanation and understanding of their meanings. In this way, we gradually built a more horizontal relationship with the teachers, which is represented in the Figure 1, that systematizes the forms of collaboration developed throughout the group's trajectory, evolving from narratives ("storytelling and scanning for ideas") to relationships with increasing levels of interdependence between participants ("joint work").



Source: Bassoli (2017).

Figure 1. Representation of collaborative relationships that occurred throughout the phases of the training process and the process of horizontalization of relationships between the researchers and the teachers.

The third form of collaboration, "sharing", corresponds to an exchange of materials, methods and ideas, occurred as teachers created bonds of affection and trust. According to Little (1990), exposing their materials and ideas to others represents a conception of collaboration that is less private and more public, fostering a climate of sharing, which only occurs when teachers feel enough confidence to expose themselves, appearing as a path rich in potential for their professional development. That being so, we noticed that in the first meetings of the group the narratives were predominant, however, with the establishment of a climate of openness and trust, sharing began to occur at a different time for each of the group members.

Dialoguing with the actions of Smyth (1989), but beyond individual reflection, we understand that sharing is an important step towards the action of informing, if, when sharing teaching practices and materials, the theories underlying these practices are also explained.

> "*As the **reflections and exchanges of experiences took place**, I was led to reflect on another issue related to my teaching practice: the lack of planning. And, **with the group**, I was able to see how much this organization could contribute (and, in fact, it helped me) to the effectiveness of my actions as a teacher*". (Flávia)

Additionally, Little (1990) also points out joint work – which is based on the vision of meetings between teachers based on shared responsibility for the work of teaching, on the idea of collective autonomy, on supporting the initiatives and leadership of the teachers with regard to professional practice, which may involve the planning of a set of tasks performed by everyone, in an interdependent manner, or the definition of a set of base criteria that guide the independent action of each one in their classes. We understand that this form of collaboration has greater potential to enable the confrontation and reconstruction of practices unless there is a group intention to problematize them, otherwise, there is a risk that the group is always legitimizing their maintenance.

In the excerpts transcribed above, the teachers claim that the group provided them with exchanges of experiences, emotional and professional support, in addition to encouraging reflection; consequently, contributing to the professional development of the participant teachers of the collaborative group.

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REFERENCES

Alarcão, I. (2011). *Professores Reflexivos em uma escola reflexiva*. 8ª ed. São Paulo, Cortez Editora. 110 p.

Bassoli, F. (2017). *Desenvolvimento Profissional Docente: Contribuições e limites de um processo formativo em um grupo colaborativo de professores de Ciências da rede pública de Juiz de Fora (MG)*. Tese (doutorado) - Universidade Federal de Juiz de Fora, ICE/Engenharia. Programa de Pós-Graduação em Química, 2017, 282p.

Bassoli, F.; Lopes, J.G.S.; Cesar, E.T. (2015). *Contribuições de um Centro de Ciências para a formação continuada de professores: percursos formativos, parcerias, reflexões e pesquisas*. São Paulo, Editora Livraria da Física.

Cachapuz, A., Praia, J.; Jorge, M. (2004). From Science Education to Science Teaching: an epistemological rethinking. *Ciênc. educ*., vol.10, n.3, pp.363-381.

Carvalho, A.M.P. & Gil-Pérez, D. (2006). *Formação de professores de Ciências: tendências e inovações*. 8ª ed. São Paulo, Cortez. 120 p.

Bardin, L. (1977). *L'Analyse de contenu* [Content analysis]. Paris, France: Presses Universitaires de France.

Darling-Hammond, L., Hyler, M. E., Gardner, M. (2017). *Effective Teacher Professional Development*. Palo Alto, CA: Learning Policy Institute.

Freire, P. (2007). *Pedagogia da Autonomia* – Saberes necessários à prática educativa. 35ª ed. São Paulo: Paz e Terra.

Gatti, B.A. (2012). Grupo Focal na Pesquisa em Ciências Sociais e Humanas. Brasília: Liber Livro.

Ibiapina, I.M.L.M. (2008). *Pesquisa Colaborativa*: Investigação, formação e produção de conhecimentos. Brasília: Liber livro Editora, 136 p.

Little, J.W. (1990). The Persistence of Privacy: Autonomy and Initiative in Teachers' Professional Relations. *Teachers College Record*,91(4), 509-536.

Louden, W. (1992). Understanding reflection through collaborative research. In: A. Hargreaves & M. Fullan (Eds.), *Understanding teacher development* (pp. 178-215). New York: Teachers College Press.

Roth, K.J. (2007). Science teachers as researchers. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of Research on Science Education* (pp. 1205-1259). Mahwah, N.J: Lawrence Erlbaum Associates.

Smyth J. (1989). Developing and Sustaining Critical Reflection in Teacher Education. *Journal of Teacher Education*. 40(2):2-9.

Marcelo, C. (2009). Professional Development of Teachers: past and future. *Sísifo/Educational Science Journal*, (8):5-20.

Megid, M.A.B. & Wasconcelos, V. L.B.M. (2015). Pesquisa Colaborativa, Práticas e Grupos Colaborativos. *Ciências em Foco*, v. 8(1): 40-48.

Parker, M., Patton, K., Gonçalves, L., Luguetti, C., Lee, O. (2021). Learning communities and physical education professional development: A scoping review. *European Physical* Education Review 0(0).

Vaillant, D. (2016). Trabajo colaborativo y nuevos escenarios para el desarrollo profesional docente. *Docencia* (60): 5-13.

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.

Wenger, E.C (1998). *Communities of practice*: Learning as a social system. Systems Thinker Newsletter, June, Pegasus Communications.

TEACHERS' BELIEFS AND GOALS CONCERNING INQUIRY-BASED SCIENCE

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For several decades now, inquiry-based learning has been an important element of science education. However, research findings show that inquiry-based learning is applied only rarely in science classes. To increase the implementation of inquiry-based learning, professional development programmes that address science teachers' beliefs and attitudes need to be offered. In the course of a teaching initiative, we created a respective programme and investigated the participating teachers' beliefs and goals concerning inquiry-based science. The programme lasted about six months and was attended by teachers from five schools. For the purpose of data collection, we conducted two group discussions with the participating teachers, one at the beginning and one at the end of the programme. The data were analysed in two steps: In the first step, the transcripts of both group discussions were analysed via qualitative content analysis, facing differences in beliefs and dispositions between the first and the second group discussion. During this analysis, it became apparent, that the formulated goals and beliefs were fostering and hindering factors for teachers when making decisions about the teaching methods. For further analysis, we applied the Documentary Method according to Bohnsack. This approach shed light on teachers' tacit knowledge. The reconstructed orientational frameworks show that the participating teachers see "inquiry" as contradictory to "learning" at school. This might constitute one obstacle to the implementation of inquiry-based learning that has not been considered yet.

Keywords: inquiry-based learning, professional development, qualitative methods

INTRODUCTION AND CONTEXT OF THE STUDY

Inquiry-based learning (IBL) has been considered an important part of science education for decades now (Dewey, 1910; Schwab, 1960). As engaging in science practices is indispensable for students to acquire scientific literacy (Barron & Darling-Hammond, 2010; Roberts & Bybee, 2014) instructional approaches such as IBL have been incorporated in several science curricula and standard documents (e.g., BIFIE, 2011; NGSS Lead States, 2013; NRC, 1996). Nevertheless, international studies indicate that IBL is still not or only rarely implemented in most of science classes (Capps et al., 2016; Forbes et al., 2020; Hofer et al., 2016). To foster the implementation of IBL, it is unrewarding to develop an abundance of "ready-to-use" material. Instead, teachers need to be supported in professional development programmes that address their beliefs and dispositions towards IBL and meet their individual needs (Capps et al., 2012; Darling-Hammond et al., 2017).

The Austrian initiative IMST (Innovations Make Schools Top!) aims at promoting the pedagogical development of schools by supporting teachers in implementing innovative pedagogical approaches in their own classes. The initiative started in 1998 and is financed by the University of Klagenfurt and the Austrian Federal Ministry for Education, Science and Research. Despite providing a manifold support system for in-service teachers (regional networks, provided instructional material, project supervision, financial contribution to material costs etc.), IMST offers professional development programmes that bridge the gap between science education research and teachers' classroom practice. IMST encourages teachers to conduct own action research projects (Laudonia et al., 2018) to evaluate developed material, instructional strategies or their own classroom practice (Krainer et al., 2019).

As science education researchers working for the initiative IMST, we developed a professional development programme called 'Inquiry Steps'. In the course of the pilot phase of this programme, we collected data for two purposes: programme evaluation and science education research. In the following, we give an overview of the professional development programme and provide an insight into initial results of our research.

DESIGN AND METHOD

Inquiry Steps is a professional development programme that aims at promoting schools' pedagogical development by implementing IBL in schools' science programmes. For this purpose, science teachers are supported in planning and applying IBL units for their own science classes. In the 2019/2020 school year, *Inquiry Steps* was offered the first time. In this pilot phase, teachers from five schools (all levels from primary to upper secondary school) participated in the professional development programme. The participating schools were required to delegate teams of teachers (at least two teachers per school) collaborating in a project in order to establish a structural basis for IBL at the school, thus increasing the impact of the professional development programme regarding the schools' pedagogical development.

Overall, the pilot phase of the professional development programme lasted about six months and was organised in two strands: the professional development strand and the research strand (see Figure 1). Arranging the programme in two strands allowed us to fulfil the professional development goals while pursuing our research interests at the same time.

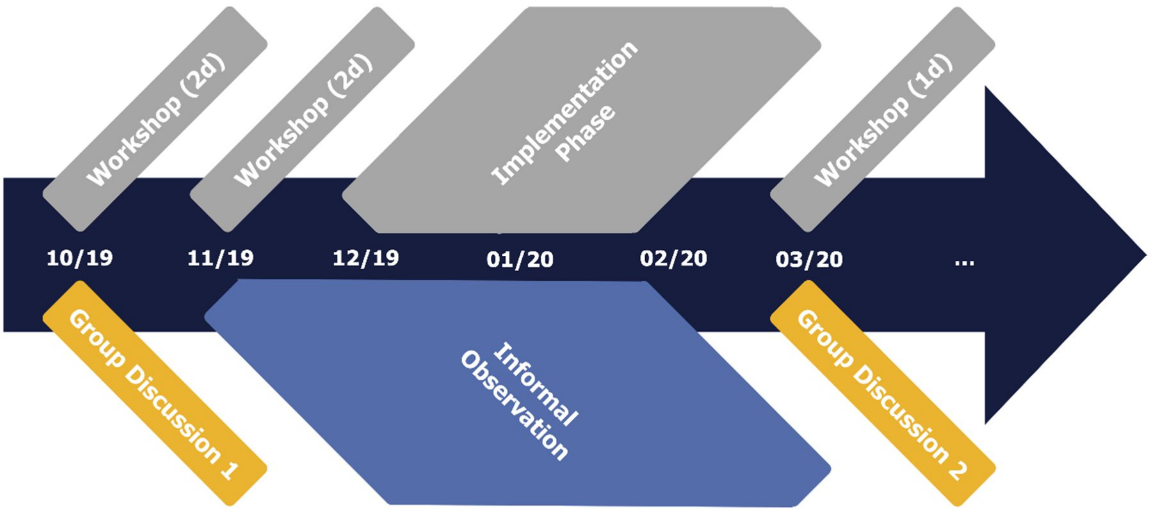

Figure 27. Schedule of the programme *Inquiry Steps* in the pilot phase. The upper part of the figure (in grey) shows the professional development strand, the lower part addresses the research strand (Hofer et al., 2020).

The professional development strand

As shown in Figure 1, the professional development strand of *Inquiry Steps* consisted of two different elements: three workshop parts (five days in total) at the University College of Teacher Education Lower Austria and one implementation phase at the teachers' own schools. In the first workshop part, the participating teachers formulated their individual expectations and needs and presented ideas for IBL-projects at their own schools. Beyond that, science education researchers provided a theoretical framework for IBL to the teachers. In short presentations, teachers learned about the instructional goals for IBL (Abrams et al., 2008), the levels of openness of IBL (Blanchard et al., 2010) as well as of scaffolding (Hammond & Gibbons, 2005) as an indispensable instructional strategy when implementing IBL in science classes. Beyond that, teachers got to know the principles of the Universal Design for Learning (Baumann et al., 2018) in order to consider their students' diversity. Based on this theoretical framework, the teachers were asked to revise and – if necessary – to re-design their initial project ideas.

The second workshop part focused on teachers' views of scientific inquiry. For this purpose, the teachers visited a research institute where they had the opportunity to keep in touch with "real" researchers in an authentic setting. During this visit, the teachers got an insight into a couple of research projects and had the possibility to talk to the researchers and ask them questions about their projects and activities. After this visit, the teachers discussed and reflected their views on scientific inquiry with the science education researchers followed by a brief input about Nature of Science (Lederman et al., 2013). Thereafter, the work on the IBL-projects was continued: the teachers specified and refined their project goals, worked on the planned instructional strategies, outlined the experimental setting and the required equipment, and started to create the teaching materials (e.g., information or instructional sheets) for the planned IBL units. After this workshop part, the teachers had to continue the work on their projects individually. In this phase, they were supported by the science education researchers. Beyond that, each team had the possibility to get financial contribution to material costs by the initiative IMST. After the teachers had finished the instructional design and the required equipment was available, the planned IBL units were proved with students (implementation phase).

In the third workshop part, the teachers presented their final IBL-projects to the other participants of the professional development programme, talked about their impressions and shared the experiences they made in the course of the implementation. Moreover, they were asked to reflect on successful and improvable aspects of their units and had to formulate plans for the sustainable implementation of the projects in their schools' science programme.

The research strand

In parallel to the professional development aspects of *Inquiry Steps*, we collected data in order to evaluate the professional development programme and pursue our research interests in the field of teacher professional development regarding IBL (see Figure 1). The focus of our research interest was reflected by the following research questions: What are the teachers' beliefs about and dispositions towards IBL prior to and after their participation in the professional development programme *Inquiry Steps*? Are there any differences?

To answer these questions, we conducted two guided group discussions (Cohen et al., 2018), one at the beginning and one at the end of the programme. Beyond that, we made informal observations in the time in between (see Figure 1). Both group discussions lasted about 60 minutes, were audiotaped and fully transcribed. To analyse the data, we applied the method of qualitative content analysis combining a deductive and inductive approach (Kuckartz, 2014). The categories used in the deductive step of the analysis were taken from Abrams et al. (2008) and Hofer et al. (2018), respectively. After having analysed the data deductively according to the main categories (learning environment, objectives, scaffolding), we inductively completed the coding manual by developing or revising subcategories.

In order to gain deeper insights into teachers' beliefs and dispositions, we decided to analyse the data one more time by applying the Documentary Method (Bohnsack, 2010). As suggested by Bohnsack (2010), the Documentary Method is especially useful to explore the tacit knowledge of participants in group discussions. When analysing data with the Documentary Method, the analytic stance has to switch from immanent to documentary meaning, from the question "What?" to the question "How?" (Bohnsack, 2010). To achieve this, we answered the "What?" in a first step by writing a formulating interpretation of the group discussions. In the next step, we selected those sequences of the transcript where many teachers were involved in the discussion and analysed these sequences more in-depth in the form of a reflecting interpretation (Bohnsack, 2010). As a result, we were able to reconstruct teachers' implicit orientations towards IBL that will be presented further down.

RESULTS

The results of the first step of analysis (qualitative content analysis) showed that the teachers extended and deepened their knowledge about IBL in several aspects, however, some of the gap identified in the first group discussion persisted even after the teachers' participation in the programme *Inquiry Steps*. For example, some of the teachers denied the necessity of a research question as starting point for IBL. The goal "learning about inquiry" (Abrams et al., 2008) was not mentioned by the teachers at all. Moreover, the teachers claimed that IBL would not match the curriculum and that younger students would be able to carry out research intuitively while older students could not carry out research anymore. The results of the qualitative content analysis are presented in detail in Hofer et al. (2021).

In the course of the qualitative content analysis, some parts of the group discussion arouse our attention. It seemed that the participating teachers would hold a common orientation towards learning that contradicts IBL in school science. This view of 'learning' is reflected in sequences such as the following (translated from German):

> *B146: […] That means I am learning a lot of things alongside, although I have the feeling that I am actually not learning anything, yes.*
>
> *B147: Mmm.*
>
> *B148: Well, I don't have to sit down and learn something, I learn alongside.*

Following this "discovery", we looked for parts of the discussion where teachers spoke about 'learning' and used the documentary method to reconstruct teachers' views on *learning* and on *inquiry*. For this step of data analysis, the following question was central: "Which shared orientational frameworks for *inquiry* and for *learning* can be reconstructed from the group discussions?" In the following, we present the reconstructed orientational frameworks on *inquiry* and *learning* in a first step and contrast them in a second step.

Applying the Documentary Method showed that teachers see *inquiry* as something positive and joyful. It is like playing, where students take active parts in and no predefined goals are needed. *Inquiry* allows for trial and error; it is open for alternative ways. Students are intrinsically motivated for *inquiry*. If they are motivated and interested in the problem, students will do some kind of *inquiry* automatically.

Reconstructing teachers' views on *learning*, we were able to identify different types of *learning* in teachers' mind. *Learning* is viewed differently depending on the area of application and the students' age. One type of learning we were able to reconstruct describes learning from the perspective of learning in early childhood. This type of learning is considered to be natural, consisting of trial and error and guided by the question "What happens if…". Contrary to this type of learning (*early childhood-learning*), learning as it takes place at school (*school learning*) is considered to be guided and artificial. There is no room for alternative ways or trial and error in *school learning*. Regarding students' age, teachers differentiate between younger students who rely on material – they learn intuitively by trying things out (haptically) – and older students who need concrete instructions and guidelines for learning.

In Table 1, the reconstructed orientational frameworks of *inquiry* and *school learning* are outlined by a few contrasting aspects. Comparing the two columns of Table 1, it becomes apparent that teachers' views on *inquiry* and teachers' views on *school learning* are not compatible – they are even contradictory. While *inquiry* is seen as joyful and playful, *school learning* is described as exhausting and joyless. *Inquiry* is seen as intrinsically motivated connected with students' active role, whereas they have a passive role in *school learning*, which is seen as rather passive. *Inquiry* is seen as open, something for that trial & error represents an appropriate method. *School learning* – on the opposite – has to be restricted and straightforward.

Table 1. The contradictory orientational frameworks for *Inquiry* and *School Learning* reconstructed from the two group discussions.

Inquiry	***School Learning***
joyful, playful	joyless, exhausting
intrinsically motivated	extrinsically motivated
active, students as producers	passive, students as consumers
open, trial & error	restricted, straightforward

In summary, *inquiry* as it is seen by the teachers is rather compatible with *early childhood learning* than with *school learning*. The older students become; the more *learning* diverges from *inquiry*. At the higher secondary level, *inquiry* is seen as effectively incompatible with *school learning*.

DISCUSSION AND CONCLUSION

The reconstructed opposing orientational frameworks for *inquiry* and *school learning* are worth discussing in terms of the implications for IBL. Teachers seem to associate IBL with their orientational framework for inquiry rather than with learning at school. This leads to contradicting goals for IBL and for traditional science classes. Teachers find themselves in a conflicting situation when trying to implement IBL what could explain findings from previous studies, where a focus on content learning was identified as an antipole to a focus on procedural skills and joy in conducting experiments (Hofer et al., 2018; Koliander, 2017). This conflicting orientational frameworks might be an obstacle for implementing IBL that has not been considered yet. As the conflicting orientational frameworks may impede the implementation of IBL, they need to be explicitly addressed in teacher education and teacher professional development, e.g., by giving pre- and in-service teachers the opportunity to reflect on their own views on *Learning* and *Inquiry*.

To find more evidence for this hypothesis, we will continue our research by analysing data from other projects (interviews, teachers' reports on action research projects) addressing teacher professional development in the field of IBL. Applying Documentary Method to these data as well, we aim at developing types of teachers' views on *learning* and *inquiry*.

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REFERENCES

Abrams, E., Southerland, S. A., & Evans, C. (2008). Inquiry in the Classroom: Identifying Necessary Components of a Useful Definition. In E. Abrams, S. A. Southerland, & P. Silva (Eds.), *Inquiry in the Classroom: Realities and Opportunities* (pp. xi-xlii). Information Age Publishing.

Barron, B., & Darling-Hammond, L. (2010). Prospects and challenges for inquiry-based approaches to learning. In H. Dumont, D. Istance, & F. Benavides (Eds.), *The nature of learning: Using research to inspire practice* (pp. 199–225). OECD Publishing.

BIFIE (2011). *Kompetenzmodell Naturwissenschaften 8. Schulstufe [Competency Model Natural Sciences Grade 8]*. BIFIE. https://www.bifie.at/system/files/dl/bist_nawi_kompetenzmodell-8_2011-10-21.pdf

Blanchard, M. R., Southerland, S. A., Osborne, J. W., Sampson, V. D., Annetta, L. A., & Granger, E. M. (2010). Is Inquiry Possible in Light of Accountability?: A Quantitative Comparison of the Relative Effectiveness of Guided Inquiry and Verification Laboratory Instruction. *Science Education, 94*(4), 577-616.

Bohnsack, R. (2010). Documentary Method and Group Discussions. In R. Bohnsack, N. Pfaff, & W. Weller (Eds.), *Qualitative Analysis and Documentary Method in International Education Research* (pp. 99-124). Barbara Budrich Publishers. https://doi.org/10.3224/86649236

Capps, D. K., Crawford, B. A., & Constas, M. A. (2012). A Review of Empirical Literature on Inquiry Professional Development: Alignment with Best Practices and a Critique of the Findings. *Journal of Science Teacher Education, 23*(3), 291-318. https://doi.org/10.1007/s10972-012-9275-2

Capps, D. K., Shemwell, J. T., & Young, A. M. (2016). Over reported and misunderstood? A study of teachers' reported enactment and knowledge of inquiry-based science teaching. *International Journal of Science Education, 38*(6), 934–959. https://doi.org/10.1080/09500693.2016.1173261

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education*. Routledge.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). Effective Teacher Professional Development. Learning Policy Institute.

Dewey, J. (1910). Science as Subject-Matter and as Method. *Science, New Series, 31*(787), 121–127.

Forbes, C. T., Neumann, K., & Schiepe-Tiska, A. (2020). Patterns of inquiry-based science instruction and student science achievement in PISA 2015. *International Journal of Science Education, 42*(5), 783-806. https://doi.org/10.1080/09500693.2020.1730017

Hammond, J., & Gibbons, P. (2005). Putting scaffolding to work: The contribution of scaffolding in articulating ESL education. *Prospect, 20*(1), 6-30.

Hofer, E., Abels, S., & Lembens, A. (2018). Inquiry-based learning and secondary chemistry education - A contradition? *Research in Subject-matter Teaching and Learning RISTAL, 1,* 51-65. https://doi.org/10.23770/rt1811

Hofer, E., Koliander, B., & Puddu, S. (2021). Teachers' beliefs about and dispositions towards Inquiry-based Science Education. In M. Rusek, M. Tothova, & K. Vojir (Eds.), *Project-based Education and other activation Strategies in Science Education XVIII. Conference Proceedings* (pp. 16–25). Charles University Prague, Faculty of Education.

Hofer, E., Lembens, A., & Abels, S. (2016). Enquiry-based science education in Austrian teacher professional development courses. In I. Eilks, S. Markic, & B. Ralle (Eds.), *Science education research and practical work: A collection of invited papers inspired by the 23rd Symposium on Chemistry and Science Education held at the TU Dortmund University, May 26-28, 2016* (pp. 271–277). Shaker.

Kainer, K., Zehetmeier, S., Hanfstingl, B., Rauch, F., & Tscheinig, T. (2019). Insights into scaling up a nationwide learning and teaching initiative on various levels. *Educational Studies in Mathematics, 102*(3), 395-415. https://doi.org/10.1007/s10649-018-9826-3

Koliander, B. (2017). Laborpraxis im Chemieunterricht – Ziele und Wege österreichischer Lehrpersonen [Dissertation] [*Laboratory courses in chemistry education – Goals and approaches of Austrian teachers [Doctoral thesis]*]. Universität Wien.

Kuckartz, U. (2014). *Qualitative text analysis: A guide to methods, practice and using software*. Sage.

Laudonia, I., Mamlok-Naaman, R., Abels, S., & Eilks, I. (2018). Action research in science education – an analytical review of the literature. *Educational Action Research, 26*(3), 480-495. https://doi.org/10.1080/09650792.2017.1358198

Lederman, N. G., Lederman, J. S., & Antink, A. (2013). Nature of Science and Scientific Inquiry as Contexts for the Learning of Science and Achievement of Scientific Literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138-147.

National Research Council. (2000). *Inquiry and the National Science Education Standards. A Guide for Teaching and Learning*. National Research Council.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press.

Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education, Vol. 2* (pp. 545–558). Routledge.

Schwab, J. (1960). Inquiry, the Science Teacher, and the Educator. *The School Review,* 68(2), 176–195.

PHYSICS TEACHERS' TRAINING WEBINARS FOR TEACHING AND LEARNING INTRODUCTORY THERMODYNAMICS IN UPPER SECONDARY SCHOOL

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This study refers to a training program addressing upper secondary school physics teachers for the development of Teaching and Learning Sequences (TLSs) for introductory thermodynamics courses. To accomplish that, we presented essential epistemological and pedagogical elements of thermodynamics and proposed an alternative approach to the relevant lessons. To investigate the status of teachers' knowledge and approach to teaching and learning of this field, we conducted an online survey addressing physics teachers in the educational district of central Athens (Greece). The pre-webinar results (N=42) indicated that teachers were rather disappointed with the traditional approach that the official curriculum promotes, and they agreed on enhancing their respective knowledge and skills to design and implement a TLS that could improve the course and advance the respective educational research. The training program was held through four webinar sessions that lasted two hours each. The participants were 30 in-service physics teachers from different upper secondary schools in Athens. The webinars addressed the teaching and learning of introductory thermodynamics in terms of (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. For the evaluation of the training program, we collected qualitative data during the webinars and after the last webinar, using recordings of four group discussions and five semi-structured interviews accordingly. Our results indicated that participating teachers were willing to change their traditional instruction towards a research-based TLS.

Keywords: physics teacher education, introductory thermodynamics, teaching and learning sequences

THEORETICAL FRAMEWORK

Theoretical framework for physics teachers' training

Contemporary science education research reveals that school students and university beginners engage with thermodynamics courses mostly in a superficial way, memorizing formulas and computational methods but not profoundly constructing essential concepts and laws. The pertinent research indicates that proper changes in introductory thermodynamics at the secondary school level can make a long-lasting difference (Leinonen et al., 2012).

Physics teachers' training can play a crucial role, especially when the official curriculum follows a rather traditional approach, in the sense that it has not been informed by recent research evidence. In such cases, a training program aims to intervene in the internal didactic transposition for the school knowledge to be taught (Christiansen & Rump, 2008); in other words, to facilitate teachers reorganize the content they have to teach to make it truly accessible to the students.

To accomplish that, teachers' readiness to redesign their Teaching and Learning Sequence (TLS) for their thermodynamics courses, is vital (Dunn et al., 2019). A prerequisite for this endeavour is for them to advance their knowledge of the subject matter epistemology and the pedagogical elements that would make a good fit for this particular content (Flores, Lopez, et al., 2000).

Gil-Pérez & Pessoa De Carvalho (1997) describe a physics teachers' training program in this direction, taking into account the theoretical and empirical conclusions that are drawn from educational research. Their framework includes four components that summarize numerous subordinate elements referring to physics as the school knowledge to be taught in general terms. Having these components adjusted to thermodynamics in particular, they are the following: (a) knowing thermodynamics as the subject matter to be taught, (b) knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics, (c) acquiring theoretical knowledge about the thermodynamics teaching and learning process, and (d) teachers' involvement in thermodynamics education research and innovation.

Content of the training program

For the content of a training program addressing in-service physics teachers for the teaching and learning of thermodynamics in upper secondary school, we considered the theoretical components suggested by Gil-Pérez & Pessoa De Carvalho (1997), the empirical evidence deriving from preceding training programs (e.g., Flores, Lopez, et al., 2000; Kanderakis et al., 2011), and the particularities of introductory thermodynamics as knowledge to be taught from both the student side (e.g., Leinonen et al., 2012; Meli et al., 2021) and the teacher side (e.g., Bezen et al., 2016; Tobin et al., 2012).

Taking these elements into consideration, the training program addressed the following four aspects of thermodynamics: (a) epistemology, (b) traditional instructional approach, (c) alternative instructional approaches, and (d) design of a TLS. A detailed description of the proposed TLS can be found in Meli & Koliopoulos (2019). The main principles that penetrated the content throughout the training program were the following: (a) operationalization of the first functional steam engine (Newcomen's) as the object under study, (b) exclusive use of the macroscopic (classical) framework of thermodynamics for the interpretation of phenomena connected to thermodynamics processes, and (c) energy distribution representations (Energy Chain Model) for bridging qualitative and quantitative aspects for the interpretation of phenomena (Meli et al., 2021).

These principles significantly contradict the traditional approach of thermodynamics, namely the one introduced by the official physics curriculum and the respective textbook. Overall, the traditional approach replicates the structure of standard university physics textbooks (e.g., Young & Freedman, 2012), simply omitting all the "difficult" parts (mostly related to advanced mathematics) instead of attempting an appropriate didactic transposition for the secondary school level. Typically, this approach gives prominence to the following aspects: (a) the microscopic (statistical) framework of thermodynamics, introduced mostly through the kinetic theory of gases, precedes the macroscopic (classical) framework that focuses on energy-related concepts and principles, (b) symbolic and quantitative representations of phenomena are presented without qualitative and semi-qualitative intermediate models that justify the formulas, and (c) real-life applications of thermodynamics and respective cultural dimensions are illustrated as "decorative" elements that do not organically connect to the knowledge to be taught. Educational research suggests that these traditional epistemological and pedagogical features are in great contrast to contemporary constructivist frameworks since they do not take into account the students' prior knowledge and cognitive needs/capacities for this particular education level (Meli et al., 2021).

RESEARCH QUESTIONS

Our research objective is to explore the impact of the training program for teaching and learning thermodynamics on in-service upper secondary school teachers. We are particularly interested in the alternative elements they would be willing to introduce in their TLS for the respective thermodynamics courses because of their training. Therefore, the research questions are the following:

1. Which were the physics teachers' epistemological and pedagogical conceptions of thermodynamics before their participation to the training program?
2. What were the subjects (connected to the conceptions) that were most frequently discussed during the training program?
3. What were the subjects (connected to the conceptions) that were most frequently discussed how did they inform the teachers' views for the design of an alternative TLS?

METHOD

For better understanding physics teachers' existing conceptions and intervening with a call to action, we follow the design of a case study (Cohen et al., 2007). As Nisbet & Watt (1984) suggest for the phases of a case study, the training program (a) commenced with a wide field of focus, addressing physics teachers of the entire regional area and sharing an online questionnaire with broad epistemological and pedagogical context to interested teachers, (b) progressively focused to narrower fields during the webinars, and (c) checked the draft conclusions with a limited number of participants during the interview phase.

To identify how physics teachers conceived their knowledge of thermodynamics epistemology and pedagogy and to what extent they were willing to explore new approaches, the coordinators of the Regional Centre of Educational Planning for the upper secondary school science curriculum (central Athens) sent an online questionnaire to 150 physics teachers that taught thermodynamics during that school year (2020-2021). 42 teachers (73% males) answered the questionnaire; the vast majority (86%) had already been teaching this course for more than four school years and more than half (57%) were holding a postgraduate degree. The questionnaire included 22 closed-type questions (with a 5-point Likert scale), that derived from the components of the theoretical framework for physics teachers' training, and was quantitatively analysed in *SPSS*.

In addition to the questionnaire, the coordinators invited teachers to participate in a 4-part webinar series for the teaching and learning of introductory thermodynamics. 30 of them participated in the training program. The webinars were held for two hours every other week (November-December 2020) and included presentation sections and time for group discussions.

Within a week after the completion of the training program, we conducted 5 interviews that each lasted 30-45 minutes. They were semi-structured with 9 questions that covered the components that had been raised in the closed-type questionnaire. As with the group discussion passages, all interviews were recorded, transcribed, and qualitatively analysed in *NVivo*.

RESULTS

Physics teachers' conceptions of thermodynamics before to the training program (questionnaire)

Tables 1-4 present the questionnaire items and the results for each component of the theoretical framework for physics teachers' training.

Table 1. Questionnaire items and results (*N*=42) for the first component of the theoretical framework for physics teachers' training (knowing thermodynamics as the subject matter to be taught).

		1	2	3	4	5
1.1*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its concepts?	4,76%	16,67%	42,86%	28,57%	7,14%
1.2*	What is your assessment of your knowledge of the history of thermodynamics concerning the development of its methods?	9,52%	23,81%	47,62%	16,67%	2,38%
1.3*	What is your assessment of your knowledge of the history of thermodynamics concerning the cultural context within it was developed?	19,05%	30,95%	26,19%	21,43%	2,38%
1.4*	What is your assessment of your knowledge of the recent scientific developments in thermodynamics (interdisciplinary)?	9,52%	35,71%	42,86%	11,90%	,00%
1.5**	What is your assessment of your readiness for the enrichment of your knowledge of thermodynamics as a subject to be taught?	,00%	2,38%	23,81%	50,00%	23,81%
1.6**	What is your assessment of your potential to restructure, enrich, or alternate the standard suggested school knowledge of thermodynamics?	,00%	2,38%	28,57%	38,10%	30,95%

* *1=I know nothing about it* up to *5=I know everything about it*
** *1=I could not do it at all* up to *5=I can absolutely do it*

Table 2. Questionnaire items and results (*N*=42) for the second component of the theoretical framework for physics teachers' training (knowing teachers' spontaneous ideas on thermodynamics and on teaching and learning thermodynamics).

		1	2	3	4	5
2.1*	Do you believe that it would be useful to present more historical elements for the development of thermodynamics (e.g., inventions, creative solutions)?	,00%	14,29%	14,29%	40,48%	30,95%
2.2*	Do you believe that it would be useful to present the scientific methods that historically led to the development of thermodynamics (and not just the ultimate results)?	2,38%	14,29%	28,57%	33,33%	21,43%
2.3*	Do you believe that it would be useful to present the scientists' collaborative work that historically led to the development of thermodynamics (and not just the persons' that were directly connected to the ultimate results)?	2,38%	16,67%	21,43%	35,71%	23,81%

2.4*	Do you believe that it would be useful to present the connection of thermodynamics with social issues (historical and recent)?	4,76%	14,29%	16,67%	33,33%	30,95%
2.5*	Do you believe that it would be useful to further utilize experiments for the school knowledge of thermodynamics?	,00%	2,38%	23,81%	28,57%	45,24%
2.6*	Do you believe that it would be useful to present thermodynamics as an interdisciplinary scientific subject?	,00%	14,29%	21,43%	47,62%	16,67%
2.7**	Do you believe that thermodynamics is a scientific subject that should be it promoted as a meaningful and approachable one for all students?	14,29%	16,67%	33,33%	23,81%	11,90%
2.8**	Do you believe that students' real-life conceptions of thermodynamics interact with the scientific ones that are introduced as school knowledge?	9,52%	33,33%	38,10%	16,67%	2,38%

**1=That would not be useful at all* up to *5=That would be absolutely useful*
***1=I don't believe that at all* up to *5=I absolutely believe that*

Table 3. Questionnaire items and results (*N*=42) for the third component of the theoretical framework for physics teachers' training (acquiring theoretical knowledge about the thermodynamics teaching and learning process).

		1	2	3	4	5
3.1*	What is your assessment of the traditional methods that are used for the introduction of thermodynamics to students?	14,29%	42,86%	35,71%	7,14%	,00%
3.2*	What is your assessment of the traditional methods that are used for the students' penetration of thermodynamics?	14,29%	42,86%	40,48%	,00%	2,38%
3.3*	What is your assessment of the level of group learning during your thermodynamics courses?	35,71%	33,33%	21,43%	9,52%	,00%
3.4**	What is your assessment of your knowledge concerning contemporary alternative approaches of thermodynamics teaching and learning?	9,52%	38,10%	35,71%	11,90%	4,76%
3.5**	What is your assessment of your knowledge concerning students' conceptions on thermodynamics?	7,14%	38,10%	28,57%	21,43%	4,76%

**1=Not satisfactory at all* up to *5=Completely satisfactory*
***1= I know nothing about it* up to *5=I know everything about it*

Table 4. Questionnaire items and results (*N*=42) for the fourth component of the theoretical framework for physics teachers' training (teachers' involvement in thermodynamics education research and innovation).

		1	2	3	4	5
4.1*	What is your assessment of your teaching of the school knowledge of thermodynamics up to now?	,00%	52,38%	26,19%	19,05%	2,38%
4.2**	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence?	,00%	4,76%	23,81%	38,10%	33,33%
4.3**	Are you interested in approaching the school knowledge of thermodynamics with a new teaching and learning sequence that will be implemented to contribute to the pertinent educational research?	,00%	4,76%	26,19%	38,10%	30,95%

***1=Not satisfactory at all* up to *5=Completely satisfactory*

***1=I am not interested at all* up to *5=I am absolutely interested*

Summarizing, the above results indicated that physics teachers considered the level of their existing knowledge of thermodynamics epistemology below average, although they were positive in introducing such elements in their formal instruction. Regarding the pedagogical perspective, they believed that the official curriculum was rather inadequate in introducing and delving into thermodynamics concepts but, at the same time, they characterized their knowledge of alternative teaching and learning approaches as rather insufficient. Therefore, it was somehow expected that they agreed to participate in a training program for the design and implementation of a TLS for thermodynamics to make use in their classroom as well as for informing the relevant educational research.

Physics teachers' conceptions of thermodynamics during the training program (group observation)

Table 5 summarizes the most prevailing conceptions in terms of frequency (minimum 5 references) as they surfaced during each of the four webinars of the training program. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 5. Frequency of references (5 references min.) to the questionnaire items during the four webinars (*N*=30).

	1st	2nd	3rd	4th	Total
1.1	5	0	2	0	7
1.5	3	0	0	2	5
1.6	1	7	10	8	26
2.1	5	0	3	0	8
2.2	2	0	0	3	5
2.4	1	3	1	2	7
2.5	0	6	0	0	6
3.1	4	5	1	1	11
3.2	1	9	0	0	10
3.5	0	5	6	1	12
4.1	1	0	2	3	6
4.2	0	0	1	8	9

During the webinars, group discussions (*N*=30) were oriented to both epistemological and pedagogical issues. Concerning thermodynamics epistemology, the participants mainly focused on the distinction between the macroscopic and microscopic approach and the non-linear historical events/ scientists' interactions that gave rise to the theory and the applications of the field. In reference to the pedagogy, they were concerned about practical issues, such as the constraints that the official curriculum sets, the different experiments that can be efficiently executed in the classroom, and the way alternative approaches can be implemented.

Physics teachers' conceptions of thermodynamics after the training program (interviews)

Table 6 summarizes the most prevailing conceptions in terms of frequency as they surfaced during the interviews for each of the interviewees. These correspond to the respective questionnaire items (as presented in Tables 1-4).

Table 6. Frequency of references (5 references min.) to the questionnaire items during the interviews (*N*=5).

	#1	#2	#3	#4	#5	Total
1.5	4	1	2	2	3	12
1.6	7	4	2	4	2	19
2.1	9	1	2	1	0	13
2.4	5	0	0	1	2	8
2.7	3	2	4	2	1	12
2.8	2	2	0	1	0	5
3.1	4	2	0	2	2	10
3.2	1	1	2	0	2	6
3.5	2	4	1	1	2	10
4.1	1	0	2	3	1	7
4.2	0	0	1	8	0	9

The qualitative analysis of the interviews (*N*=5) indicated that the training program facilitated physics teachers in putting existing and new knowledge of thermodynamics epistemology in a pedagogical perspective. The most prevailing elements of this holistic approach are related to the clear distinction between the macro/micro frameworks with prominence to the macroscopic energy concepts, the use of technological components as case studies for introducing concepts/laws, and the introduction of socio-economic context to justify the significance of the field. Indicative passages from the interviews, that suggested a differentiated approach to the TLS, are the following:

To begin with, we should omit the microscopic framework, it comes out of the blue, it creates misconceptions. We should instead focus on the cultural perspective, on small-range research so the students learn where the various thermodynamics principles are applied… I would give prominence to the way knowledge was developed, the historical perspective of thermodynamics, by adopting elements from the training program. I would possibly use passages that demonstrate the difficulties (scientists) faced when constructing steam engines and the method they used while constructing them and how this method was improved. (Teacher #1)

Well, what hadn't occurred to me before (the training program) is that I can at first bypass the kinetic theory of gases… I could go straight to the First Law of Thermodynamics and work towards the thermodynamics processes. I liked this suggestion very much… You gave me many ideas, because I used to start with the kinetic theory and then move on to the processes and I usually faced many problems there. Now I believe that I can seamlessly go straight to teaching the energy part, I mean the First Law, and work all concepts through that chapter and this is *extremely positive. I wouldn't decide doing this change on my own, but since you propose a ready-to-go idea, this is pivotal.* (Teacher #5)

CONCLUSIONS

In-service physics teachers that participated in the training program confirmed the trend shown in the relevant research worldwide that there is a growing scepticism over the epistemological and pedagogical approach of introductory thermodynamics at the secondary school education level (e.g., Bezen, 2016; Flores, López, et al., 2000; Gil-Perez & Pessoa de Carvalho, 1997). Official physics curricula do not yet apply a didactic transposition that properly fits the requirements of thermodynamics school knowledge, turning a blind eye to educational research recommendations for the adaptation of a constructivist approach. During formal instruction, several issues concerning thermodynamics epistemology and pedagogy come on the surface, making instruction even more challenging.

The training program for thermodynamics school knowledge attempted to reconstruct teachers' conceptions of thermodynamics epistemology, indicate the problematic spots on the traditional teaching and learning approach and introduce alternative ways for the design of a TLS. Pre-webinar results indicated that teachers' knowledge on these aspects, that would allow them to redesign their TLS was rather limited, however they demonstrated a positive learning attitude. During the webinars, the conceptions appeared to be somehow destabilized and change-oriented. This repositioning was more obvious during the post-webinar interviews, where the participants indicated in which direction they would adjust a training-informed TLS. The feasibility of the proposed approach was especially important for them, therefore it was essential that they seemed confident to go rather seamlessly from theory to practice.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The main limitation of this research is the lack of further results deriving from the class environment that would justify the training program impact on the participants. Due to the restrictions enforced due to the pandemic, it was impossible for the researchers to observe the respective courses in order to identify how the webinars affected in practice the design of alternative TLSs for thermodynamics courses and/or what was the learning outcome for the students.

A possible extension of this research is the broader use of the pre-webinar questionnaire to investigate physics teachers' epistemological and pedagogical conceptions in a national level or as part of a comparative study between countries with similar approach to the school science curriculum for units of thermodynamics. In addition, this instrument can also be easily adjusted for the exploration of teachers' conceptions on another specific physics field (e.g., mechanics, electromagnetism) or physics in general, for the design of respective training programs and beyond.

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REFERENCES

Bezen, S. (2016). Conceptual Comprehension of Pre-Service Physics Teachers Towards 1st Law of Thermodynamics. *Journal of Turkish Science Education*, *13*(1), 55–75. https://doi.org/10.12973/tused.10157a

Bezen, S., Aykutlu, I., & Bayrak, C. (2016). Conceptual comprehension of pre-service physics teachers towards 1st law of thermodynamics. *Journal of Turkish Science Education*, *13*(1), 55–75. https://doi.org/10.12973/tused.10157a

Christiansen, F. V., & Rump, C. (2008). Three Conceptions of Thermodynamics: Technical Matrices in Science and Engineering. *Research in Science Education*, *38*(5), 545–564. https://doi.org/10.1007/s11165-007-9061-x

Cohen, L., Manion, L., & Morrison, K. (2007). *Research Methods in Education* (6th ed.). RoutledgeFalmer.

Dunn, R., Hattie, J., & Bowles, T. (2019). Exploring the experiences of teachers undertaking Educational Design Research (EDR) as a form of teacher professional learning. *Professional Development in Education*, *45*(1), 151–167. https://doi.org/10.1080/19415257.2018.1500389

Flores, F., Lopez, A., Gallegos, L., & Barojas, J. (2000). Transforming science and learning concepts of physics teachers. *International Journal of Science Education*, *22*(2), 197–208. https://doi.org/10.1080/095006900289958

Gil-Pérez, D., & Pessoa De Carvalho, A. M. (1997). Physics teacher training: Analysis and proposals. In A. Tiberghien, E. L. Jossem, & J. Barojas (Eds.), *Connecting Research in Physics Education with Teacher Education* (pp. 97–101). International Commission on Physics Education.

Kanderakis, N., Dossis, S., & Koliopoulos, D. (2011). Teachers' conceptions about the implementation of a HPS sequence concerning the movement of a simple pendulum. In F. Seroglou, V. Koulountzos, & A. Siatras (Eds.), *Proceedings of the 11th International IHPST and 6th Greek History, Philosophy and Science Teaching Joint Conference "Science and Culture: Promise, Challenge and Demand"* (pp. 687–696). Epikentro.

Leinonen, R., Asikainen, M. a., & Hirvonen, P. E. (2012). University Students Explaining Adiabatic Compression of an Ideal Gas-A New Phenomenon in Introductory Thermal Physics. *Research in Science Education*, *42*(6), 1165–1182. https://doi.org/10.1007/s11165-011-9239-0

Meli, K., & Koliopoulos, D. (2019). Research-based design of a teaching and learning sequence for the First Law of Thermodynamics. In O. Levrini & G. Tasquier (Eds.), *ESERA 2019 Conference "The beauty and pleasure of understanding: engaging with contemporary challenges through science education"* (pp. 622–630).

Meli, K., Koliopoulos, D., & Lavidas, K. (2021). A Model-Based Constructivist Approach for Bridging Qualitative and Quantitative Aspects in Teaching and Learning the First Law of Thermodynamics. *Science & Education*, in press. https://doi.org/10.1007/s11191-021-00262-7

Nisbet, J., & Watt, J. (1984). Case study. In J. Bell, T. Bush, A. Fox, J. Goodey, & S. Goulding (Eds.), *Conducting Small-Scale Investigations in Educational Management* (pp. 79–92). Harper & Row.

Tobin, R. G., Crissman, S., Doubler, S., Gallagher, H., Goldstein, G., Lacy, S., Rogers, C. B., Schwartz, J., & Wagoner, P. (2012). Teaching Teachers About Energy: Lessons from an Inquiry-Based Workshop for K-8 Teachers. *Journal of Science Education and Technology*, *21*(5), 631–639. https://doi.org/10.1007/s10956-011-9352-x

Young, H. D., & Freedman, R. A. (2012). *Sears and Zemansky's university physics: with modern physics* (13th ed.). Addison-Wesley.

USING A VIGNETTE TEST TO MONITOR HOW SITUATIONAL COMPETENCES DEVELOP OVER TIME

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In the context of professional competence research may problems are in continuous discussion, especially in the context of competence assessment. Often it is unclear what is meant with the term "competence", and this problem – in turn – is then reflected in the construction of tests. In addition, long-term studies are scarce and there is a black spot in the monitoring of competence development, as most studies follow a short-term pre-post experimental design. This study intends to address three issues in science education research: the difference between knowledge and competence, the problem to assess professional competences and the long-term development of professional competences. Here, competence is defined as a skill-oriented deep level entity that can be visualized with a situational vignette test. The three-year monitoring shows that pedagogical content competence is a stable characteristic, but general pedagogical competence changed with a negative trend independent of school level (primary vs. lower-secondary). This counterintuitive result was further investigated using competence profile comparisons. The profiles indicate a "contraction" of competences which may indicate that teachers were less motivated in the post test. Interestingly, this regression is at the expense of pedagogical aspects. These results need further discussion, especially in the context of developmental processes of teachers after they leave university.

Keywords: Evaluation, Teacher Professionalism, Educational Reform

INTRODUCTION

Professional knowledge and teacher competences have been widely addressed in practically all fields of educational research. Many studies have been dedicated to the topic of how relevant professional competences are in terms of instruction and student learning. Yet, in many studies, "competence" seems an opaque construct, especially in direct comparison to knowledge. Often knowledge and competence are used as interchangeable entities, but which they are not. In this paper I want to draw attention to the conceptual understanding of knowledge and competence and present a cognitive approach to theoretically discriminate between knowledge as a fact accumulation and competence as a skill which based on fact bundles. This differentiation allows to align knowledge and competence at two prototypical levels of classroom observations: surface and deep structure. Crossing these two approaches results in the need of an appropriate data collection method that is can function on both levels. I propose vignette tests to access both surface and deep levels of teacher knowledges and competences, and I will give an empirical example.

THEORETICAL BACKGROUND

Knowledge, the basis of instruction

Before any instructional action can be performed, any type of knowledge is needed. This knowledge – for example – can be based on every-day experience, recommended by non-formal reference or informed by professional education. In the field of teacher professionalism, one usually refers to university education, teaching experience, and further education as profound sources of professional knowledges (Egloff & Kade, 2006). In many cases these knowledges have been related to the three-dimensional model of content knowledge, pedagogical knowledge, and pedagogical content knowledge

(Shulman, 1987). These dimensions have been of controversial discussion on their relation to instructional performance: While some researchers find a very low direct correlation between knowledge and action/ instruction (Baier et al., 2018), others model a direct effect of competence and instructional quality (Kunter et al., 2013). Yet, as one takes a closer look at the research on the relation of knowledge and action one can identify various definitions of knowledge and action. Some researchers equal knowledge and competence while other draw a clear line between both concepts. The same is true for action. Sometimes action is determined by a quality measure on student level (e.g. "The teacher helped me when I got stuck on a task."), another approach is to determine instructional practice from an outside perspective that can be rated by observers.

Besides the framing of concepts, there is also a differentiation between intentional and functional definitions of the knowledge-action relation. While in intentional theories of action, knowledge is attributed a direct causality for action with a specific purpose, this is no longer readily possible in functional approaches, since the goal of action is no longer clearly defined (Gerstenmaier & Mandl, 2000) According to Hermanns (1987), intentional, purposive action is a special case of functional action. The concept of skill can be located between knowledge and action and accordingly has a procedural character. In this respect, skill describes a competence as a prerequisite for action. In addition to the question of the extent to which knowledge is relevant to action, there is also the question of how knowledge is represented (implicit/ explicit; procedural/ declarative). However, the representation of knowledge also depends on the situation in which it is acquired. To make matters worse, the application of knowledge depends on the situation in which it becomes relevant. In this respect, skill in the form of competence can be defined as the translator of knowledge into action.

According to Schaper (2003) competences are dispositions or cognitive, sensorimotor, social-communicative, emotional-motivational performance prerequisites and personality characteristics that can be actualised in action. Therefore, competence is closely related to an activity, situation or requirement and can be assessed situationally in comparison to the performance prerequisites and personality traits. The closeness to action of this definition of competence with its cognitive component has significant consequences for the acquisition of competence itself. From a learning theory perspective, performance and success in action are thus dependent on knowledge, mediation and goals (Anderson et al., 1996; Paas & Van Merrienboer, 1994; Lefrancois, 2006). From this perspective, content and knowledge should be staged in such a way that learners are induced to acquire schemas efficiently and in a way that is suitable for action (Kirschner et al., 2009). Schemas can also be understood as "chunks" (Anderson, 1996, p. 356) and individual chunks can together form a sequence of events. This chunking is the structuring of behaviour sequences into subsequences and can also be referred to as a script in the context of classroom action. Such scripts can then be processed as cognitive representations or concepts and translated into an instructional action.

In this framework competence can also be defined as a translation of knowledge into action in the context of a specific situation: Teaching competence: „is the capacity of a teacher to perform a reflected single action. Such an action is for instance might be asking an open question in a situated learning process. The performance of this action and its assimilation to a pedagogical necessity is an indicator of the existence of such a competence" (Maiello & Oser, 2009, p. 5). This means, that a certain situation may trigger off a pre-stored experience that helps to get through the situation. According to the Adaptive Control of Thought (ACT) theory, the knowledge or the experience that is retrieved can either be located on a declarative level or on a procedural level (Anderson & Lebiere, 1998; Anderson, 2007). Declarative knowledge is acquired from the outside and stored as fact units. These units can be clustered into chunks which represent bunches of facts of any combination. The declarative knowledge is also seen as easy to verbalize. Procedural knowledge (also known as production rules) summarise declarative knowledge chunks. For example, chunks can be acquired by declarative step-by-step units that define a single procedure (e.g. learning a sequence by heart) and acting it out. Chunks may also routinise by exercise and become non-reflectible, what makes them implicit and hard to verbalise. In that case a reflex-like action takes place. In general, procedural knowledge has been treated as a skill-oriented knowledge that is situationally activated and turned into action (Blömeke et al., 2015), which makes it a competence.

Figure 28 shows an integrated perspective of the relation of knowledge and competence, and how it can be related to observations. Unexperienced teachers may have acquired declarative knowledge and researchers may find out what these teachers perceive. Over time the novice teachers mature and at a certain point a researcher may assess the decision-making process. The difference between a novice and experienced teacher are: the first has a weak background for decisions and thus can only retrieve one solution that fits in a more or less proper way, the latter has experienced several options to act upon, but has to re-think about the reasons for the decision.

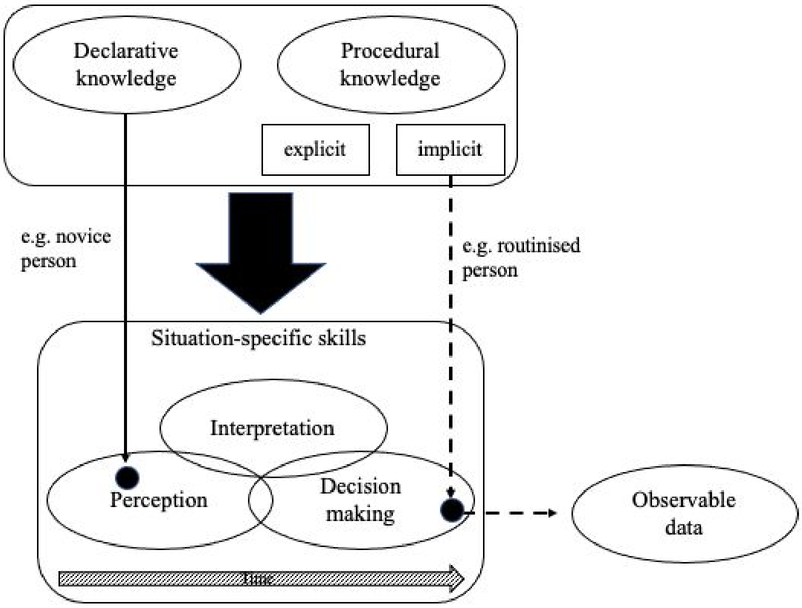

Figure 28: Model of knowledge-action relation and data acquisition.

One asset of Figure 28 is that is differentiates between what type of knowledge is used. In an attempt to combine cognitive research about knowledge types and educational research about the structure of competences and expertise the claim in Figure 28 is that instructors with little teaching experience mainly rely on declarative procedural knowledge when inside a teaching situation. Instructors with plenty of teaching experience use implicit procedural knowledge in most teaching situations. This idea is represented in

In close relation to the knowledges mentioned above, research in teacher education and teacher professional development has proposed to differentiate between surface and deep structures of instruction. While surface structures are easily observable on a low-inference level, deep structures need to be inferred from observable data (= high inference). The alignment of knowledge types and structural level can be combined in a 2x2 table (see Table 41). While instructional actions on the surface structure and declarative knowledge can rather easily be coded with low-inference rating, competence-related deep structures of teaching and implicit knowledge need to be coded with high inference, because they cannot be accessed directly by the rating person.

Table 41: Coding of instruction and knowledge.

		Level of coding inference	
		Low-inference coding	**High-inference coding**
Observation unit	**Instruction**	Surface structure	Deep structure
	Knowledge	Declarative knowledge	Implicit knowledge

Procedural knowledge and deep structures of teaching can be inferred from observable data. In other words, competence is reflected in observable utterances and actions which by themselves are based on the perception of a situation that trigger implicit knowledge in the deep structure of instruction and result in an observable behaviour. Research on the professional vision has shown that the classroom perception of teachers has two dimensions, noticing and interpretation (Wiedmann et al., 2019). While noticing depends on the teacher's attention, the interpretation includes three levels of complexity: the description of a situation, the explanation why the situation is as it is and the prediction of the consequences of the situation (Seidel & Stürmer, 2014). Explanation and prediction rely on the declarative knowledge of the teacher. This is the underlying idea of the test construction of the vignette test that was used as a competence test.

Test construction theory

In sum, if one wants to assess instructional competences of teachers one needs to address procedural knowledge in a test. Procedural knowledge can be triggered by having teachers comment on classroom situations. This open-answer approach is well-established in qualitative research in the social sciences. Besides just asking for comments, there have been manifold approaches to assess teacher competence. Three prominent ways are the following ones:

- Declarative knowledge tests: „Please outline as many different ways as possible of explaining this mathematical fact to your student. "(e.g., Krauss et al., 2008). This type of test tries to access the amount of teacher knowledge and experience and the idea is the more items they can name, the more competent there are. These tests are fairly easy to code and very efficient.
- Procedural knowledge tests: „Please, describe how you would prefer to teach…" Test items like that primarily ask either for the teachers' first choice that comes to his/ her mind, or for a model-like approach to a theoretical problem. The main advantage of this test is the evaluation of a teacher's theoretical knowledge on how to solve a theoretical situation.
- Combined tests: „Please, evaluate the teaching situation and reflect on the situation..“The combination of evaluation and reflection on a given situation gives researchers the chance to get insight into a teacher's mind and how he/ she arrives at a decision or a qualitative judgment.

Mena Marcos and Tillema (2004), in a review study on reflection and action among teachers, arrive at four categories of studies: a) studies that deal with the reconstruction of action-relevant beliefs, b) studies that grasp intentionality as pre-actional reflection, c) studies that capture classroom action as ex-post rationalisation, and d) studies that capture classroom action directly, for example via video recording. Mena Marcos and Tillema, however, see a deficit in the independence of the studies and therefore demand for assessment instruments that address the relation of thought and action. They see triangulative or mixed methods as an approach to researching reflection and action. In this paper, I understand triangulation in a broader sense as taking multiple perspectives on the same phenomenon and try to build the bridge called for by Mena Marcos and Tillema (2004) in terms of complementary data collection. This includes the above categories a) to c) and takes a first step towards data triangulation.

METHOD

Instrument

The vignette test is an instrument to approach competences in teachers. A vignette shows a classroom situation. Based on the underlying theory the vignettes can be discussed in terms of proper instruction in the sense of the underlying theory. In this case the underlying theory is constructivist and each situation was pre-analysed by science education experts. This procedure normatively imposes problems from a constructivist perspective. Teachers are asked to comment on the situations and (in the data coding) the score if they indicate a problem in their comment. The vignette test used in this study includes 8 situations with 40 items (21 for PCK and 12 for PK). PCK and PK can be sub-divided, each in three dimensions (Rehm et al., 2016):

- PCK_a – The competence to adapt to student learning for example to support linked learning or to establish cognitive activation;
- PCK_d – The competence to diagnose content specific issues such as false conceptions;
- PCK_m – The competence to methodologically arrange learning processes based on the content and build learning-supportive instructional sequences
- PK_s – The competence to support student learning;
- PK_d – The competence to diagnose and take the student perspective;
- PK_m – The competence to apply multiple methods for learning processes

Each vignette in the test is a short description of a classroom situation with an open-end question "Please, comment to this situation with as many words you need." There was also a time limitation, long situations were to be answered within 10 minutes, shorter situations within 5 minutes. The items automatically moved on to the next one, when the time limit was reached. The idea was to simulate real reflective conditions, because in reality teachers would usually take 5-10 minutes to reflect on preceding situations before they move on to prepare the next lesson. The comments of the teachers could pick up on the pre-defined problems. Each comment was later coded on a high-inference level at a 0 – 1 – 2 scale by three trained, but independent raters (see the descriptives section below) per problem. A zero score means that the comment does not refer to a pre-defined problem, a score of one point was given if the comment referred to a problem or indicated a reflection of the problem, and a score of two was given if the comment included an idea to solve the problem or alternative option for the problematic situation (even if it was not mentioned that the situation is problematic).

Data set and sample

This study used data that were acquired in the Swiss Science Education project. A detailed description can be found in Koch et al. (2016). In the project an experimental group of 125 teachers received individualized offers as to improve/ innovate their science teaching. In addition, a control group of 20 science teachers was followed. The data acquisitions were just before the project began (pre) and right after the project ended (post). The time period between pre and post was three years. For this analysis we could use data from 136 teachers with teaching experience between 15-18 years: 117 project teachers (60% lower secondary, 40% primary + kindergarten), and 19 control teachers (53% lower secondary, 47% primary + kindergarten).

Descriptives and data analysis procedure

The sample was 136 teachers, 117 in the project group (60% lower-secondary teachers), 19 in the control group (53% lower-secondary teachers). The average teaching experience was 15-18 years (SD≈10).

Data were analyzed using SPSS 25. Vignettes were rated by three independent coders, coder 1 was a reference person, i. e. a lower-secondary science teacher working on at a university of teacher education. Coders 2 and 3 were university students, the one with a background in primary school teaching, the other with a background in general educational sciences. Krippendorff's alpha (α_K) was used to compute the three-person inter-rater reliabilities for ordinal data. A value of α_K=.67 is recommended for sufficient reliability (Krippendorff, 2004). The PCK scale was .65; the subdimensions PCK_a=.71, PCK_d=.54, PCK_m=.66. The PK scale was .74; the subdimensions PK_s=.67, PK_d=.78, PK_m=.79. A repeated measures analysis of variance (ANOVA) was conducted with PCK/PK as dependent variables. Independent variables were group (project vs. control) and school level (kindergarten+primary vs. lower secondary). For exploratory person profiles, hierarchical and k-means cluster analyses were used. First, in the hierarchical analysis (Ward method), the number of clusters was determined, and in a second step this number was used in the k-means procedure to optimize the cluster identification. In the next step the pre and post competence values were attributed to the clusters.

RESULTS

The repeated measures ANOVA showed a significant within subject main effect of time (p=.001) and univariate tests indicated time effects for PK sub-dimensions, but not for PCK subdimension (see Table 42). Despite a p< .05 significance level one can see in Table 2 a positive trend for PCK_m over time which means that the teachers develop in the recognition of test problems, but there was no difference between the project and the control group or between school grades. The inspection of pre-post correlations (also in Table 2) showes statistically significant pre-post correlations for all competence dimensions in PCK.

Table 42: Competence development and pre-post correlations (n=92).

Competence	Sig. of ANOVA Main Time Effect*	Within Group Effect Trend	Pre-Post Correlation	Sig. of r (pre-post)
PCK_a	p= .569	0	r= .47	p= .000
PCK_d	p= .459	0	r= .45	p= .000
PCK_m	p= .168	+	r= .34	p= .000
PK_s	p= .048	-	r= .51	p= .000
PK_d	p= .001	-	r= .11	p= .293
PK_m	p= .108	-	r= .18	p= .079

*Note: Controlled for school grade (lower secondary vs. primary + kindergarten and group (project vs. control); + 0 -: positive neutral negative trend

All PK effects showed a negative trend, i. e. means decreased from pre to post, independent of any group attribution. A time*project group interaction was significant in PK_s (p= .026) and an indication was found in PK_d (p= .126). In PK_s the project group kept on the same competence level over time, whereas the control group decreased in their scoring. Also, a time*grade interaction was found in PK_d for p= .116): The lower-secondary teachers had a stronger decrease than the primary/ kindergarten teachers. The PK pre post correlations indicate that teachers who scored high in the pre test did not necessarily score high again in the post test, especially in the PK_d dimension.

In order to try explain these counter-intuitive results, a cluster analysis on pre-competences was conducted and pre-cluster-membership was used to visualize pre and post competence profiles (Figure 29 and Figure 30). The inspection of the dendrogram suggested a four cluster solution.

In cluster 1 one can see low scores on every competence and a progression in the post test toward improvements on PK_m and PK_s. In cluster 2 teachers scored high on PK_d in the pre test and were stable in the post test. There is a regression on PK_d. In cluster 3 the pre test showed high scores on PK_s which were stable in the post test. There was an improvement on PK_m. In cluster 4 we found high scores on PK_m, but the progression to the post test we could not identify a clear structure. There were improvements on PK_m, and there was a regression on PK_d.

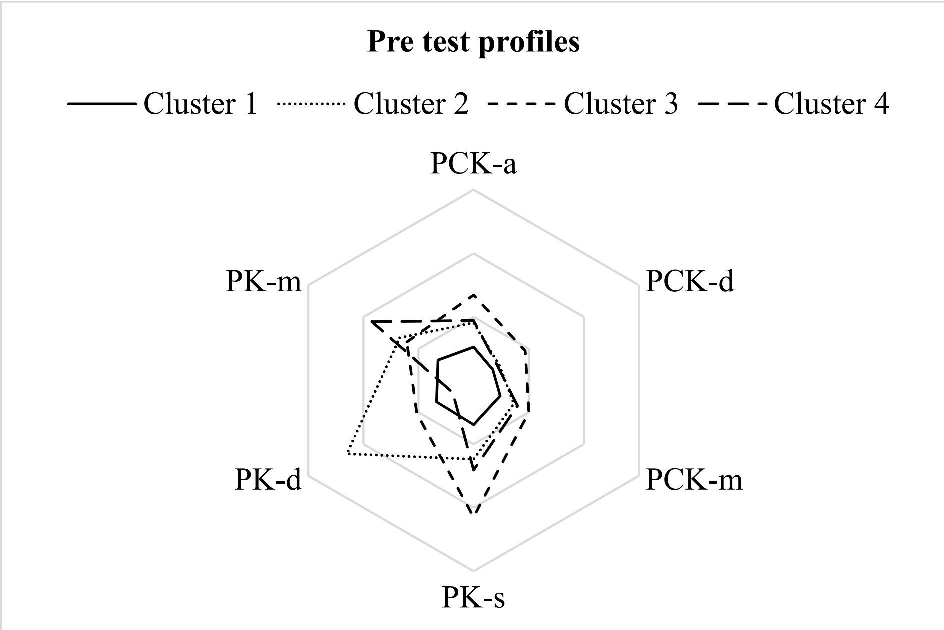

Figure 29: Competence profile of the pre test.

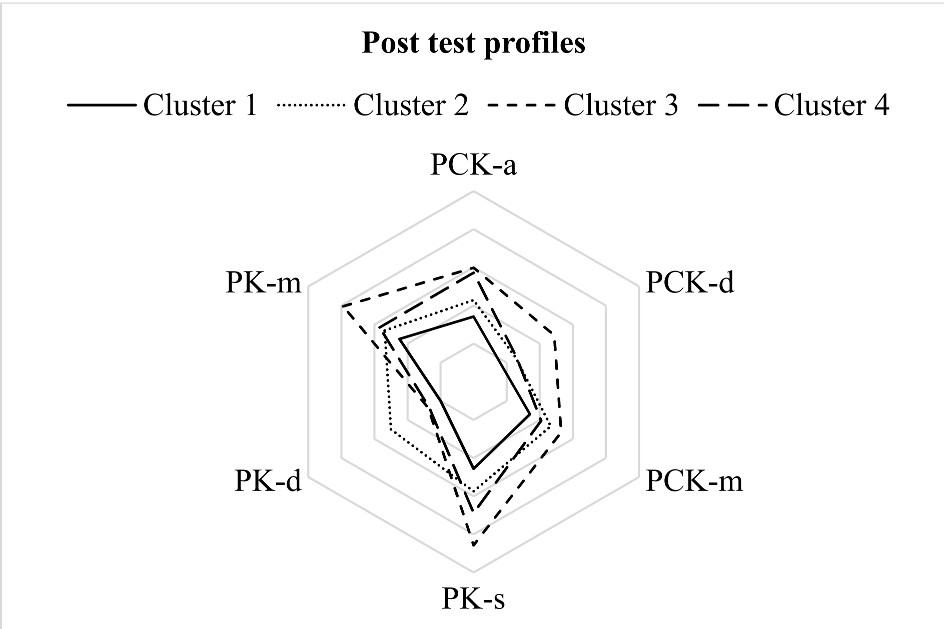

Figure 30:Competence profile of the post test.

The relative changes of cluster means are given in the Table 43 below: PCK_a shows increases in the clusters 1 and 5, PCK_m shows increases in the clusters 1 and 2.

PK_s has an increase in the cluster 1, but a decrease in cluster 3. PK_d diverges, while there are decreases in the clusters 1,2, and 3, there is an increase in cluster 4; PK_m drifts apart with increases in the clusters 1 and 3, but decreases in the clusters 2 and 4.

In terms of clusters, all clusters face similar but heterogeneous patterns, with increases and decreases on the competences. PCK_d seems to be the most stable competence in all clusters, while only for cluster 4 PK_d shows an increase.

Table 43: Changes in cluster means.

	PCK-a	PCK-d	PCK-m	PK-s	PK-d	PK-m
Cluster 1	29%	-2%	42%	31%	-41%	39%
Cluster 2	-6%	8%	28%	-7%	-57%	-20%
Cluster 3	-11%	5%	6%	-20%	-47%	30%
Cluster 4	21%	18%	3%	-2%	42%	-38%

With reference to the results of the ANOVA, cluster 4 is the only group of teachers that shows an increase on the PK_d competence. The cluster primarily consist of lower-secondary teachers (72% within the cluster) and the average teaching experience of all cluster members is 15 years (SD= 10). Almost the opposite development profile can be found in cluster 1, with many developments, but a plummet in PK_d. Cluster 1 members are 59% lower-secondary teachers with an average teaching experience of 12.5 (SD= 9.5) years. Cluster 2 has got a predominantly negative development profile; its members are 57% lower-secondary teachers with an average teaching experience of 17 (SD= 10.5) years. Cluster 3 consists of 49% lower-secondary teachers with an average teaching experience of 19 (SD= 15.5) years. The relative amount of project teachers in each cluster was around 73%.

DISCUSSION

This study we investigated long-term developments in teacher competence development. It was proposed to use a vignette test that allows to access and assess teacher competences on a deep structure level. In the initial analysis of variance ambiguous results were found: On the PCK dimension to methodologically arrange learning processes a positive trend toward improvement was found, but the trend did not differ between any of the grouping variables (project vs. control or lower-secondary vs. primary + kindergarten). Further analyses indicated that the trend may be attributed to test motivation. As the correlation of test motivation and the competence scores was zero for all except PCK_m, we assume that teachers found the problems of PCK_m interesting and perhaps spent more time to think about them, even though they were not aware that it actually was a test item.

The inspection of pre-post correlations showed a low and insignificant value for PK_d which indicates either the assessment or the data coding were not coherent. Perhaps the rating persons became more rigorous, but we did not have data to check for this phenomenon. As all other dimension have significant pre-post correlations one alternative explanation could be the problems that are attached to this dimension. They predominantly deal with the teaching person and his/ her work with the student pre-knowledge which is very difficult to assess in vignettes.

As the results of the ANOVA did not show many differences between the predefined groups, we used an exploratory approach to understand the data. A cluster analysis on the pre data suggested four clusters and these were compared with the post scores. Yet, the findings were very heterogeneous: While some clusters improved on one competence, another cluster showed strong drawbacks on the same cluster. Especially the clusters 1 and 4 seem to be counter-matches, because they develop in opposite ways. The most striking result of the cluster analysis was the insight into the development of the PK_d competence. Despite cluter 4, all other clusters decreased in the competence to diagnose and take the student perspective. In order to disentangle this finding, we used teaching experience and grade to explain the result, but hardly any differences were found when compared to the other clusters. We want to contextualise, that the competence to diagnose student perceptions is correlated to other competences and/ or beliefs of teachers, perhaps even content knowledge (which was not assessed in this study). Perhaps, also the idea of the importance in the consideration of student perspectives could explain the differences in the development.

Besides the discussion of results, we want to draw the attention also to the drawbacks of our study. First of all, we used a relatively small sample and some statistically insignificant effects may turn significant in a larger sample. Despite this, we also used a test instrument that is based on highly inferential coding. High inference coding has been under discussion for almost a century in psychology. Yet, it has also been a fruitful approach to understand phenomena and formulate new hypotheses. Finally, it is to state that this study is a secondary analysis of a data set that was not made for our research question. Thus, we lack interesting variables that could explain the group differences in the exploratory part of this paper.

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REFERENCES

Anderson, J. R. (1996). ACT: A Simple Theory of Complex Cognition. *American Psychologist*, *51*(4), 335–365.

Anderson, J. R. (2007). *Kognitive Psychologie.* (J. Funke, Ed.; G. Plata, Trans.; 6th ed.). Springer.

Anderson, J. R., & Lebiere, C. (1998). Introduction. In J. R. Anderson & C. Lebiere (Eds.), *The Atomic Components of Thought.* (pp. 1–17). Lawrence Erlbaum.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated Learning and Education. *Educational Researcher*, *25*(4), 5–11.

Baier, F., Decker, A.-T., Voss, T., Kleickmann, T., Klusmann, U., & Kunter, M. (2018). What makes a good teacher? The relative importance of mathematics teachers' cognitive ability, personality, knowledge, beliefs, and motivation for instructional quality. *British Journal of Educational Psychology*, *0*(0).

Blömeke, S., Gustafsson, J.-E., & Shavelson, R. J. (2015). Beyond Dichotomies: Competence Viewed as a Continuum. *Zeitschrift Für Psychologie*, *223*(1), 3–13.

Egloff, B., & Kade, J. (2006). Erwachsenenbildungsforschung. In H.-H. Krüger & C. Grunert (Eds.), *Wörterbuch Erziehungswissenschaft.* (pp. 133–140). Budrich.

Gerstenmaier, J., & Mandl, H. (2000). Wissensanwendung im Handlungskontext: Die Bedeutung intentionaler und funktionaler Perspektiven für den Zusammenhang von Wissen und Handeln. In H. Mandl & J. Gerstenmaier (Eds.), *Die Kluft zwischen Wissen und Handeln. Empirische und theoretische Lösungsansätze.* (pp. 289–322). Hogrefe.

Hermanns, F. (1987). Handeln ohne Zweck: Zur Definition linguistischer Handlungsbegriffe. In F. Liedtke & R. Keller (Eds.), *Kommunikation und Kooperation.* (pp. 71–106). Niemeyer.

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). A Cognitive Load Approach to Collaborative Learning: United Brains for Complex Tasks. *Educational Psychology Review*, *21*(1), 31–42.

Koch, A. F., Felchlin, I., & Labudde, P. (Eds.). (2016). *Naturwissenschaftliche Bildung fördern. Indikatoren und Zusammenhänge bei Entwicklungsprozessen in SWiSE.* Haupt.

Krippendorff, K. (2004). Reliability in Content Analysis: Some Common Misconceptions and Recommendations. *Human Communication Research.*, *30*(3), 411–433.

Kunter, M., Klusmann, U., Baumert, J., Richter, D., Voss, T., & Hachfeld, A. (2013). Professional

Competence of Teachers: Effects on Instructional Quality and Student Development. *Journal of Educational Psychology*, *105*(3), 805–820.

Lefrancois, G. R. (2006). *Psychologie des Lernens.* (4th ed.). Springer.

Maiello, C., & Oser, F. (2009). Psychological Variables and Evaluation of Distinctive Characteristics of Teaching Standards. In F. Achtenhagen, F. K. Oser, & U. Renold (Eds.), *Teachers' professional development: Aims, modules, evaluation* (606607188; pp. 3–23). Sense Publ.

Mena Marcos, J. J., & Tillema, H. (2004). Studying studies on teacher reflection and action: An appraisal of research contributions. *Educational Rsearch Review*, *1*(2), 112–132.

Paas, F., & Van Merrienboer, J. J. G. (1994). Instructional Control of Cognitive Load in the Training of Complex Cognitive Tasks. *Educational Psychology Review*, *6*(4), 351–371.

Rehm, M., Brovelli, D., Wilhelm, M., & Marx, C. M. (2016). Effektive Lehrerinnen-und Lehrerbildung für das integrierte Fach «Naturwissenschaften». *Beiträge Zur Lehrerinnen-Und Lehrerbildung*, *34*(3), 317–334.

Schaper, N. (2003). Arbeitsproben und situative Fragen zur Messung arbeitsplatzbezogener Kompetenzen. In J. Erpenbeck & L. v. Rosenstiel (Eds.), *Handbuch Kompetenzmessung.* (pp. 185–199). Schäffer-Poeschel.

Seidel, T., & Stürmer, K. (2014). Modeling and Measuring the Structure of Professional Vision in Preservice Teachers. *American Educational Research Journal*, *51*(4), 739–771.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, *57*(1), 1–22.

Wiedmann, M., Kaendler, C., Leuders, T., Spada, H., & Rummel, N. (2019). Measuring teachers' competence to monitor student interaction in collaborative learning settings. *Unterrichtswissenschaft*, *47*(2), 177–199.

TEACHERS' DIGITAL COMPETENCE IN MODELLING AND EXPERIMENTING WITH AUGMENTED REALITY

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Understanding and creating physical models are a main part of the scientific way of acquiring knowledge and are embedded in curricula. Yet, pupils and teachers often have difficulties with these aspects of science lessons. Augmented Reality (AR) is a digital tool to superimpose virtual visualisations on real backgrounds. It can help linking models and experiments, which usually are not part of the same lesson. Nevertheless, both pre-service and experienced teachers consider their digital teaching competences insufficient.

Within the project diMEx (main project: Digi_Gap), a concept for continuing professional development (CPD) was developed to guide teachers in using AR in secondary school practical physics lessons and promote their digital media and modelling skills. The CPD was pilot tested in 2021 and a second CPD will be carried out in 2022 in the German state of Hesse. To assess the teachers' needs beforehand, data has been gathered from an online questionnaire, including teachers' individual needs for support, their different attitudes towards using digital media, open educational resources (OER), and user-generated content (UGC) in their class. The effectiveness of the CPD will be evaluated by measuring the development of the teachers' modelling competences, their digital skills for modelling AR experiments, and their willingness to use digital tools, especially AR, in school.

Keywords: ICT Enhanced Teaching and Learning, Modelling-based Learning, Teacher Professional Development

THEORETICAL BACKGROUND

Scientific Models and Modelling Competences

Creating and working with models is a main part of acquiring scientific knowledge and is embedded in curricula (German Conference of the Ministers of Education and Cultural Affairs, 2005). These active processes require modelling competences, hence the teachers' ability to work with models and to explain them to pupils. It also means explicitly discussing the construction of models and the necessary idealisations (Winkelmann, 2021). A modelling competence framework has been developed by Upmeier zu Belzen et al. (2019). It consists of three competence levels (models as copies of something, as idealized representations, as a theoretical reconstruction of something), with five aspects of models (the nature of models, multiple models, the purpose of models, testing models, and changing models).

Nevertheless, national and international studies have shown that teachers' and pupils' modelling competences are in need of improvement (Gobert et al., 2011; Nicolaou & Constantinou, 2014; Gilbert & Justi, 2016). Models and their construction are often not further addressed at a secondary school level (Oh & Oh, 2010) and only taught superficially in a positivist manner (Henze et al., 2007). Many pupils find them abstract and difficult, in contrast to experimenting (Winkelmann et al., 2021). Therefore, a training in modelling for teachers is needed, so models are more widely introduced in class.

An idea of combining models and experiments while acquiring scientific knowledge is designed by Teichrew and Erb (2019). Their cycle of knowledge acquisition consists of four topics, arranged in a circle: Pupils identify a phenomenon (1), construct a model for it (2), formulate a hypothesis from that model (3) and test the hypothesis in an experiment (4). To reflect the process, they reverse it: Based on the outcome, they test their hypothesis, review their model and its limits, to characterise the initial phenomenon and explain new experimental outcomes based on their knowledge.

Augmented Reality and AR Experiments

The digital tool Augmented Reality (AR) enables users to add virtual components to a real-world environment by superimposing visual information directly on a real-time camera view (Carmigniani & Furht, 2011). This process is possible via a smartphone or tablet camera, as well as through smartglasses. As Milgram et al. (1994) defined, AR is set in the Reality-Virtuality Continuum, and – instead of immersing the user in a completely virtual environment like VR – augments certain aspects of the real world. When using an AR-capable mobile device, applications can either access the internal sensors (e.g., camera, gyroscope, accelerometer) to detect a surface (markerless), or react to visual markers and triggers with a marker-based software (Johnson et al., 2010).

AR technology can be used in many fields, such as advertising, gaming, or navigation, but also in research and medicine (Carmigniani & Furht, 2011). In the last few years, AR has become more and more prominent in various contexts, including education (Altınpulluk, 2019). As a digital learning tool, AR enables linking an abstract concept to a real-life context, making it easier to understand (Bloxham, 2014). A promising example from physics class is overlaying real-life experiments with virtual, dynamic 3D models created by using *GeoGebra 3D Calculator*. This free browser and mobile app allows placing 3D objects modelled in *GeoGebra* (geogebra.org/3d) via a device's camera on any surface and adjusting them to the real experiment (Teichrew & Erb, 2020). This way, usually unobservable (micro- or macroscopic) objects with an explanatory power enrich the traditional classroom experiments by linking and comparing models and experiments in real time (see figure 1).

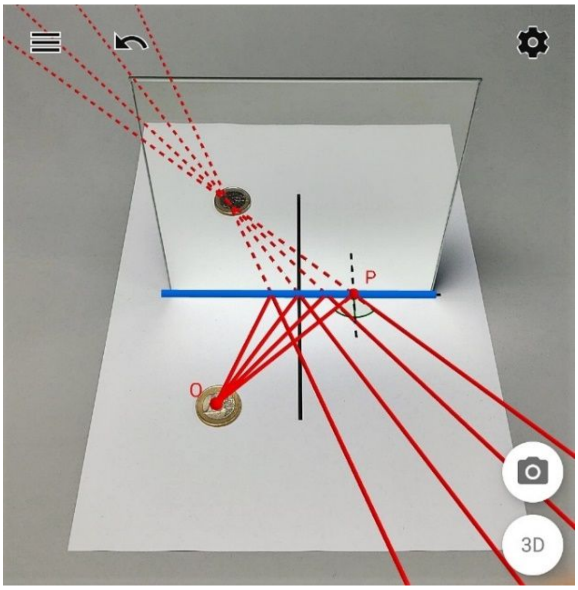

Figure 31. Image formation behind a real-life plane mirror with modelled rays of light.

Digital (Modelling) Competences for AR Experiments

In modern society, digital skills and competences are necessary for many domains of life. With digital media being an essential part of their everyday life, young people grow up as digital natives (Prensky, 2001). In school, the significance of digital media has grown, too, and teachers need to handle them competently. Therefore, digital competences have often been defined and structured in various competence frameworks, for example with the interdisciplinary TPACK framework (Mishra & Koehler, 2006) and the DigCompEdu reference framework by the European Commission (2017). For German-speaking countries, Becker et al. (2020) created the DiKoLAN framework, which aims at student teachers of natural sciences. However, those frameworks cover many aspects of digital competences that teachers should be trained in. Therefore, the presented project will concentrate specifically on those digital competences that are needed for implementing AR experiments in physics lessons. These include operating the software (*GeoGebra*) and hardware (tablets and smartphones), but primarily using the digital tool AR purposefully in the classroom, which is a combination of both technological and content knowledge and its didactic implementation (Guillén-Gámez et al., 2020). In order to promote modelling competences with AR experiments, these particular digital competences are needed. Both are necessary and their overlap must be trained in a CPD.

Successful Continued Professional Development

After the university studies and the practical internship in schools, continued professional development (CPD) marks the third phase of teacher training. It enables in-service teachers to face new challenges of their profession and meet further requirements while also impacting pupils' learning success (Polly et al., 2015). However, an effective CPD needs to fulfil specific requirements (Lipowsky & Rzejak, 2015), among them a longer period of sessions, the combination of input, practice and reflection phases, a focus on subject-specific learning needs, and providing helpful feedback to the teachers. Furthermore, integrating open educational resources (OER) in a CPD can positively influence the innovative use of teaching material – both searching for it and designing their own OER content (Karunanayaka & Naidu, 2017).

STUDY DESIGN

The aim of the interdisciplinary project "Digi_Gap – Bridging digital gaps in teacher education", funded by the German Federal Ministry of Education and Research, is to locate, analyse, and close digital gaps related to didactic, organisational, individual, and technological factors in educational processes (Academy for Educational Research and Teacher Training, n.d.). Within the subproject "diMEx – Digital Competences in Modelling and Experimenting" a CPD concept for implementing Augmented Reality experiments in physics classes is developed, conducted, and evaluated. The goal is to increase secondary school physics teachers' digital competences regarding dynamic 3D models. Furthermore, it investigates how a combination of real experiments with digital models in an AR learning environment can lead to a better understanding of models and a more frequent explicit use of them in physics classes, by reflecting the construction process of models and underlying idealisations. The following research questions are therefore addressed:

(1) Does a CPD about using AR experiments in physics lessons improve the teachers' modelling competence?

(2) Can the CPD improve the teachers' digital competences needed for creating dynamic 3D models?

(3) How does the teachers' willingness to use digital tools in class change by attending the CPD?

Preliminary Study: Teachers' Need for Professional Development

To develop the CPD, a preliminary study was conducted in summer 2020 (Freese et al., 2021). With an online questionnaire, the attitudes and experiences of secondary school physics teachers (n = 81) regarding the use of digital tools in class were examined. It contained seven Likert items and two additional open questions about a definition of and experiences with AR. Twelve applications of analogue and digital tools were presented, for which the teachers had to report if and how they had used them in class. Using scales by Vogelsang et al. (2018), the Likert items explored the attitudes and motivation for using digital media in lessons, the teachers' skills, and the availability of digital devices in school. Furthermore, the teachers' attitudes towards open educational resources (OER), created by internet users (user-generated content, UGC), were examined.

As the results of the preliminary study show, the teachers' experience in the use of (digital) media and tools in physics lessons is mainly limited to well-known applications, like photos and videos, or static drawings and sketches. The field of AR and VR calls for further training, as there is a lack of knowledge about the possible use and suitable tools. Only 15% of the teachers consider themselves able to use AR technology in their lessons. The open question to define AR was answered by 38 teachers, of which half of them match the definition given in Teichrew and Erb (2020). In the feedback questionnaire, the teachers expressed the wish for a CPD about digital tools which also takes care of beginners in this field. Furthermore, as expected, the lack of technical equipment at schools is criticised by almost 80% of the teachers.

Regarding OER and UGC, there is a high willingness (90%) on the teachers' part to share self-designed teaching and learning material on the internet. However, 83% have not yet made their material available online. Some teachers are concerned that the current OER teaching material has often undergone no quality control and cannot be used in all learning groups. In conclusion, the further training concept will include all school forms for networking and exchanging internally differentiated teaching material.

Main Study: A Concept for Continuing Professional Development (CPD)

Based on the preliminary survey results, a CPD concept for secondary physics teachers was developed. In five sessions over several months, the teachers learn to create AR experiments with the modelling software *GeoGebra* and implement them in their lessons. The CPD is based on the TPACK framework (Mishra & Koehler, 2006). It starts with the basic principles of models as a part of acquiring scientific knowledge, after which the teachers learn to use the software and platform *GeoGebra*. This includes searching for suitable existing 3D models on the platform's OER database and modifying them for their lessons. Subsequently, the teachers create their own models and enhance them with short info texts, images, and open or multiple-choice questions. Those dynamic teaching materials can later be uploaded themselves as OER on the *GeoGebra* platform, which allows them to be shared and reused by others. The focus of the input and workshop phase is not on the correct use of mobile devices like tablets, but on their didactically appropriate implementation with self-developed AR experiments. A self-study module and interviews accompany this practical phase. Lastly, the teachers reflect on the implementation with the whole group and their AR experiments are evaluated (peer and expert feedback).

Regarding content, the teachers can choose the physical phenomena they want to cover in their AR experiment – depending on what classes they teach and what subjects are in the curriculum. The *GeoGebra* OER database contains some of the organisers' prepared models, e.g., the subject areas mechanics, electricity, and optics (Erb & Teichrew, 2020; Teichrew & Erb, 2020; Teichrew et al., 2019).

The CPD was pilot tested from May to July 2021 at the University of Education Schwäbisch Gmünd, Germany. Due to the pandemic situation, only five secondary school teachers participated, and the first two sessions had to be held online via video conferencing. In the first session, in addition to a theoretical introduction to AR experiments, the teachers were trained to use *GeoGebra* on AR-ready tablets. A few already had some experiences with *GeoGebra* from other contexts, like mathematics classes. Between each of the five input and development sessions, the teachers had to use AR experiments in their lessons – starting with AR experiments prepared by the organisers, up to their own created models. Every following session, they would reflect on and discuss their experiences to enhance their models for the subsequent classroom use.

Some aspects of the pilot tested CPD concept were adapted after evaluating the results and the teachers' feedback. As the first two online video sessions did not reach the quality of on-site sessions, the main CPD was planned to take place exclusively at premises of the Goethe University Frankfurt, Germany. Because of the pandemic, the sessions were held in external conference rooms, with an elaborate hygienic concept and split groups. As the pilot testing took place while the schools were still closed, some teachers had difficulties implementing their AR experiments in remote learning. Therefore, the main CPD was supplemented by screen-sharing and online teaching tutorials. Sharing the screen with a projector is also a great way to make the AR experiment accessible to the class when there aren't enough devices for students to practice independently.

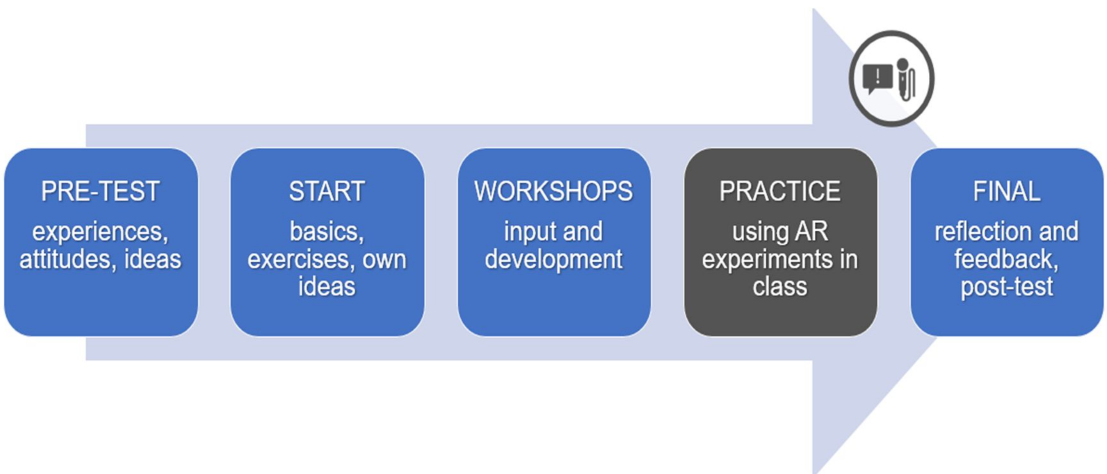

Figure 32. Structure of the main CPD.

The most noticeable edit was the structure of the input and implementation phases (see figure 2). With an overall duration of six months, the main CPD started in September 2021 by providing the teachers with basic information on AR experiments, exercises, and collecting their ideas on possible subjects. It continued with three consecutive workshop sessions to develop the *GeoGebra* 3D model. During the three-month practice phase (December 2021 to March 2022), the teachers had enough time to finish their model and to implement the AR experiment in their lessons. However, they have been accompanied by the organisers and were given online self-study modules written by the organisers, with detailed manuals on all aspects of *GeoGebra* models and AR experiments. The teachers have also been requested to participate voluntarily in semi-structured interviews in which they can give individual feedback.

The final reflection and feedback session is scheduled for March 2022, before the schools' graduation exams. The teachers' experiences with the AR experiments are presented and discussed in the group. They can exchange advice, aims and conditions for a successful implementation, and are furthermore given expert feedback by the organisers. The AR experiments are evaluated according to a rating system (see below).

Measuring Instruments

To answer the three research questions (see above), the pilot test of the CPD was evaluated with a pre-post survey, questionnaires at several times of measurement, and semi-structured interviews. For the main CPD, a rating system has been developed which focuses on the digital competences needed for modelling the AR experiments. It is based on the TPACK framework and has five variables which are validated with a template filled in by the teachers after implementing their AR experiment in class.

Table 1 gives an overview of the measuring instruments for research question (1), regarding the teachers' modelling competence.

Table 44. Measuring instruments for modelling competence.

Variable	Method	Basic instrument
Teachers' understanding of scientific models	Open questions	Windschitl & Thompson (2006)
Didactical handling of models in class	Closed-ended vignettes	Billion-Kramer et al. (2020)
Willingness to use models explicitly in the lessons	Self-assessment (post-test and follow-up)	Semi-structured interview, own design

Research question (2), regarding the digital competences needed for modelling dynamic 3D models, will be answered with the rating system shown in table 2. The AR experiments are evaluated by expert raters based on a profile template the teachers fill out after their lesson. It includes a learning objective, a screenshot of the AR experiment, and the link to the original *GeoGebra* model. In a follow-up inquiry, the teachers will be interviewed approximately six months after the CPD about their current use of digital tools, and their self-assessed ability to use AR experiments in class.

Table 45. Measuring instruments for digital competences.

Variable	Description of the highest competence level
Digital skills (TK)	The teachers can construct and operate their own dynamic 3D model from scratch and open it on a mobile device using the AR mode.
Content-related design (TCK)	The physical content of the dynamic model is accurate and the relations between all variables are transparent.
Didactical design (TCK)	The dynamic model is visually appealing: the user's view has been reduced to the relevant variables and only contains necessary labels. The list of algebraic commands has been properly shortened (auxiliary objects hidden). The model can be operated intuitively.
Didactical use of AR experiments (TPK)	The teachers have phrased an appropriate learning objective for the implementation of the AR experiment which matches its complexity and underlines the profitable character of this technology.
Digital modelling competence (TPACK)	By being augmented by the virtual contents, the real experiment is enhanced so that the underlying model can be easier understood. It is clear which parts of the phenomenon are represented by real experiment materials or by virtual objects (Teichrew & Erb, 2020).

Table 3 shows the instruments used for answering research question (3) regarding the teachers' willingness to use digital tools, such as AR, in class.

Table 46. Measuring instruments for willingness to use digital tools.

Variable	Method	Basic instrument
Teachers' attitudes towards using digital tools	Likert scales	Vogelsang et al. (2019)
Teachers' experiences with *GeoGebra*	Likert scales and open questions	Own design
Willingness to use digital tools, such as AR experiments, in class	Self-assessment (follow-up)	Semi-structured interview, own design

EXPECTED RESULTS AND CONCLUSIONS

After the CPD, we expect the teachers' modelling competence to improve due to reflecting the construction process of scientific models and the idealisations that go with them. This means a higher understanding of models to acquire scientific knowledge and a more confident didactical handling of them in class. This leads to an increased willingness of the teachers to explicitly use models and teach their construction process in their lessons.

The digital competences needed for modelling dynamic 3D models are expected to improve thanks to the instructed handling of the software *GeoGebra* and the associated mobile app, as well as the thoroughly prepared implementation of the AR experiments in class. This competence's highest level (TPACK) requires successful modelling, an appropriate content-related and didactical design of the model and teaching material, and a purposeful use of the model in class.

As a result of the improved digital and modelling competences, the teachers' willingness to include digital tools (especially AR) in their physics lessons is expected to increase. In general, we expect that the CPD will help make digital teaching and learning contexts more accessible. Teachers will be able to implement AR experiments particularly more effectively in schools.

ACKNOWLEGMENTS

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REFERENCES

Academy for Educational Research and Teacher Training (ABL). (n.d.). *Digi_Gap: Digitale Lücken in der Lehrkräftebildung schließen*. https://www.uni-frankfurt.de/87779603/

Altınpulluk, H. (2019). Determining the trends of using augmented reality in education between 2006-2016. *Education and Information Technologies, 24*, 1089–1114. https://doi.org/10.1007/s10639-018-9806-3

Becker, S., Bruckermann, T., Finger, A., Huwer, J., Kremser, E., Meier, M., Thoms, L.-J., Thyssen, C., & von Kotzebue, L. (2020). Orientierungsrahmen Digitale Kompetenzen für das Lehramt in den Naturwissenschaften. In S. Becker, J. Meßinger-Koppelt, & C. Thyssen (Ed.), *Digitale Basiskompetenzen – Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften* (pp. 14–43). Joachim Herz Foundation.

Billion-Kramer, T., Lohse-Bossenz, H., & Rehm, M. (2020). Vignetten zum Modellverständnis – eine Chance für die Lehrerbildung in den naturwissenschaftlichen Fächern. In M. E. Friesen, J. Benz, T. Billion-Kramer, C. Heuer, H. Lohse-Bossenz, M. Resch, & J. Rutsch (Eds.), *Vignettenbasiertes Lernen in der Lehrerbildung – Fachdidaktische und pädagogische Perspektiven*. Beltz Juventa (pp. 138–152).

Bloxham, J. (2014). Augmented Reality Learning. *ITNOW, 56*(3), 44–45. https://doi.org/10.1093/itnow/bwu078

Carmigniani, J., & Furht, B. (2011). Augmented Reality: An Overview. In B. Furht (Ed.), *Handbook of Augmented Reality* (pp. 3–46). Springer.

Erb, R., & Teichrew, A. (2020). Geometrische Optik mit GeoGebra. *Naturwissenschaften im Unterricht Physik, 31*(175), 24–28.

European Commission, Joint Research Centre, & Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu* (Y. Punie, Ed.), Publications Office. https://data.europa.eu/doi/10.2760/178382

Freese, M., Winkelmann, J., Teichrew, A., & Ullrich, M. (2021). Nutzung von und Einstellungen zu Augmented Reality im Physikunterricht. In S. Habig (Ed.), *Naturwissenschaftlicher Unterricht und Lehrerbildung im Umbruch?* (pp. 390−393). University of Duisburg-Essen.

German Conference of the Ministers of Education and Cultural Affairs (Ed.) (2005). *Beschlüsse der Kultusministerkonferenz: Bildungsstandards im Fach Physik für den Mittleren Schulabschluss (Jahrgangsstufe 10)*. Luchterhand. https://www.kmk.org/themen/qualitaetssicherung-in-schulen/bildungsstandards.html

Gilbert, J. K., & Justi, R. (2016). *Modelling-based Teaching in Science Education.* Springer International Publishing. https://doi.org/10.1007/978-3-319-29039-3

Gobert, J. D., O'Dwyer, L., Horwitz, P., Buckley, B. C., Levy, S. T., & Wilensky, U. (2011). Examining the Relationship Between Students' Understanding of the Nature of Models and Conceptual Learning in Biology, Physics, and Chemistry. *International Journal of Science Education, 33*(5), 653–684. https://doi.org/10.1080/09500691003720671

Guillén-Gámez, F. D., Mayorga-Fernández, M. J., Bravo-Agapito, J., & Escribano-Ortiz, D. (2020). Analysis of Teachers' Pedagogical Digital Competence: Identification of Factors Predicting Their Acquisition. *Technology, Knowledge and Learning, 26*, 481–498. https://doi.org/10.1007/s10758-019-09432-7

Henze, I., van Driel, J. H., & Verloop, N. (2007). Science Teachers' Knowledge about Teaching Models and Modelling in the Context of a New Syllabus on Public Understanding of Science. *Research in Science Education, 37*, 99–122. https://doi.org/10.1007/s11165-006-9017-6

Johnson, L., Levine, A., Smith, R., & Stone, S. (2010). *The 2010 Horizon Report*. The New Media Consortium.

Karunanayaka, S. P., & Naidu, S. (2017). Impact of integrating OER in teacher education at the Open University of Sri Lanka. In C. Hodgkinson-Williams & P. B. Arinto (Eds.), *Adoption and impact of OER in the Global South* (pp. 459–498). https://doi.org/10.5281/zenodo.600398

Lipowsky, F., & Rzejak, D. (2015). Key features of effective professional development programmes for teachers. *Ricercazione, 7*(2), 27–51.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Proceedings of Telemanipulator and Telepresence Technologies, 2351*(34), 282–292. https://doi.org/10.1117/12.197321

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Nicolaou, C. T., & Constantinou, C. P. (2014). Assessment of the modeling competence: A systematic review and synthesis of empirical research. *Educational Research Review, 13*, 52–73. https://doi.org/10.1016/j.edurev.2014.10.001

Oh, P. S., & Oh, S. J. (2011). What Teachers of Science Need to Know about Models: An overview. *International Journal of Science Education, 33*(8), 1109–1130. https://doi.org/10.1080/09500693.2010.502191

Polly, D., McGee, J., Wang, C., Martin, C., Lambert, R., & Pugalee, D. K. (2015). Linking professional development, teacher outcomes, and student achievement: The case of learner-centered mathematics program for elementary school teachers. International Journal of Educational Research, 72, 26–37. https://doi.org/10.1016/j.ijer.2015.04.002

Prensky, M. (2001). Digital Natives, Digital Immigrants Part 1. *On the Horizon, 9*(5), 1–6. https://doi.org/10.1108/10748120110424816

Teichrew, A., Erb, R., Wilhelm, T., & Kuhn, J. (2019). Elektrostatische Potentiale und Felder im GeoGebra 3D Grafikrechner. *Physik in unserer Zeit, 50*(5), 254–255. https://doi.org/10.1002/piuz.201970513

Teichrew, A., & Erb, R. (2019). Analysis of learning with dynamic models and experiments in optics. In O. Levrini & G. Tasquier (Eds.), *Electronic Proceedings of the ESERA 2019 Conference. The beauty and pleasure of understanding: Engaging with contemporary challenges through science education, Part 3* (co-Ed. Fechner, S., & Vorhoeff. R.), (pp. 330–336). ALMA MATER STUDIORUM – University of Bologna.

Teichrew, A., & Erb, R. (2020). How Augmented Reality enhances typical classroom experiments: examples from mechanics, electricity and optics. *Physics Education, 55*, 065029. https://doi.org/10.1088/1361-6552/abb5b9

Upmeier zu Belzen, A., van Driel, J., & Krüger, D. (2019). Introducing a framework for modeling competence. In A. Upmeier zu Belzen, D. Krüger, & J. von Driel (Eds.), *Towards a competence-based view on models and modeling in science education* (Models and Modeling in Science Education, vol. 12.) (pp. 3–19). Springer.

Vogelsang, C., Laumann, D., Thyssen, C., & Finger, A. (2018). Der Einsatz digitaler Medien im Unterricht als Teil der Lehrerbildung - Analysen aus der Evaluation der Lehrinitiative Kolleg Didaktik:digital -. In C. Maurer (Ed.), *Qualitätsvoller Chemie- und Physikunterricht* (pp. 230–233). University of Regensburg.

Windschitl, M., & Thompson, J. (2006). Transcending Simple Forms of School Science Investigation: The Impact of Preservice Instruction on Teachers' Understandings of Model-Based Inquiry. *American Educational Research Journal, 43*(4), 783–835.

Winkelmann, J. (2021). On Idealizations and Models in Science Education. *Science & Education*. Advance online publication. https://doi.org/10.1007/s11191-021-00291-2

Winkelmann, J., Freese, M., & Strömmer, T. (2021). Schwierigkeitserzeugende Merkmale im Physikunterricht. Die Perspektive von Schüler*innen. *Progress in Science Education, 5*(2), 6–23. Advance online publication. https://doi.org/10.25321/prise.2022.1168

E-LEARNING TRAINING OF BIOLOGY TEACHERS WITH A FOCUS ON DIGITAL GAME DESIGN

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This work presents, in general, the intervention period of a PhD research in Educational Sciences, in the area of Educational Technology, with a focus on the training of Biology teachers for the development of constructionist teaching strategies, more precisely Digital Game Design (DGD). The research context is located in Portugal and in Rio Grande do Sul, Brazil, aiming to identify the DGD space in initial and continuous training of Biology teachers. In each context, two training courses were developed, one for practicing teachers and the other for teachers in initial training. The activities, in a total of sixty hours, were carried out through e-learning, supported by the Moodle platform, with a synchronous weekly meeting. During this period, teachers worked on their knowledge about Constructionism, Computational Thinking and Digital Game Design itself, developed on the Scratch platform (MIT). In addition to the challenges already inherent to teacher training, the concomitance of the COVID-19 pandemic impacted teacher participation, but also brought a new look into the need for frequent adaptation of teachers to current needs and the benefits of collaborative work within the school community.

Keywords: Technology in Education and Training; Initial Teacher Education; In-service Teacher Training.

INTRODUCTION

This work intends to present an overview of the activities developed in a teacher training course regarding the Design of Digital Games in Teaching Biology. The investigation entirely problematizes the space of Digital Game Design (DGD) in the initial and continuous training of Biology teachers in Portugal (PT) and Rio Grande do Sul (RS- Brazil). In a previous phase of this investigation, a documentary survey was carried out in the syllabus of training courses for Biology teachers in this research context. No mention was found to this teaching strategy. This result can corroborate the gap between initial teacher training and new educational technologies. In this way, the relevance of this topic is highlighted, as it precisely shows the need to include the DGD in the range of strategies presented to teachers in training, its feasibility as a training course and also as a teaching strategy in the classroom. The importance of reporting this experience is also evident, due to the fact that it was developed exactly during the adaptation period of both contexts surveyed to the pandemic caused by the SARS-Cov-2 virus.

Digital Game Design

Digital Game Design (DGD) is a Constructionist learning strategy, based on the creation and development of digital games by students, with the objective of learning topics of interest. As innovative as it may seem, this is not a new strategy. The Constructionist learning theory was proposed by Seymour Papert in the 1960s, inspired by his experience in teaching mathematics and in Piaget's theory of development.

It assumes that learning can be enriched and enhanced by using the computer, as long as it is the student who teaches the computer, and not the other way around. This theory of learning points out that students consciously build their intellectual structures, elaborating an external product, with the aid of a computer, where they can see the result of their reflection and action (Papert & Harel, 1991).

In this sense, the foundations of computational thinking are worked with students, based on challenges proposed in a virtual environment called *Microworld*. In this virtual environment, students can work out, test and develop hypotheses for solving problems (Papert, 1985). A very popular example and the choice for game development in this project was the Scratch platform (MIT Media Lab, 2021).

Projects developed by Scratch users can be narratives, presentations and games. These, after being published, are identified with the author's name and may be improved by other users. This improvement can happen through comments, made by the community and even the elaboration of new versions of another user's project (Resnick et al., 2009). These possibilities lead the community to engage in continuous and collaborative learning, which is also a prerequisite for constructionist learning.

It is worth highlighting some points that contribute to the development of digital games, which are also suitable environments for learning biology. The scientific method, in general, can be the basis for science teaching and learning (Aparecida et al., 2005; Demo, 2011). Therefore, in this investigation, was possible to approach the understanding of the scientific method to the DGD, comparing their steps: elaborating on a matter of interest;

developing research on the topic, developing and testing strategies for game design (hypothesis), reflecting on the feedback; adapting the project and present to peers.

DEVELOPMENT OF ACTIVITIES

The teacher training course “Digital Game Design: Building Constructionist Strategies for Biology teaching” was carried out for 12 weeks, a weekly synchronous meeting and a total of 60 hours of activities. For this, a Virtual Learning Environment was created on the Moodle platform.

Initially, b-learning format was used for continuous training, and on-site for initial training.The choice for the e-learning format for continuous training was due to the need to reach the full context: Portugal - throughout the whole country, and Rio Grande do Sul - throughout the whole state. In addition, there is greater engagement and flexibility of schedules for the participation of teachers working in the school context. In the initial training, a face-to-face intervention was planned, since the contexts surveyed were two teacher training courses, at partner universities: Universidade do Minho (PT) and Universidade Federal de Pelotas (RS). For both levels of training, face-to-face seminars to present the final projects were planned. The intervention process was planned in these phases:

- Disclosure: by sending e-mail to school groups and regional groups on social networks. To inicial training was make contact with the universities.

– Selection: to continuing education, were selected Teachers working in the subjects of Mathematics and Natural Sciences in the 2nd Cycle of Basic Education, or Biology and Geology in the 3rd cycle of Basic Education and Secondary Education. To initial training, students could be in any semester

– Development: the courses were developed in Portugal in the first semester of 2020 and, in Brazil, in the second semester.

After the selection, the teachers answered a questionnaire survey, self-assessing their Technological Pedagogical Content Knowledge (TPACK).) (Koehler & Mishra, 2009). This concept deals with the interactions between these dimensions for teachers to effectively integrate knowledge, strategies, technologies and content in their teaching activity. This survey was developed based on the work of Graham (2009) and Schmidt (2009).

In order to meet the needs of enrolled professors and the necessary demands related to shutdown periods determined by the authorities of each research context, the development of the course has undergone adaptations. The initial training courses were transferred to the e-learning mode. The Continuing Education course also had its modality fully adapted so that the final seminars for presenting projects were carried out through the Moodle platform.

The contents and activities developed were divided into modules, comprising from the theoretical bases, computational thinking and the Design of Digital Games itself. The activities were reflective but shared with colleagues through forums and presentation of class projects. In the last module, learning was resumed, with teachers writing a reflective text about the period of training. There were also self-assessment activities, through a new filling out of the TPACK survey and also a form for evaluating the course and the trainer.

CONSIDERATIONS ON SOME EMERGENT ASPECTS OF TRAINING

When proposing and developing a training course that deals with a sensitive topic for teachers, dealing with digital technologies through a collaborative teaching strategy and centered on the student, not the teacher, we faced several challenges and resistance, already known and mentioned in literature.

In addition to what was described, there were, simultaneously to the beginning of the course activities, the restrictions on circulation and social interaction, related to the pandemic of COVID-19. Therefore, the stressful situations related to the sanitary, social and economic uncertainties caused by the pandemic have been aggravated by the increase in working hours, adaptation to remote education and the home office. All of these issues may partly justify the difference between the number of new entrants and finalists in the course that was 50.5% on average in Initial Training and 30% in Continuous Training.

As it was possible to identify by the TPACK survey, we deal with a heterogeneous group in terms of knowledge and use of digital technologies in the classroom. The degree of confidence in the TPACK were important, both in adapting to the e-learning course and in the learning phase of the Scratch platform. The perception that the role of the teacher, in a constructionist class, is more to guide and monitor the students' productions, than to present didactic material or ready-made games, was an interesting turning point, especially in continuing education (Papert, 1993) On the other hand, in the reflective texts and surveys, the participants mentioned the overcoming of challenges of this period, as well as the adaptation of strategies and resources to current needs.

We emphasize here the understanding given by the empirical experience, that training in this context is viable at both levels and modalities. It is also worth mentioning that only training will not necessarily change an entire context and history of teaching practices. Teamwork and support from colleagues, that is, knowledge of context, according to the TPACK theory, comes to collaborate for the insertion of new teaching strategies in the school environment. This was clearly noticeable to teachers who had co-workers in the same training class and developed much more robust interdisciplinary DGD projects, which involved the school community more effectively.

The degree of confidence in the use of technological resources, within the theoretical perspective of TPACK, as well as the content analysis to be developed in reflective self-assessment texts, will be the basis for future work.

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REFERENCES

Aparecida, M., Marsulo, G., Rejane, E., & Ghisolfi Da Silva, M. (2005). Os métodos científicos como possibilidade de construção de conhecimentos no ensino de ciências. In *Nº* (Vol. 4).

Demo, P. (2011). *Educar pela pesquisa* (8.ª ed.). Autores Associados.

Jacobson, N. S. & Truax, P. (1991). Clinical significance: A statistical approach to defining change in psychotherapy research. *Journal of Consulting and Clinical Psychology*, *59,* 12-19.

Kafai, Y. B. (2005). Constructionism. Em R. K. Sawyer (Ed.), *The Cambridge handbook of the Learning Sciences* (pp. 35–46). Cambridge University Press. https://doi.org/10.1017/CBO9780511816833.004

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70.

https://tecfalabs.unige.ch/mitic/articles/koehler_mishra_2009_what_is_technological_pedagogical_content_kno wledge.pdf

MIT Media Lab. (2021). *Scratch - Sobre*. https://scratch.mit.edu/about

Papert, S. (1985). *Logo: Computadores e Educação*. Brasiliense.

Papert, S. (1993). *The Children's Machine: Rethinking School In the Age of the Computer*. Harvester Wheatsheaf.

Resnick, M., Maloney, J., Monroy-Hernández, A., Rusk, N., Eastmond, E., Brennan, K., Millner, A., Rosenbaum, E., Silver, J., Silverman, B., & Kafai, Y. (2009, Novembro). Scratch: Programming for All. *Communications of the Association for Computing Machienery*, 60–67. https://doi.org/https://doi.org/10.1145/1592761.1592779.

QUANTITATIVE VALUATION OF THE REPRESENTATIONAL SURVEILLANCE DIMENSIONS

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The visual representations are in the core of science teaching, so their role reviewing in teaching is a key point in science education research. A descriptive, exploratory pilot study with quantitative approach was carried out in order to value the four dimensions of Representational Surveillance process: Epistemic, Pedagogical, Cognitive and Contextual. The metacognitive nature of this process allows the teachers to examine visual representations used in their teaching practices. A group of 22 university science teachers voluntarily participated in this study. A paper-and-pencil task was applied in order to collect teachers' explanations about their habits of representational surveillance in their classes. Descriptive and inferential statistics was used in data analysis. The results showed an important imbalance in the different representational surveillance dimensions, and a particular underestimation of the visual representation context in the process. The tested methodology resulted appropriate to review the use of visual representations in science classes. Therefore, this would be added as a significant resource to review the educative work with visual representations in science teaching planning and practices in order to pose reflective thinking, and to enhance science teaching practices.

Keywords: Visual Representations, Teacher Professional Development, Science Education

INTRODUCTION

The external representations are in the very core of all the disciplines that take part of the widespread field of the Natural and Health Sciences. These are public cognitive instruments that make available things or ideas that are intangible or far from us, and therefore an important part of the communicative system of sciences. They are made by a set of signs and certain rules or codes that mediate between an object or phenomena and our possibilities of interpreting, knowing, redescribing and transforming or using them to do something.

Particularly, those which are displayed on a bidimensional surface are known as visual representations. They have a prominent role for natural science teaching because of their capabilities to communicate. When an object or phenomena is described, the different semiotic systems (linguistic, mathematics, visual representations) act synergistically, revealing particular aspects of the same that offer a more complete understanding of the situation. For this reason, visual representations contribute to the meaning construction while they are being used as cognitive prosthesis (Pozo, 2017). Consequently, they are always present in science education, and they set up several conditions for science teaching and learning. Therefore, learning is settled by the external representation in use (Andrade, Freire, Baptista & Shwartz, 2022).

However, a great diversity of visual representations that are usually used in different ways and with diverse purposes exists. According to their ownership, the visual representations have been classified (Postigo & Pozo, 2004) as:

- Graphs, when a quantitative relation among the elements is considered
- Diagrams, when a conceptual relation is depicted
- Maps and sketches, when some selective spatial relations are represented
- Drawings and pictures, when it is intended to represent some reproductive features.

The visual representations are a fundamental part of the learning environment, so it is necessary to know the way that they are presented and used in science teaching practices to enhance teaching and learning, taking into account their rules and restrictions. In this sense, they are part of the semiotic hybrid that take part in the communication process, they hold the experimental work and enable the empirical data analysis.

Throughout science education, the graphical or visual literacy process must help students to go beyond the explicit and implicit processing levels to reach the conceptual one. Hence it is necessary to rethink traditional teaching practices where the representations are just considered as clear and easy objects to be grasped from transparent rules of understanding (Treagust, 2018). To do that, decision making should be founded on the different uses of visual representation (García García y Perales, 2006) as follows:

The *pedagogical use* that refers to the teacher's communicative intention:

- Expositive: visual representations are used to describe objects, models or phenomena.
- Problem-solving: visual representations are used to solve questions or problems.
- Instrumental: visual representations are used as tools in experimental activities.

The *scientific use* related with the nature, methods and characteristics of the research:

- Experimental: visual representations are used to represent the behaviour of a set of data.
- Theoretical: visual representations are used as a theoretical model about the behaviour of phenomena.

The studies about visual representations in science education have been flourishing from the past decades (Gilbert & Treagust, 2009, Treagust & Tsui, 2013). Some of them were focused on the graphical or visual competence, the presence of visual representations in explanations and activities included in science textbooks. Others were trying to identify some preservice teachers' understanding of several specific topics (Akaygun, Adadan & Kelly, 2019, Tippett & McClune, 2019) or to compare the role of visual representations in science learning and scientific practices (Evagorou, Erduran & Mäntylä, 2015). Nowadays, renewed interest exist about the role of visual representations when students are engaged in metacognitive activities that require making external representations during problem-solving (Ijirana, Mansyur, Rizal & Aminah, 2021) and the way that they can enhance people's understanding of the information in the current times of the big data and other experiences mediated by technologies.

According to the previously mentioned, the educative practices need to be reviewed taking into account the features of the semiotic systems that the teachers display while teaching science. In addition, the impressive changes occurred because of the pandemic of COVID-19 have posed a new challenge to keep teaching alive. Circumstances such as the emergency remote teaching (Hodges, Moore, Lockee, Trust & Bond, 2020) or the new hybrid learning settings (Tyagi, 2021) appeal for the development of new interfaces (Scolari, 2018) to guarantee pedagogical continuity and to enable the experimental activities in digital supplies. Consequently, the usage of visual representations is maximized these days and deserve special attention, which will likely increase in the next years.

Therefore, during science education, a graphicacy process is promoted. This requires the observation of the different aspects of the representational nature and the semiotic cognitive activities. In order to do that, the *Representational Surveillance* is the appropriate mechanism of control. It is a metacognitive process, which is useful in order to examine the role of the visual representations in science teaching and learning. As a systemic strategy to collect key evidence which spotlight their attention on the following four main dimensions:

- *Epistemic*, it is centred in each type of visual representations as a specific domain of knowledge. It includes their features and the quantity of informative elements that can be recognised in them.
- *Pedagogical*, it focusses on the application of visual representations in several teaching practices (planning, lectures, presentations, written tasks, experimental activities) and the way that they participate in the learning activities proposals and assessment.
- *Cognitive*, it refers to the students processing and interpreting the information included in the visual representations in order to construct scientific knowledge as well as the obstacles that could disturb the learning processes.
- *Contextual*, it pays attention to the role of visual representations in natural educative environments (academic, professional and daily life).

Moreover, each of these dimensions are constituted by four items (Table 1) which, all of them, require to be considered in a complete and harmonious process of surveillance. In this way, this new proposal offers a diagnostic tool to the teachers and researchers community in order to review the science teaching practices. So, they will be able to supervise and monitor the diversity of visual representations aspects included in the teaching and learning.

In the line of this theoretical framework, the objective of this work is to present the application of this new proposal to a quantitative valuation of the representational surveillance dimensions.

METHODOLOGY

This first study was conducted in order to describe the representational surveillance process in natural sciences teaching practices. A descriptive, exploratory pilot study with quantitative approach was carried out.

Participants: A group of 22 science university teachers (8 men and 14 women) of *Universidad de la República* of Uruguay voluntarily participated in this research. They teach some subjects in Veterinary, Medicine, Nursing and Agronomy careers with 3-25 years of teaching experience.

Instrument: An open paper-and-pencil task was applied in order to collect teachers' explanations about the different aspects of teaching and learning *of* and *with*, visual representations that should be taken into account during the representational surveillance process. Teachers were invited to respond the following request:

'Please, propose, at least, five inherent aspects of teaching and learning of *and* with *visual representations which should have particular representational surveillance. Write a text (around 1500 words) to complete each of these aspects to justify their importance and explaining how you would do that.'*

Data analysis: In order to value the texts written by the participants, relevant statements were recognized and classified according to the four dimensions. A discrete dichotomy variable was proposed and presence/absence was registered, thus the range of values was between a minimum of 0 to a maximum of 4 (Table 1):

Table 1. Dimensions and its valuation (VR: Visual Representations).

Dimension	As includes references to:	Values
Epistemic	1) Type of VR. 2) Representational character of discourse. 3) Sources of VR. 4) Quantity of information of VR.	0 a 4
Pedagogical	1) Pedagogical use of VR. 2) Proposed activities. 3) Multiple Representational Teaching models. 4) Assessment	0 a 4
Cognitive	1) VR processing. 2) Students' knowledge about VR. 3) Cognitive difficulties related with VR. 4) Procedural contents that include VR	0 a 4
Contextual	1) VR in schooling. 2) VR in professional activities. 3) VR in research activities. 4) VR in daily life.	0 a 4

Descriptive and inferential statistics was used in data analysis (SPSS v. 22). The statistical central tendency, medians and the first and third quartiles were calculated to estimate the dispersion. To detect global difference among medians, no parametric test of Friedman with 0.05 signification level was applied. To identify the significant differences among dimensions, Wilcoxon test of ranges and signs with Bonferroni correction was applied.

RESULTS AND DISCUSSION

The analysis of the collected teachers' explanations and reflections related to the different aspects of the visual representations showed that the participants could recognise a different number of the elements that need to be surveilled (Table 2).

Table 2. Examples of teachers' explanation by dimension analysed.

Dimension	EXAMPLES
Epistemic	P5: 'To review the type of visual representations in teaching proposal is fundamental' P7: 'It is necessary to include graphs with different amount of information' P13: 'Histology has its representational discourse. This must be explicitly enlightened in teaching'
Pedagogical	P17: "We must guarantee that the visual representations aren't used only to expose, but also to pose problems" P15: 'When we are planning our classes, it is important to review if the activities include the construction and the conversion of different graphic representations P5: 'The classes' planification and also, the pedagogical material design must be carried out including multiple representations of the subject-contents'
Cognitive	P8: 'It´s essential to check the processing level that is claimed by each visual representations' P12: 'Students have to get over different difficulties to access to graphic information and everyone can do it at the same time. That is the reason why we have to be conscious of their progress in such abilities so that can take them into account in our teaching proposal' P14: 'Students have very varied ideas about what the visual representations are and what they are for. These ideas must be checked to take them into account in the planification'
Contextual	P20: 'We need to be sure that visual representations used in clinical laboratory are present' P15: 'An aspect of particular interest is the inclusion of visual representations that appear in the papers that we use in the research'

The epistemic, pedagogical and cognitive dimensions were more considered by the professors than the contextual one as are shown in Table 3. These outcomes could be interpreted like an expression of their attributions to central topics in the educative process.

Table 3. Medians and interquartile range.

Dimension	Media	Interquartile range
Epistemic	2	1 a 3
Pedagogical	2	1 a 2,25
Cognitive	2	1 a 2
Contextual	0	0 a 1

The analysis of the statistical data reveals that significant differences existed according to the value of the dimension considered ($\chi 2 = 21{,}348$, $p < 0{,}0001$). It is to say that representational surveillance dimensions are not equally taken into account by the teachers (Figure 1) and with media scores that are not higher than 2 corresponding just to two of the mentioned items of the four of each dimension.

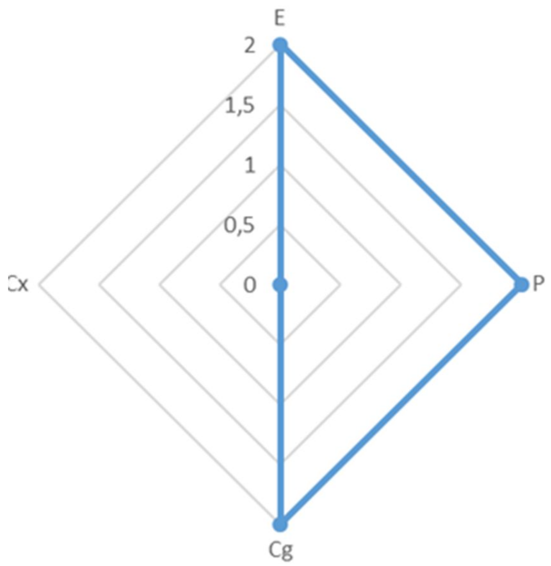

Figure 1. Score by dimension. E: Epistemic, P: Pedagogical, Cg: Cognitive, Cx: Contextual.

The post-hoc test with Bonferroni correction ($p < 0{,}01$) displayed significant differences between the contextual dimension and the others (contextual vs epistemic, $p = 0.001$; contextual vs. pedagogical, $p= 0.001$; contextual vs cognitive, $p = 0.001$). The other dimensions were not significant (epistemic vs pedagogical, $p = 0.236$; epistemic vs cognitive, $p = 0.138$; pedagogical vs cognitive, $p = 0.542$).

These results show up that the contextual dimension is the least considered by the teachers when they have to comment about how they include visual representations in their teaching practices. In a similar way, this could be thought about the cognitive dimension (a major sample of date is required to confirm this idea).

In sum, from this particular group of university teachers, an important underbalance of the different representational surveillance dimensions was detected. Epistemic and pedagogical dimensions were the most considered by the teachers. The cognitive one was in a minor consideration, and contextual dimension was almost ignored by the majority of the participants.

CONCLUSION AND PERSPECTIVES

This work exposes a significant contribution in two complementary coordinates. The first one is the enlargement of the knowledge about the science teaching practices related to visual representations and their foremost aspects that require to be surveilled during science teaching and learning. Secondly, it offers a comprehensible tool to access to the teachers' knowledge and other valuable information. Both of them constitute a relevant resource to achieve teachers' professional development, mainly at university level where pedagogical teachers training is an indisputable requirement of these uncertain days.

Although all the participants were university teachers of scientific and technological courses of studies, the poor consideration given by them to the contextual dimension is at least disturbed. Even more taking into account that visual representations are also essential not only in the professional development of the future university graduates but also in the daily life of all the citizens.

The new methodological strategy to analyse the representational surveillance in science teaching yielded an evidence of its utility. Visual representations are seen in the core of the scientific knowledge construction as a crucial feature of the graphicacy settings. In addition, it would be added as a significant resource to review the educative work with visual representations in science teaching planning and practices in spaces of teacher education.

The noticeable results of this study could be considered as a milestone in future research with a large number and diversity of participants. Besides, it is a contribution in order to rethink teaching practices from STEM approach or other holistic points of view.

Finally, considering the high relevance of visual representations, this work opens an attractive line of research that recognises the central role of the teachers in the supervision of learning environments, as individuals, and mainly, as a collective group.

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REFERENCES

Akaygun, S., Adadan, E., & Kelly, R. (2019). Capturing preservice chemistry teachers' visual representations of redox reactions through storyboards. *Israel Journal of Chemistry*, *59*(6-7), 493-503. https://doi.org/10.1002/ijch.201800133

Andrade, V. D., Freire, S., Baptista, M., & Shwartz, Y. (2022). Drawing as a Space for Social-Cognitive Interaction. *Education Sciences*, *12*(1), 45. MDPI AG. http://dx.doi.org/10.3390/educsci12010045

Evagorou, M., Erduran, S. & Mäntylä, T. (2015). The role of visual representations in scientific practices: from conceptual understanding and knowledge generation to 'seeing' how science works. *International Journal of STEM Education*, *2* (11). https://doi.org/10.1186/s40594-015-0024-x

García García, J. J., & Perales, F., (2006). ¿Cómo usan los profesores de química las representaciones semióticas? [How do the Chemistry teachers use the semiotic representations?] *Revista Electrónica de Enseñanza de las Ciencias*, 5(2), 247-259. http://reec.uvigo.es/volumenes/volumen5/ART3_Vol5_N2.pdf

Gilbert, J. K. & Treagust, D. (Eds.) (2009). *Multiple Representations in chemical education*. Dordrecht, The Netherlands: Springer.

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020). The Difference Between Emergency Remote Teaching and Online Learning. https://er.educause.edu/articles/2020/3/the-difference-between-emergency-remote-teaching-and-online-learning

Ijirana, I., Mansyur, J., Rizal, M., & Aminah, S. (2021). Longitudinal Study of Metacognitive Skills and External Representation of Students in the Context of Problem-Solving. *Indonesian Journal on Learning and Advanced Education (IJOLAE), 3*(3), 194-206. doi:https://doi.org/10.23917/ijolae.v3i3.13563

Postigo, Y. & Pozo J. I. (2004). In the road to graphicacy: the learning of graphical representation systems, *Educational Psychology*, 24(5), 623-644. https://doi.org/10.1080/0144341042000262944

Pozo, J. I. (2017). Learning beyond the body: from embodied representations to explicitation mediated by external representations. *Infancia y Aprendizaje: Journal for the Study of Education and Development*, 40(2), 219-276.

Scolari, C.A. (2018). *Las Leyes de la Interfaz. Diseño, ecología, evolución, tecnología. [The laws of the interface. Design, ecology, evolution, technology].* Barcelona: Gedisa.

Tippett, C., & McClune, W. (2019). *Pre-service science teachers' use of visual representations when communicating science information*. In The beauty and pleasure of understanding: engaging with contemporary challenges through science education.", Bologna, Italy. https://pure.qub.ac.uk/en/publications/pre-service-science-teachers-use-of-visual-representations-when-c

Treagust, D. F. (2018). The Importance of Multiple Representations for Teaching and Learning Science. In M. Shelley y S. Kiray (Eds.), *Education Research Highlights in Mathematics, Science and Technology 2018*: ISRES. https://www.isres.org/the-importance-of-multiple-representations-for-teaching-and-learning-science-97-s.html#.YfQU-urMLb0

Treagust, D. F. & Tsui, C. (2013.), *Multiple Representations in Biological Education*, Springer

Tyagi, M., Singh, K., Goel, N., & Sharma, R. (2021). Hybrid perspectives in higher education. *Cosmos An International Journal of Art & Higher Education*, *10*(2), 36-38. https://cosmosjournals.com/wp-content/uploads/2021/09/CAHE-JD21-Richa-Sharma.pdf

PHYSICAL SCIENCES TEACHERS' BELIEFS ABOUT THE UNIT FACTOR METHOD FOR SOLVING STOICHIOMETRY CALCULATIONS: THE SOUTH AFRICAN CASE

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South African Physical Sciences (SA PS) teachers have difficulty recognising when it is appropriate to apply proportion in stoichiometry calculations. A possible solution is encouragement of use of a generic proportion method, the unit factor method, through professional development opportunities. According to the Theory of Planned Behaviour (TPB), uptake behaviour is affected by relevant beliefs. Therefore, measuring teachers' beliefs regarding the unit factor method, and determining biographical factors which affect these beliefs, may help inform teacher educators of the likelihood of the unit factor method being received favourably by various groups of teachers. To this end, a 14-item Likert-scale questionnaire was administered to 159 SA PS teachers immediately after they had attended a two-day stoichiometry professional development workshop which introduced them to the unit factor method. The questionnaire was designed to measure the three constructs of beliefs according to TPB, in relation to teaching learners to use the unit factor method to solve stoichiometry calculation questions. Data were also collected using an open-response item and biographical questions. Furthermore, a count of the number of written calculation questions (/4) for which the unit factor method was used, was obtained for each participant. The quantitative data were analysed using descriptive and inferential statistics. Inductive content analysis was performed on the qualitative data. Although the unit factor method was hardly used at the start of the professional development intervention, by its end the teachers, irrespective of qualification, experience level and the context in which they taught, tended to be favourably disposed to its use. However, a two-day intervention appears to have been too short for many of the teachers to gain enough confidence with the method for likely realisation of professed intentions regarding uptake of the method.

Keywords: In-service Teacher Education, Teacher professional development, Values in Science Education

INTRODUCTION

Proportionality is the central concept of stoichiometry, which forms a large part of chemistry curricula around the world, including the chemistry component of the South African Physical Sciences (SA PS) curriculum (DBE, 2011). It is therefore essential to empower Physical Sciences teachers to be able to use and teach proportion. This is particularly true for those who have difficulty with proportion, which includes most SA PS teachers (Selvaratnam 2011). The unit factor method, also called the factor label method or dimensional analysis (DeMeo 2008), is a generic proportion method which can provide effective support to people who find proportional reasoning difficult (Gabel and Sherwood 1983). In this method the question's given value is multiplied by a conversion factor which is the proportional relationship between given and required variables and which is, in effect, unity, since its numerator and denominator are equivalent. The given and required units guide the process, reducing cognitive load (DeMeo 2008) and increasing the likelihood of correct execution of calculations involving proportion (Gabel and Sherwood 1983). Currently, SA PS teachers tend to underutilise proportion, to the detriment of their stoichiometry solution success, possibly partly due to an overemphasis on formulae (Stott 2021). Use of a generic proportion method such as the unit factor method might help direct these teachers' focus towards, and develop competence in, proportion, since the method is inherently proportional and it can be applied to any proportion-related topic, thus potentially replacing multiple narrowly applicable formulae.

PROBLEM STATEMENT

Despite these potential advantages of the unit factor method for improving teachers' stoichiometry subject matter knowledge and teaching competence, it is not clear that SA PS teachers would choose to adopt the method for their own stoichiometry calculations and in their stoichiometry teaching. According to the Theory of Planned Behaviour (TPB), beliefs affect intentions, which affect behaviour (Ajzen 2011). Therefore, understanding SA PS teachers' beliefs regarding the value of using and teaching use of, the unit factor method for stoichiometry calculations, their intentions to use the method, and the biographical factors affecting these, would provide insight into the likelihood of various groups of teachers adopting this method in their teaching. Such insight would be valuable for directing teacher education initiatives.

Consequently, this study's aim is investigation of the beliefs and intentions of South African Physical Sciences teachers regarding use of the unit factor method for solving reaction-based stoichiometry questions, at the end of a two-day professional development workshop at which the teachers were exposed to this method. The research is guided by the questions: (1) What beliefs and intentions did these teachers profess regarding the unit factor method? (2) How were these professed beliefs related to the teachers' teaching experience, educational background and the socioeconomic status of the school at which they taught? (3) How were these professed beliefs and intentions related to the extents to which the teachers used the unit factor method in the post-test, and what does this indicate about the validity of these professed beliefs and intentions?

BACKGROUND LITERATURE

The three constructs of the TPB are attitude beliefs, subjective norms and perceptions of behavioural control (Ajzen 2011). In terms of SA PS teachers' likelihood of embracing the unit factor method in their stoichiometry teaching, the following is a brief review of literature relevant to each of these constructs. Teachers in developing world contexts, such as South Africa, tend to be particularly constrained by their attitude beliefs regarding what will earn higher marks in examinations (Makhechane and Qhobela 2019). Particularly relevant to such attitude beliefs, as well as to perceptions of what significant others may expect of teachers, i.e., subjective norms, is a perception that current examination marking practices tend to disadvantage use of the unit factor method (Stott 2021). Relevant to both attitude beliefs and perceptions of behavioural control is the finding that people with high mathematical anxiety levels tend to find stoichiometry in general (Ralph and Lewis 2018), and the unit factor method in particular, (Gabel and Sherwood 1983) difficult. This is particularly relevant since a high proportion of SA learners (Reddy, Visser, Winnaar, Arends, Juan, Prinsloo, and Isdale 2016) and even SA PS teachers (Selvaratnam 2011) display low levels of mathematical competence. Furthermore, successful use of the unit factor method requires an understanding of stoichiometrically equivalent values, which SA PS teachers, particularly those without Bachelor of Science (BSc) degrees and who teach learners of lower socioeconomic status, tend both to be poor at, and to show little progress in developing across at least a short (two-day) professional development intervention (Stott 2020).

METHOD

This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright 2011). Data were collected from South African Physical Sciences teachers who attended a two-day stoichiometry professional development workshop at which I taught them how to use the unit factor method to solve stoichiometry calculation questions. I held eight of these workshops throughout the Free State province of South Africa, between November 2017 and March 2018. The Physical Sciences subject advisors extended an open invitation to the teachers in their area to attend, with the incentive that they would receive teaching resources and earn continuous professional development points. A total of 220 teachers attended these workshops. However, the sample relevant to this study is a sub-group of this (n = 159), since only teachers who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included. Although this convenience sample cannot be claimed to be representative of the population of South African Physical Sciences teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 47 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 47: Characteristics of the sample.

Socioeconomic status of the learners taught	Possess a Bachelor of Science (BSc) degree	Stoichiometry teaching experience category	N
High (teach at a quintile 5 school) n = 15 (9%)	No (n = 8)	Inexperienced*	5
		Moderately experienced**	3
		Experienced***	0
	Yes (n = 7)	Inexperienced	2
		Moderately experienced	1
		Experienced	4
Low (teach at quintile 1-4 schools) n =144 (91%)	No (n = 94)	Inexperienced	48
		Moderately experienced	19
		Experienced	27
	Yes (n = 50)	Inexperienced	26
		Moderately experienced	14
		Experienced	10

Years' experience teaching stoichiometry: *0-3 **3>10 ***10 or more

Within the pragmatic paradigm, validity is determined by warrantability, which is affected by internal consistency and logic (Plowright 2011). Consistent with this, a questionnaire was designed specifically for this study, informed by relevant literature, the theoretical framework used in this study (TPB), and the research questions. This questionnaire was used to measure the teachers' beliefs regarding use of the unit factor method for stoichiometry calculations and was administered at the end of the two-day workshop. This questionnaire consisted of: 14 Likert scale items (see Table 48) with a 5-scale level of agreement for each (see the key to Figure 33 for the wording of these levels); an open response item; four questions regarding qualifications, teaching experience, and school. As indicated in the last column in Table 48, three of the Likert scale items refer to prior usage and intentions for future usage, of the unit factor method, six questions measure various aspects regarding relevant attitude beliefs, two regarding subjective norms and three regarding perceptions of behavioural control.

Table 48: The statements given in the 5-scale Likert questionnaire items, the code used to refer to each, and the category each question falls into.

Question	Statement	Code	Category
1	I have used the unit factor method **in the past** to help me **solve problems myself**.	Prior personal use	Prior use
2	I have used the unit factor method **in the past in my teaching**.	Prior teaching use	
3	I plan to use the unit factor method **in the future** in my **teaching**.	Future planned use	Future planned use
4	Using the unit factor method has / will **improv(ed) my teaching.**	Improve teaching	Attitude beliefs
5	The unit factor method makes stoichiometry **easier.**	Ease learning	
6	The unit factor method makes learners learn stoichiometry **better.**	Learning improvement	
7	There are **better ways** to teach stoichiometry than the unit factor method. (Reversed item)	The best way to teach	
8	Using the unit factor method in stoichiometry teaching **saves time.**	Time saver	
9	If learners use the unit factor method in **exams,** they will get **higher** marks.	Mark raise	
10	My **subject advisor/principal/head of department/learners' parents** will **encourage** me to use the unit factor method in my teaching.	Adult encouragement	Subjective norms
11	My **learners will want** me to use the unit factor method in my teaching.	Learners will want	
12	I **know** how to use the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence self	Perceived behavioural control
13	I know how to **get learners to use** the unit factor method to **solve** stoichiometry problems **myself**. I feel confident to do this.	Confidence teach	
14	My learners are **too slow and weak** to learn the unit factor method in the **time** available. (Reversed item)	Learners not too slow and weak	

The two-day intervention consisted of roughly four hour-long periods of interactive direct instruction, interspersed with four two-hour-long periods of individual written work using a structured workbook and supported by small-group discussion. These activities were focused on developing an understanding of the mole concept and proportion, and application of these within the unit factor method. The participants answered stoichiometry pre- and post- tests at the start and end of the intervention, respectively. Relevant to the third research question, the number of questions (/4) for which each teacher used the unit factor method, was recorded for each participant for the four calculation questions in the post-test. These questions were similar to those reported on in Stott (2021), i.e. to the pre-test calculation questions.

The following data-transforming techniques were used during data analysis: (1) the reverse-score (6 minus score) was used for the reversed items (questions 7 and 14); (2) averages (/5) were calculated for each of the three belief components of the Theory of Planned Behaviour, with the question responses included in each of these indicated in Table 48; (3) a Belief Index (/55) was calculated from a sum of all except the first three (prior-use and intended future use) Likert-scale responses.

To answer the first research question, the Likert scale questionnaire responses were analysed using descriptive statistics and the open response questionnaire responses were categorised according to emerging themes. To answer the second research question, relationships were sought between the Likert scale questionnaire responses and the biographical data. This was done in a pragmatic and iterative manner, using correlation, t-test and ANOVA statistics and using pivot tables and graphs to group and represent the data in various ways to search for patterns. To answer the third research question, correlations were sought between the count (/4) of questions for which the unit factor method was used in the post-test and: (a) the Belief Index (/55); (b) the response to question 3 (/5), referred to as the Intentions Index.

RESULTS AND DISCUSSION

Professed beliefs and intentions regarding the unit factor method

Figure 33 shows the numbers of participants who indicated each of the five levels of agreement offered for each of the statements given in This is a pragmatically conducted mixed-methods survey study guided by the framework for integrated methodologies (FraIM) (Plowright 2011). Data were collected from South African Physical Sciences teachers who attended a two-day stoichiometry professional development workshop at which I taught them how to use the unit factor method to solve stoichiometry calculation questions. I held eight of these workshops throughout the Free State province of South Africa, between November 2017 and March 2018. The Physical Sciences subject advisors extended an open invitation to the teachers in their area to attend, with the incentive that they would receive teaching resources and earn continuous professional development points. A total of 220 teachers attended these workshops. However, the sample relevant to this study is a sub-group of this (n = 159), since only teachers who completed all the data sources relevant to the analyses conducted here and provided informed written consent for their data to be included in this study, are included. Although this convenience sample cannot be claimed to be representative of the population of South African Physical Sciences teachers, there were no externally imposed biases to inclusion in the sample. Characteristics of the sample are given in Table 47 to enable readers to judge the generalisability of claims made to the broader population. Before data collection commenced, ethical clearance was awarded by the University of the Free State (UFS-HSD2017/1520).

Table 47 Note that the reversed scores are plotted here for the two reversed items (7 and 14), which is why the captions for these items are worded positively, rather than in their original negative form. The first two columns show very low levels of prior use of the unit factor method, in stark contrast to DeMeo's (2008) finding that the unit factor method (dimensional analysis) was used by 90% of his sample of high school and university chemistry teachers mainly from the United States of America. Besides these first two columns, the general impression given by Figure 33 is high extents of moderate, strong and very strong, agreement with favourable statements about the teachers' intention to use the unit factor method in the future and the method's usefulness for performing, and teaching, stoichiometry calculations. This corresponds to the finding that only two of the 94 answers to the open response items displayed any negativity towards the unit factor method. These two both referred to national marking practices which would likely penalise use of the unit factor method: "Learners get marks for using formulae and substitutions. Not sure if they'll get marks with the unit factor method."; "I am worried about the memorandum discussion that might not recognise the unit factor method. A guideline in terms of mark allocation would be required so that it can be included in exams." See Stott (2021, p. 454) for suggestions for such guidelines.

The teachers' responses to the attitude belief items of the questionnaire (Columns 4 to 9 in Figure 33), while generally positive, are somewhat erratic, possibly undermining reliability to some extent. The following themes emerged, regarding attitude beliefs, from the open-ended responses regarding the unit factor method: (1) poses initial difficulty (4 comments); (2) improves stoichiometry understanding and generic problem solving (7 comments); (3) makes stoichiometry easier (15 comments); (4) will improve learner performance in stoichiometry (15 comments). It is possible that incorporation of games (e.g. Saitta et al., 2011) and heuristics (e.g. Krieger, 1997) in teacher-education workshops such as these, may help overcome the initial difficulty reported, e.g. "The first time when this method was introduced, I felt like it was difficult, but now I am so excited because after this workshop I realise that this is the easiest method and it saves time." The following comments suggest resolution of the apparent contradiction between this comment, regarding the unit factor method saving time, and the many (33) comments about the method taking a long time to learn: "I think in spending more time on the unit factor method it will save time later in other topics as well"; "Method very much good, could help in handling any problem that requires conversion. I love it and impressed about it." These comments suggest that the generic nature of the unit factor method makes it a versatile time-saver once it has been mastered.

The perceptions of behavioural control dimension (see the last three columns in Figure 33) was the least favourable, on average, of the three TPB dimensions. This corresponds to the finding that 33 of the 94 open-response items referred to the need for more time to practice using the method than was provided in this two-day workshop. For example: "The unit factor method used during the workshop is easy, but one needs time to go back and practice it so that I can master it to be able to teach my learners"; "Very fruitful, but needs more time than these two days".

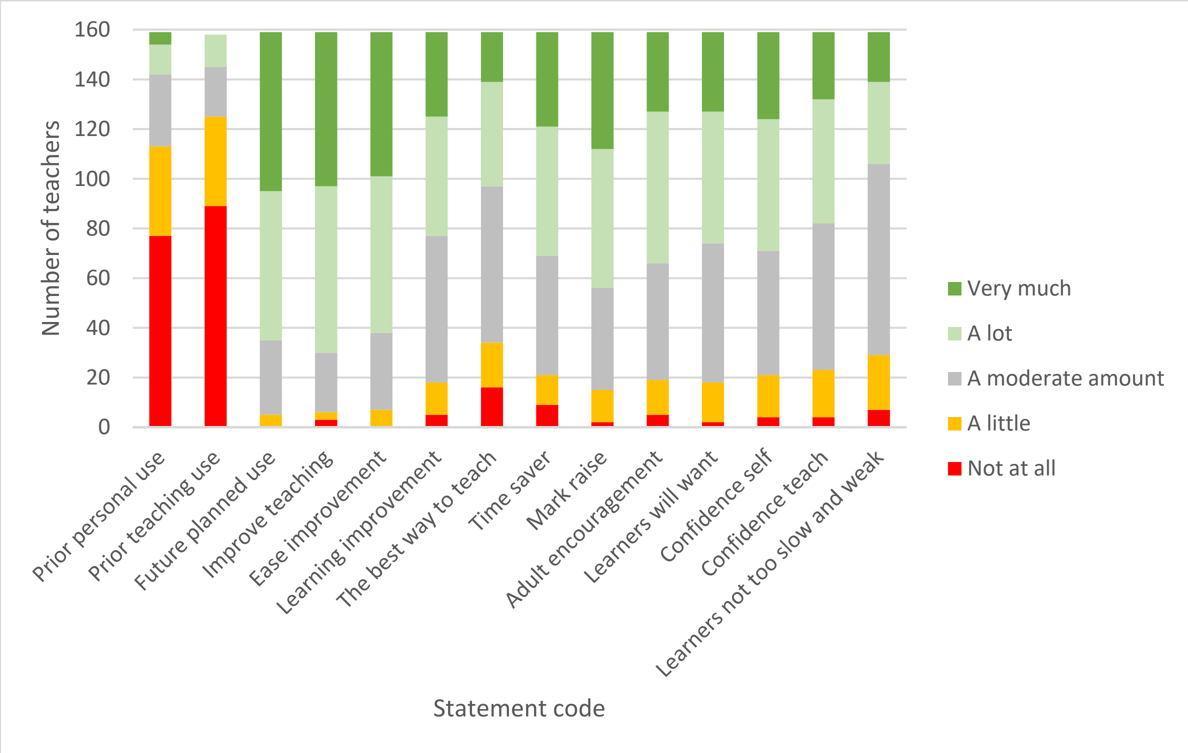

Figure 33: The number of teachers who indicated each of the provided Likert-scale levels of agreement to each of the questionnaire statements about usage, intentions, and beliefs regarding the unit factor method. See Table 2 for the full statement that corresponds to each statement code.

As shown in the final column in Figure 1, the final statement, about learners being too slow and weak to learn the unit factor method effectively, provided considerable concern. However, this concern may apply to stoichiometry, rather than only to the unit factor method. No relevant open-ended comments were made to clarify this. Stoichiometry is known to be particularly difficult for learners with low mathematics competence (Ralph and Lewis 2019), which South African learners, generally, are known to be (Reddy, Visser, Winnaar, Arends, Juan, Prinsloo, Isdale, et al. 2016). Furthermore, since many South African Physical Sciences are also known to have low mathematics competence (Selvaratnam 2011), it is unsurprising that 33 of the teachers remarked that a two-day workshop was not long enough for them to develop confidence in the unit factor method. Perhaps any method would have received the same criticism. Further research would be needed to determine the validity of this speculation.

Relationship between professed beliefs and teaching and qualification factors

No statistically significant relationships could be found between the beliefs the teachers professed towards the unit factor method and the teaching and qualification factors measured in the questionnaire. Figure 34 shows the average ratings assigned to questions about attitude beliefs, subjective norms and perceived behavioural control, for teachers without (n = 102) and with (n =57) a BSc degree, plotted according to their stoichiometry teaching experience level. Consistent with Figure 33, a general average slight positivity is evident, with all averages being in the range between 3 (*moderately agree*) and 4 (*agree a lot*) out of 5. Also consistent with Figure 34, except for both the experienced groups, attitude beliefs are the highest and perceptions of behavioural control the lowest.

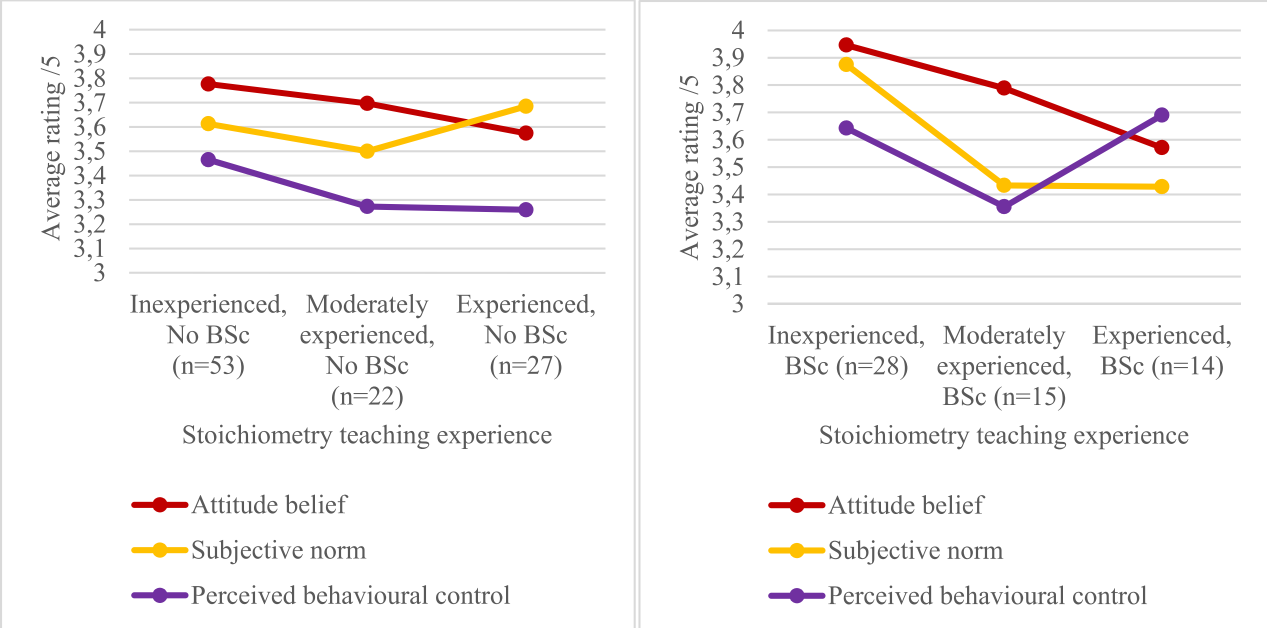

Figure 34: Belief profiles, regarding use of the unit factor method, for teacher groupings according to experience and qualification: Graph a: no BSc, n=102; Graph b: with BSc, n=57.

As shown in Figure 34, on average the teachers who had taught stoichiometry for 3 years or fewer (inexperienced category, $n = 81$) held the most positive beliefs regarding the unit factor method ($M = 41.0/55$, $SD = 54.3$). However, this was not found to be statistically significantly different to the beliefs of those who had taught stoichiometry for 4-9 years (moderately experienced category, $n = 37$, $M = 39.3/55$, $SD = 42.5$) or for 10 years or more (experienced category, $n = 41$, $M = 38.9/55$, $SD = 40.0$), $F(2, 156) = 1.6$, $p = 0.2$. The teachers with a BSc degree (Figure 34b) ($M = 40.9/55$, $SD = 54.9$) were more positive, on average, than those without a BSc degree (Figure 34a) ($M = 39.6/55$, $SD = 44.5$). However, this was also not found to be statistically significant, $t(157) = -1.2$, $p = 0.2$). The teachers teaching at schools serving learners of low socioeconomic status held more positive beliefs about the method ($n = 144$, $M = 40.1/55$, $SD = 49.1$), on average, than their counterparts ($n = 15$, $M = 38.9/55$, $SD = 41.8$), although this was also statistically insignificant, $t(57) = -0.7$, $p = 0.5$). The small size of the latter group should be noted.

Relationships between professed beliefs and intentions and extent of post-test usage

The third research question refers to the relationship between the teachers' professed beliefs and intentions regarding the unit factor method and the extents to which they chose to use this method in the post-test. The purpose of this research question is to evaluate the validity of the questionnaire based on the TPB's premise that beliefs affect intentions which affect behaviour (Ajzen 2011). The inconsistency of the contexts referred to by the various measures should, however, be noted. The professed beliefs and intentions are related to the teachers' use of the unit factor method in their teaching, whereas the measured behaviour refers to the teachers' own use of the unit factor method in answering a test immediately after the 2-day intervention. So, for example, some teachers with relatively low beliefs about the value of the unit factor method in teaching and learning might have felt that they were expected to use the unit factor method in this test since it followed an intervention focused on this method. This concern is reduced by the fact that the teachers were instructed to use whichever method they wished when answering this test. As a further example of concern, teachers with favourable beliefs regarding use of the unit factor method in the future after additional practice, might have felt safer, under test conditions, to resort to their previously used methods. Nevertheless, it is assumed that although these limitations will weaken any relationships detectable between the measured indices, a valid questionnaire should enable their detection to some degree.

Following from this reasoning, the findings given in Table 49 are taken to suggest that the Belief Rating (/55), obtained from 11 of the questionnaire items, has acceptable validity, whereas the Intention Rating (/5), obtained from a single questionnaire item, likely does not. Table 49 shows that a statistically significant weak positive correlation was found between the beliefs the teachers professed regarding the unit factor method's value in learning and teaching stoichiometry, and the extent to which they used the unit factor method in their own calculations in the post-test. In contrast, the teachers' professed intention to use the unit factor method in their teaching in the future showed no significant correlation to the extent to which they used the method in the post-test.

These findings suggest that this study's detection of: (1) generally positive beliefs towards the unit factor method can be trusted, but (2) high intentions to use the unit factor method in the future should be treated with scepticism. Such scepticism appears to be particularly justified if these teachers are not provided any further support regarding use of the unit factor method, and if SA PS marking guidelines continue to penalise its use.

Table 49: Details of the correlation analysis between professed beliefs and intentions regarding use of the unit factor method and the extent of its use in the post-test

Variable	**Index**	**Index calculation**	**Correlation between index and number of questions for which the unit factor method was used in the post-test (/4)**	**Remarks**
Beliefs regarding the value of the unit factor method in stoichiometry teaching and learning	Belief Index (/55)	Sum of responses to questions 4-14, with 7 and 14 reversed	$r(157) = 0.20$, $p < 0.01$	Significant, weak positive correlation
Intention for future use of the unit factor method	Intention Index (/5)	Response to question 3	$r(157) = 0.12$, $p = 0.13$	No significant correlation

CONCLUSION

The following assertions are given, in answer to the research questions: (1) The teachers professed positive beliefs regarding, and intentions for future use of, the unit factor method, despite their very limited prior use of this method; The relatively low measured perceptions of behavioural control partly arose from the intervention being too short to provide a considerable number of the teachers with enough time to practice the method sufficiently to attain the confidence needed to teach it; (2) The teachers' professed beliefs regarding the unit factor method were not significantly related to their teaching experience, whether they possessed a BSc degree, or the socioeconomic status of the learners they taught; (3) The lack of significant correlation between the teachers' professed intentions to use the unit factor method in their teaching and their own use of the method in the post-test undermines the likelihood that the teachers' generally positive professions of intentions to use the unit factor method in their classes will translate into reality; Based on the Theory of Planned Behaviour's premise that beliefs affect behaviour, the presence of significant correlation between the teachers' professed beliefs regarding the use of the unit factor method in teaching and learning, and their own use of the method in the post-test, lends support to the validity of the questionnaire items used to measure these professed beliefs, and therefore also to the validity of the finding of general positivity towards the unit factor method.

Based on these assertions, the following recommendations are made regarding Physical Sciences teachers, at least in South Africa, and possibly in other developing world contexts too: (1) teachers should be given access to professional development interventions, of longer than 2-day duration, which focus on the unit factor method and its application of the mole concept and proportional reasoning; (2) examination marking guidelines should not penalise use of the unit factor method.

Many teachers in the developed world consider the unit factor method the most likely to help learners obtain the correct answer (DeMeo, 2008). Indeed, some authorities even decry the method for enabling attainment of the correct answer without conceptual understanding (DeMeo, 2008). Whether or not this accusation is justified, it is ironic that in a context, such as South Africa, in which even teachers struggle to obtain the correct answer to stoichiometry calculation questions (Stott, 2011), the unit factor method should be underutilised and penalised. This research is significant in suggesting that this underutilisation is not explainable, and this penalisation is not justified, by teacher beliefs.

REFERENCES

Ajzen, Icek. 2011. "The Theory of Planned Behaviour: Reactions and Reflections." *Psychology & Health* 26(9):1113–27.

DBE. 2011. "Physical Science Curriculum and Assessment Policy Statement" Pretoria: Department of Basic Education.

DeMeo, Stephen. 2008. *Multiple Solution Methods for Teaching Science in the Classroom: Improving Quantitative Problem Solving Using Dimensional Analysis and Proportional Reasoning*. Boca Raton, Florida: Universal-Publishers.

Gabel, Dorothy L., and Robert D. Sherwood. 1983. "Facilitating Problem Solving in High School Chemistry." *Journal of Research in Science Teaching* 20(2):163–77. doi: https://doi.org/10.1002/tea.3660200207.

Krieger, Carla R. 1997. "Stoogiometry: A Cognitive Approach to Teaching Stoichiometry." *Journal of Chemical Education* 74(3):306. doi: https://doi.org/10.1021/ed074p306.

Makhechane, Mamohato, and Makomosela Qhobela. 2019. "Understanding How Chemistry Teachers Transform Stoichiometry Concepts at Secondary Level in Lesotho." *South African Journal of Chemistry* 72(1):59–66.

Plowright, David. 2011. *Using Mixed Methods: Frameworks for an Integrated Methodology*. London: SAGE Publications.

Ralph, Vanessa R., and Scott E. Lewis. 2018. "Chemistry Topics Posing Incommensurate Difficulty to Students with Low Math Aptitude Scores." *Chemistry Education Research and Practice* 19(3):867–84.

Ralph, Vanessa R., and Scott E. Lewis. 2019. "An Explanative Basis for the Differential Performance of Students with Low Math Aptitude in General Chemistry." *Chemistry Education Research and Practice* 20(3):570–93.

Reddy, Vijay, Mariette Visser, Lolita Winnaar, Fabian Arends, A. L. Juan, Cas Prinsloo, and Kathryn Isdale. 2016. *TIMSS 2015: Highlights of Mathematics and Science Achievement of Grade 9 South African Learners*. Pretoria: Human Sciences Research Council.

Reddy, Vijay, Mariette Visser, Lolita Winnaar, Fabian Arends, A. L. Juan, Cas Prinsloo, Kathryn Isdale, and K. Reddy, V., Visser, M., Winnaar, L., Arends, F., Juan, A.L., Prinsloo, C. & Isdale. 2016. *TIMSS 2015: Highlights of Mathematics and Science Achievement of Grade 9 South African Learners*. Pretoria: Human Sciences Research Council.

Saitta, Erin K. H., Michael J. Gittings, and Cherie Geiger. 2011. "Learning Dimensional Analysis through Collaboratively Working with Manipulatives." *Journal of Chemical Education* 88(7):910–15. doi: https://doi.org/10.1021/ed100019f.

Selvaratnam, Mailoo. 2011. "High School Physical Sciences Teachers' Competence in Some Basic Cognitive Skills." *South African Journal of Chemistry* 64:231–36.

Stott, Angela Elisabeth. 2020. "Influence of Context on Stoichiometry Conceptual and Algorithmic Subject Matter Knowledge among South African Physical Sciences Teachers." *Journal of Chemical Education* 97(5):1239–46. doi: DOI: 10.1021/acs.jchemed.9b01056.

Stott, Angela Elisabeth. 2021. "South African Physical Sciences Teachers' Use of Formulae and Proportion When Answering Reaction-Based Stoichiometry Calculation Questions." *Chemistry Education Research and Practice* 22(2):443–56.

QUANTUM TECHNOLOGIES: A PROJECT FOR TEACHER PROFESSIONAL DEVELOPMENT

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We present some results on an ongoing project for teacher professional development whose purpose is to enhance physics teachers' knowledge, awareness, and drive to educational innovation along the lines of the "second quantum revolution". The project started with an initial course whose focus was not only on physical content, but on developing in teachers a professional commitment to the common goal of curriculum innovation and is now in the phase of developing into a community of practice. Although centered on quantum computation, the course opened a much wider perspective on a longitudinal thread which touches several areas of physics, mathematics, logic, and information science. Seen from a teachers' perspective, such thread gives the possibility of exploring, throughout the curriculum, various crucial intersections in which the discourse on computation and the discourse on physics get closer and overlap, to the point of becoming essentially identical with the development of quantum computation. Adopting this perspective as a general guide, teachers can develop examples of educational design not necessarily directly related to quantum mechanics, but covering disparate areas of physics and mathematics, such as propositional logic, classical algorithms, thermodynamics, circuit theory.

Keywords: Teacher professional development, Community of practice, Culture and education

INTRODUCTION

The Strategic Agenda of the European Quantum Flagship (2020) expresses a strong urge for a change in physics education which leads teachers and students, also at the level of secondary school, to perceive "*the paradigm shift from quantum theory as a theory of microscopic matter to quantum theory as a framework for technological applications and information processing*", which is what is meant with the expression "second quantum revolution". The goal is clearly ambitious given that in most European educational systems quantum physics is a recent addition to the physics curriculum, often only a few selected topics are covered (Stadermann et al., 2019) and, in general, more research is needed to develop strategies to help students overcome learning difficulties at secondary school level (Krijtenburg-Lewerissa et al., 2017). Given such limitations, an attempt to encourage teachers to a plain and simple extension of the physics curriculum to include quantum information and computation topics would probably not be appropriate. Thus, our approach was instead to attempt, by means of an initial course providing common grounds and motivation, the formation of a community of practice (Wenger, 1998) motivated to longitudinal and inter-disciplinary curriculum innovation towards the objectives of the Quantum Flagship. To this aim, the initial course stimulates teachers to a high-level reorganization of the physics content (Van Heuleven, 1991) grouping different topics in the physics and mathematics curriculum under the common perspective of representing instances of overlap and interplay between the discourse of physics and the problem of computation. In this way, we thought teachers could be motivated to introduce topics of quantum information and computation, not as one further subject of the physics curriculum, but as the culmination point of a longitudinal and interdisciplinary path which they could have developed through the course of several years.

RESEARCH QUESTIONS

Our final goal is the construction of a community of practice (Wenger, 1998) whose common goal is to perform curriculum innovation towards topics related to the second quantum revolution. In this view, the aim of the initial course is on one hand to provide a first nucleus of shared knowledge about quantum information and computation topics to the attending teachers, on the other hand to provide hints about the ways through which the task could be performed, i.e., elements of curriculum innovation and inter-disciplinary connections distributed longitudinally along the five years curriculum. This shared content is meant to be elaborated by the teachers and researchers within the community of practice into several different types of educational intervention, distributed along the curriculum, also depending on the classes each of the participant teachers currently works in. A central aim of the course is to have teachers develop some degree of personal commitment to the objectives of curriculum innovation. As will become clear in the next section, the initial course has a quite wide span, both in the interdisciplinary sense (physics, mathematics, logic and information science) and in the longitudinal direction, touching subjects from different physics years. As mentioned in the Introduction, this is meant to stimulate a new organization of physics content by which teachers could identify and expand into educational interventions the possible concepts and areas related to an interplay and overlap between the language of physics and the language of computation. Overall, our project is aimed to provide at least a partial response to the following research questions:

1. Do the contents and themes of the second quantum revolution appear sufficiently fruitful to teachers to develop a personal commitment to longitudinal, interdisciplinary educational innovation directed towards themes of quantum information and computation?
2. What are the most appropriate environment and methods for building a distributed, online community of practice of teachers revolving around the themes of the second quantum revolution?

RECONSTRUCTION OF CONTENTS

From the point of view of content reconstruction, our course aims at presenting topics related to the second quantum revolution as the apex of a long progression in the interplay between physics, mathematics and logic revolving around the problem of computation. The course starts discussing the pioneering works of Bennett on the thermodynamics of computation (Bennett, 1982), those of Toffoli and Fredkin on reversible logic (Fredkin and Toffoli, 1982), and the intuitions concerning the possibility of simulating physical systems using computers expressed by R. Feynman (1982). These works play a significant role in bringing the problem of computation even closer to the realm of physics and pave the way for a reflection on the possibility of using quantum mechanics to encode and manipulate information in a profoundly different and innovative way. By using two-level systems – thus in fact adopting a spin first approach well established in PER but moving from the computational side of the problem (Dür and Heusler, 2014) - we can generalize the concept of the classic bit to the quantum bit - qubit - and study some logical operators that act on them. The generalization allows us to establish a correspondence between Boolean functions, describing classical connectives, and unitary operators describing the evolution of a system in quantum physics. All the objects involved in the formalism used also have a simple circuital representation that is a distinctive feature of approaching quantum mechanics from the side of quantum computation but may also open the way for a longitudinal reflection on the different uses of "circuit representation" in physics. At this point the course has three months pause in which the first cornerstones of a community of practice are laid: creation of a dedicated online discussion forum for the participant teachers, assignation of individual and group tasks. In the second part of the course, Bell entangled states are introduced through the newly developed circuital language. These states are sufficient to study some pioneering quantum protocols, crucial in current quantum technological applications, explaining the most significant aspects of entanglement: dense-coding, quantum teleportation, quantum cryptography (López-Incera et al., 2020).

STRUCTURE OF THE INITIAL COURSE

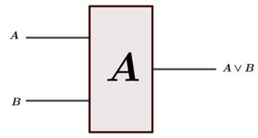
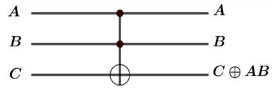
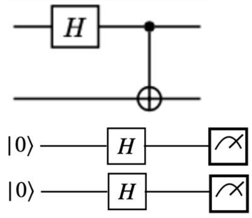
The Educational path has a total duration of about 20 hours and is structured according to the following steps summarized in table 1: 1) introduction to physics problem of classical computation; 2) building the quantum logical language and the origin of quantum algorithms; 3) introduction to entanglement and development of quantum protocols.

Table 1. Structure of the educational path.

Introduction	**Building**	**Development**
Physics problem of computation	**QP with Stern-Gerlach device**	**Entanglement**
	From bit to qubit – Quantum circuits	**Bell's inequalities** **No-cloning theorem**
	Quantum algorithms	**Quantum protocols (Dense coding, quantum teleportation)**
		Cryptography

The first four meetings took place in October and November; the other four in February and March. The key idea around which the entire course moves is the one that best expressed R. Feynman about the simulation of physical systems (Feynman, 1982): "What kind of computer are we going to use to simulate physics?" and even before that "what kind of physics are we going to imitate?". The route we explore with teachers, is that if we want to imitate quantum physics, the natural choice is to renounce both classical logic and classical probability. To understand this fundamental aspect, we have first described using the language of set theory the basic structure of classical physics, and then shown how propositional logic and probability can be constructed as theories concerning subsets of the set S of possible states of classical physics (Isham, 2001).

Table 2. From classical to quantum computation.

	Information coding (preparation)	Logic gate (transformation)	Decoding of information (measurement)	Circuital representation
Classical logic	**Bit 0, 1**	**Boolean functions** $f:\{0,1\}^n \longrightarrow \{0,1\}^m$ $Not, And, Or\ldots$	**Confirms the value of the bit on which it acts. We obtain a bit of classical information**	
Reversible classical logic	**Bit 0,1**	**Invertible Boolean functions** $f:\{0,1\}^{n+m} \longrightarrow \{0,1\}^{n+m}$ $Toffoli, Fredkin$	**Confirms the value of the bit on which it acts. We obtain a bit of classical information**	
Classical computation	**Classical state (potential)**	**Diodes, transistor**	**Measurement instrument (circuit element) of the potential**	
Quantum logic	**Qubit** $\lvert\psi\rangle = \alpha\lvert 0\rangle + \beta\lvert 1\rangle$ $\lvert\alpha\rvert^2 + \lvert\beta\rvert^2 = 1$ $\alpha, \beta \in C$	**Unitary operators** $X, Or, And, H, Z\ldots$	**It randomly chooses one of the two eigenvalues associated with the basis qubit states. We get a bit of classical information**	
Quantum computation	**Quantum state** **Spin** $\lvert\uparrow\rangle, \lvert\downarrow\rangle$ **Polarization** $\lvert V\rangle, \lvert H\rangle$	**Different experimental realizations**	**Measurement devices (intrinsically probabilistic)**	

By using two-level systems, we can then generalize the concept of the classic bit to quantum bit - a qubit - and study some logical operators that act on them (See Table 2). The generalization allows us to establish a correspondence between Boolean functions, describing classical connectives, and unitary operators describing the evolution of a system in quantum physics. All the objects involved in the formalism used also have a simple circuital representation (Coecke & al., 2016), which may be seen as one of the distinctive features of our approach. The possibility of working on new and strongly decontextualized symbolic representations allows the development of an autonomous and complete language that we believe can be of great interest and help for the more in-depth exploration characterizing the second part of the educational path.

The probabilistic interpretation of qubits makes it possible to introduce composite systems and the tensor product fairly and introduce multi-qubit logic gates. The action of logic gates has been described both in Dirac notation and with matrices. An in-depth understanding of the correspondence between circuit element, the Dirac and the matrix formalism, and the physical systems that implement them, is an essential part of learning and grasping the concepts introduced.

The formalism introduced and the corresponding diagrammatic representations made it possible to develop in the following lessons quantum algorithms and protocols that show the deep characteristics of quantum physics, in particular the role of superposition, interference, compound systems and entanglement.

CONTEXT AND DATA COLLECTION

The course was organized in the context of the Italian PLS-Piano Lauree Scentifiche (Plan for Science Degrees) and the education section of the Quantum Flagship. We divided the twenty hours planned in two parts: first 10 hours in October and November; the second part in February and March. Due to the restrictions imposed in response to the COVID-19 pandemic, all lessons, although initially planned as a traditional classroom course, were performed in synchronous distance learning. Interaction between teachers was limited, and the means of delivery were, approximately, 80% frontal lesson, 10% full group discussion, 10% teachers performing individual activities such as exercises or answering questions, which were discussed immediately afterwards. The course was attended by around 30 teachers in the first part and 17 in the second. Asynchronous discussion was performed using both generally available tools (Google drive, forms etc.) and a dedicated online forum set up on the servers of the University of Pavia.

Within the initial course, we collected data by several means:

- 23 pre-questionnaires completed, touching both disciplinary aspects and items related to personal engagement and involvement
- Sheets with solutions to problems and exercises produced by teachers during the course, and answers to on-the-fly clicker type questions given during one lesson of the course
- 14 post-questionnaires completed, touching both disciplinary aspects and items related to personal engagement and involvement
- Semi-structured interviews with four volunteering teachers

In this work we will analyze only the 14 post-questionnaires competed and the semi-structured interviews.

DATA ANALYSIS

Post-course questionnaires

As shown from Figure 1 in general teachers displayed a strong appreciation for the topics covered, particularly on the second part about the entanglement which using the logic gate formalism can be treated in a formally rigorous and conceptually meaningful way. Regarding the first research question, we can note positive answers about having dealt with the course topics and the importance they would have for the students; on the other hand, one can note a significant scepticism about the possibility of introducing them into the curriculum also in a longitudinal and multidisciplinary perspective (See Figures 2 and 3).

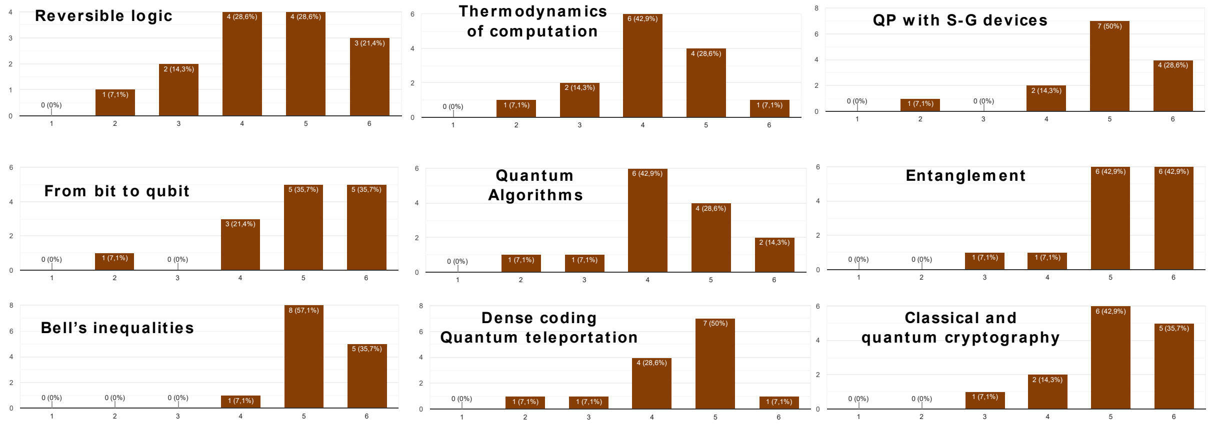
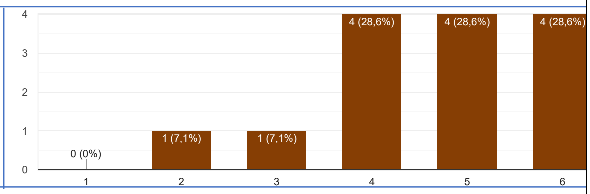


Figure 1. Interest level about topics introduced.

How beneficial do you think it is for your professional development to have studied quantum technology issues in depth during the course?



How much do you think it would be theoretically beneficial for your students' cultural development to introduce some themes - dealt with during the course - related to quantum technologies?

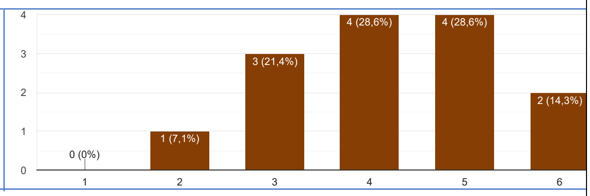
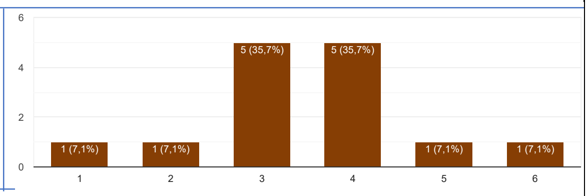


Figure 2. Teachers' and students' beneficial about the studies in quantum technologies.

How do you think it would be feasible to introduce some quantum technology issues to your students?



How practicable do you think the idea of a multidisciplinary (physics, mathematics, computer science) and longitudinal (developed along the entire five-year cycle) path based on the physical aspects of computation is?

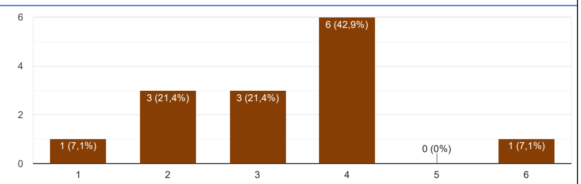


Figure 3. Propensity to introduce the topics of the second quantum revolution into the curriculum and from the perspective of a longitudinal and multidisciplinary approach.

It is also extremely interesting that teachers found the circuit language introduced able to relate phenomenon, mathematical formalism and syntactic representation (See Figure 4).

Regarding the second research question (What are the most appropriate environment and methods for building a distributed, online community of practice of teachers revolving around the themes of the second quantum revolution?), although the teachers greatly appreciated the materials prepared and shared (lecture recordings and slides) and found the lessons as well structured and interesting as they had hoped at the beginning (See Figure 5), they struggled to create a shared community of practice during the course, and teacher-to-teacher or collective online communication did not happen to any significant extent, notwithstanding the instruments we provided the group with (community forum, google drive folders).

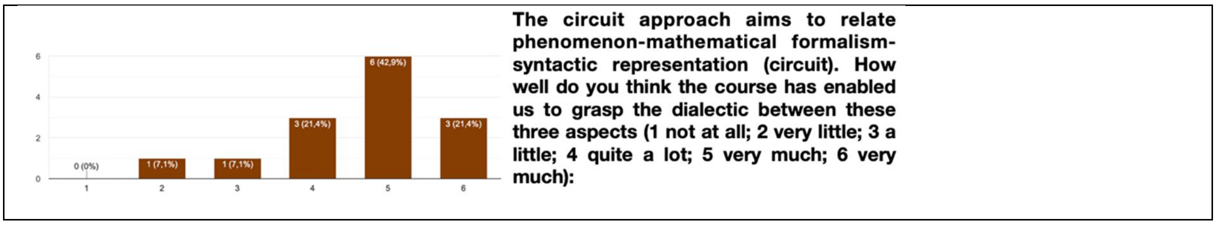


Figure 4 The importance of the circuital representation.

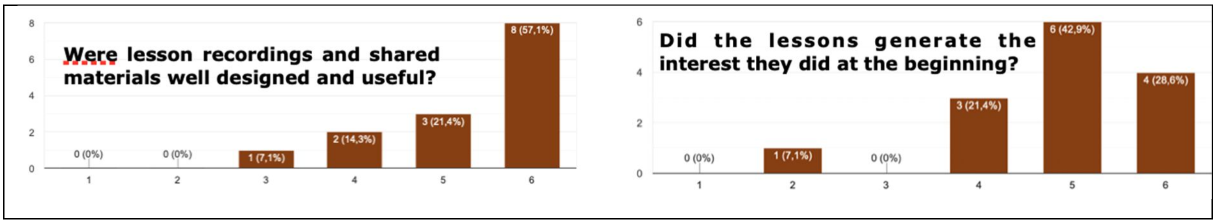


Figure 5 Quality of shared materials and level of satisfaction with respect to expectations.

Semi-structured interviews

We created a matrix for mapping interview questions onto research questions (Castillo, 2016). The interview protocol, after introductory questions, was divided into four parts:

- specific questions about the topics treated;
- teacher opinions on didactic feasibility, multidisciplinary and cultural impact;
- questions about the formalism used and circuital language;
- teacher evaluation of lessons and materials.

Thus, for each section, part of the interview protocol is linked to a research question. The transcription of interviews was used for analysis and comparison guided by the matrix previously created. An *a priori* coding scheme (Otero & al., 2009) is developed also considering the course goals and two of our corollary hypotheses which we intended to verify: 1) that the topics covered would have been interesting especially for mathematics graduates; 2) that the possibility of introducing such topics before the final year would have made them more practically usable in teaching.

Concerning the first part of the course, the introduction to the physics problem of computation, all teachers bring up the issue that mathematical logic it is not taught in great depth in school these days, and is only linked to set theory and propositional calculus, often in passing, in the first year. Teachers after the course believe it would be appropriate to expand the weight of the topic, but this seems not easy in a school context that seems to progressively dismiss its relevance. The cultural importance of introducing non-classical logic is recognized. The strong link proposed between logic and the thermodynamics of computation has caused surprise and difficulty, in particular to the two teachers with a degree in mathematics. All teachers acknowledge the effectiveness of the introduction to QP through the Stern-Gerlach device, but some would prefer to use polarization because it is a topic already known to students. The formalism used for the introduction to quantum computation is considered suitable for high school students if appropriately trained, and it is seen to be very promising especially by the two mathematics graduates. The abstractness of language, however, raises the problem of immediate physical interpretation. This aspect is even more evident in the study of the two proposed algorithms, whose computational aspect seem, in part because of their complexity, to be prevailing on its physical aspects.

Concerning the second and third parts of the course, more directly linked to the development of the language of quantum computation and communication, the interviewees generally agree on the high cultural value of the proposal, and the importance of a multidisciplinary approach for the education of future scientists. However, they recognize the introduction of these topics into the traditional curriculum as problematic, unless some of the content is deeply revised from the early years. The possibility of introducing topics linked to very recent technological developments is viewed as a likely source of students' engagement. Particular importance was attached to the cultural impact of the course, and that the two teachers with a degree in mathematics, in their free final remarks, stressed the great impact that the topics covered had had on their desire to study and explore QP and on a new vision of the world arising from it.

Development of a community of practice

As mentioned above, communication between teachers and in full group was judged insufficient by us during the course. However, and despite the moderate inclination to build multidisciplinary and longitudinal pathways expressed in the final questionnaire, 7 teachers asked to continue to deepen the introduced topics in view of an experimentation with their classes. They asked to go into some aspects in greater depth and are currently engaged in planning teaching sequences which also cover topics that are addressed before the final year.

Follow-up course, co-design and research action projects

At the end of the course, we organised five more meetings meant for teachers who expressed at least an initial interest in experimenting some of the topics treated in school. It was clear that they still needed to go more in depth in the topics treated and, above all, to focus on an educational reconstruction adapted to classroom work. In the first two meetings an introduction to quantum physics with a two state approach based on polarisation instead than on spin was presented, as most teachers had expressed in questionnaires and interviews that they preferred this approach, and it seemed at least equally suitable for an introduction to quantum technologies. The next three meetings concerned the introduction of a possible educational reconstruction for students using materials based on the course on quantum technologies for self-selected fourth- and fifth-year high school students which we held in Pavia in the same period (Sutrini et al, 2021). At the end of these additional 10 hours of meetings, we started work on co-design of customised teaching-learning paths with the 7 teachers willing to prosecute on this route. Experimentations carried on by each teacher will be focused on one or more of the following topics: thermodynamics of computation; the relationship between logic, physics and computation (presented as a multidisciplinary sequence); from classical to quantum cryptography; from classical to quantum search algorithms; entanglement and quantum teleportation protocol

The work we are doing with teachers shows the need for a different approach to some of the fundamental themes of mathematics and physics that students encounter well before the fifth year: propositional logic and the role it can play in the experimental work of a physicist; the concept of probability; the concept of physical system and state; the microscopic approach to the second principle of thermodynamics (Malgieri et al., 2019); the concept of information and its importance in physics. Some of these considerations arise from the research work in physics education that the University of Pavia has been carrying out for years, and they fit into the teachers' teaching practice without constraining it, as teachers are encouraged to take inspiration from it in order to enhance and expand it in the most fruitful way possible.

In this final phase of teacher professional development, we also oversaw a significant increase of socialization, communication and participation within the small group, with teachers with similar interests and aims actively exchanging ideas and materials for design. Our intention is that, at the end of the design and implementation of these teaching sequences, a first nucleus of community of practice can be established that can contribute actively to future project to teacher professional development.

CONCLUSIONS

We have presented in detail a teacher professional development project focused on quantum technologies, but presented within a broad cultural and interdisciplinary perspective which is now ongoing for over one year. To summarize the partial answers we provided to our research questions, we may say that:

- Based on questionnaire and interview answers, the proposed approach is considered engaging and personally enriching by teachers, but they still hold doubts on the practical feasibility in class. The percentage of teachers going all the way from the initial enrolment in the course to the co-design of an educational experimentation was about 25%, similar or slightly better than in our previous experiences of in-service teacher formation on modern physics (e.g., Malgieri et al., 2014) and it must be considered that in the case of the present course all activities were held in distance learning.
- Correspondingly, encouragement to use online socialization tools, prompt requests of comments and sharing of offline work did not seem effective in stimulating an appropriate level of communication, cooperation and sharing within a group of teacher which was not, in its majority, actually motivated to bring the proposed topics to the classroom. The degree of participation expected for a community of practice was only approached within the smaller group of teachers involved in deepening of the topics and co-design. Or hope is that, in future repetitions of the course which are bound to start this spring, the sharing of classroom experiences of these teachers can be inspirational

for the new teachers enrolled, and that the small group we are currently working with can form the seed of an actual community of practice.

Among the other relevant outcomes of the project, we mention the fact that teacher feedback prompted us to change the initial approach to basic QP from a two state approach based on spin to one based on polarisation. This was among the factors which helped us design a (we believe) better and more physically grounded educational reconstruction of quantum computation and communication for secondary school, on which we will report in forthcoming works.

REFERENCES

Bennett C H 1982 The thermodynamics of computation—a review Int. J. Theor. Phys. 21(12), 905-940.

Castillo-Montoya M 2016 Preparing for Interview Research: The Interview Protocol Refinement Framework. Qual. 21(5).

Coecke B, Duncan R, Kissinger A, and Wang Q 2016 Generalised compositional theories and diagrammatic reasoning Quantum Theory: Informational Foundations and Foils (Springer, Dordrecht) pp. 309-366

Dür, W., & Heusler, S. (2014). Visualization of the invisible: The qubit as key to quantum physics. The Physics Teacher, 52(8), 489-492.

European Quantum Flagship (2020, February). Strategic Research Agenda. https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=65402

Feynman, R. P. (1982). Simulating physics with computers. Int. J. Theor. Phys, 21(6/7).

Fredkin E and Toffoli T 1982 Conservative logic Int. J. Theor. Phys. 21(3-4), 219-253.

Krijtenburg-Lewerissa, K., Pol, H. J., Brinkman, A., & Van Joolingen, W. R. (2017). Insights intoteaching quantum mechanics in secondary and lower undergraduate education. Physical review physics education research, 13(1), 010109.

Isham C J 2001 Lectures on quantum theory Mathematical and structural foundations (Allied Publishers)

López-Incera, A., Hartmann, A., & Duer, W. (2020). Encrypt me! A game-based approach to Bell inequalities and quantum cryptography. European Journal of Physics.

Malgieri, M., Onorato, P., & De Ambrosis, A. (2014). Teaching quantum physics by the sum over paths approach and GeoGebra simulations. European Journal of Physics, 35(5), 055024.

Malgieri, M., Sutrini, C., Di Savino, M., Onorato, P., & De Ambrosis, A. (2019) A teaching learning sequence to brdge the gap from micro to macro in thermodynamics. Teaching-Learning Sequences as Innovations for Science Teaching and Learning, 711.

Otero V K and Harlow D B 2009 Getting started in qualitative physics education research. Reviews in PER, 2(1).

Stadermann, H. K. E., van den Berg, E., & Goedhart, M. J. (2019). Analysis of secondary school quantum physics curricula of 15 different countries: Different perspectives on a challenging topic. Physical Review Physics Education Research, 15(1), 010130.

Sutrini, C., Zuccarini, G., Malgieri, M., Macchiavello, C. (2021) A possible role of the second quantum revolution in physics education. Poster presented at the 2021 ESERA conference.

Van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based instructional strategies. American Journal of physics, 59(10), 891-897.

Wenger, E. (1998) Communities of Practice: Learning, Meaning, and Identity (Cambridge University Press, Cambridge, England, 1998).