ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 8| Issue: 4| April 2022|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2022: 8.205 || ISI Value: 1.188

REVIEW OF PCK ENHANCEMENT PROGRAMS FOR SCIENCE AND TECHNOLOGY TEACHERS: PROSPECTS FOR LOCAL INTERVENTIONS IN THE PHILIPPINES

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Article DOI: https://doi.org/10.36713/epra9900
DOI No: 10.36713/epra9900

ABSTRACT

Utilizing the systematic literature review method, this paper analyzed past professional development programs aimed at enhancing science and technology teachers' pedagogical content knowledge to provide prospects for local interventions. Lesson study, teacher-mentoring, and school-based collaborative curriculum development were the most locally appropriate, demographically, and contextually. However, they can afford a few participants only. This setback can be offset by supporting the interventions with a partly technology-based delivery platform. The study concluded that an innovative intervention must be designed for local use because it must be acceptable to the country's situation along all stages of implementation. The intervention must be collaborative, not too multi-faceted, and flexible enough to use quality materials and human resources without compromising efficiency and effectiveness.

KEYWORDS: ***Lesson study, PCK, pedagogical content knowledge, science education, systematic review***

INTRODUCTION

Since the time of Shulman (1986), pedagogical content knowledge (PCK) has been regarded as a core construct in the teaching profession. Particularly in science and technology education, it has become clear to teachers, school managers, and researchers that PCK is crucial to both good teaching and student understanding. Many have corroborated its positive contribution to realizing science and technology learning goals. It is the primary determinant of instructional quality (Lange et al., 2011; Abell, 2007); and is influential in student achievement in chemistry (Lange et al., 2011), physics (Ohle et al., 2015), biology (Gess-Newsome et al., 2010), and mathematics (Olfos et al., 2014) education. It defines the teacher's ability to assess student learning (Tacoshi, 2014) appropriately.

The importance of PCK in the realm of science and technology education indeed cannot be overemphasized. Furthermore, the need for researchers to explore and devise frameworks that would enhance PCK among science educators is unquestionable. In actuality, several studies have already highlighted many variables impacting teachers' PCK, and the most prominent was the quantity and quality of experience (Simmons et al., 1999), interactions with colleagues (Kind, 2009), and learning opportunities (Haston & Leon-Guerrero, 2008) during in-service teaching.

While the literature has clarified the "must-haves" and "the must-be-done" in enhancing science and technology PCK, most of them have been challenging to actualize in the school setting. They have been almost neglected for various reasons, such as insufficient funding, poor physical facilities, and lack of qualified resource persons, especially in third-world countries where resources are meager, and the bureaucracy is inefficient. In the Philippines, the predominant hindrances to science and technology PCK development are insufficient to support further studies among teachers, the proliferation of low-quality teacher education institutions, poor quality of the overall educational system, and lack of regular and poor quality in-service training opportunities. While there are programs to improve the science and technology PCK on the job, most have been sporadic, if not ineffective. Several in-school local training programs have been borne out of the necessity to comply with administrative requirements only—such as cluster meetings, departmental echo-seminars, and the like—and are usually not taken seriously by teachers and administrators themselves are not engaging. On the other hand, Off-school training is rare and costly—requiring teachers to leave their workstations and travel to distant training centers and reach few beneficiaries only. Advanced studies, another typical off-school professional development means, have been practical to some due to lack of time and motivation and apparent inadequacy of scholarship opportunities.

Given these circumstances, it is imperative to explore and analyze past accounts on PCK-focused professional development programs intended for science and technology teachers. It is well-established that PCK must be central to professional teacher training efforts; thus, the researcher believed that understanding how recent PCK-focused interventions work could help frame sound ones locally in the Philippines. Such may improve teaching quality and enhance our students' science and technology education achievement.

OBJECTIVES

This paper explores and analyzes past professional development programs to enhance science and technology teachers' PCK, utilizing the systematic literature review method. Specifically, this paper attempts to meet the following objectives:

1) Describe past local and foreign PCK-focused professional development programs for science and technology teachers in terms of methodology.
2) Determine the compelling features of these programs and discuss the challenges encountered by their implementers and beneficiaries.
3) Suggest what prospects may be taken for effective and efficient PCK-focused professional development programs for local science and technology teachers.

METHODOLOGY

This paper employed the systematic literature review method of investigation. In this method, the researcher addresses specific research questions; and then identifies, appraises, selects, and synthesizes high-quality research evidence and arguments pertinent to those questions. Systematic here means that "reviewers follow an appropriate (but not uniform) design and that they communicate what they have done" (Briner & Denyer, 2012). In principle, a systematic literature review means "research about research" and applies the same process of reviewing literature that is generally done in primary research papers (Briner & Denyer, 2012).

The following databases were used for gathering research: Google Scholar, Proquest, EBSCO, and SCOPUS. These databases were utilized because they contain quality and relevant educational research repositories. Four combinations of search terms were used in browsing for appropriate literature to wit "pedagogical content knowledge," "science education," "professional development," and "teacher." There were approximately 100 potentially relevant hits in all three databases using at least three combinations of the keywords chosen. So, the dataset was filtered to only ten manuscripts based on four criteria implicit in this paper's objectives: 1) the articles must be peer-reviewed and written in English; 2) they must be studies—not just conceptual manuscripts—on the effectiveness of a specific professional development program or activity for science and technology teachers; 3) they must be studies conducted in the last ten years locally or internationally; 4) and they must focus on PCK.

All ten studies were thoroughly reviewed based on this paper's objectives. Each intervention's delivery or methodology was described to fulfill the first objective. Each project's seeming features, the issues encountered by their implementers and clienteles upon their implementation, and the challenges they posed to involved entities were discussed to meet the second objective. Lastly, inferences from the researcher, mainly covering each intervention's prospects for possible local usage in the future, were given to satisfy the third objective.

RESULTS AND DISCUSSION

PCK has been both expanded and implemented widely in education since the concept was introduced by Shulman (1986). Now that it is so well-embedded within the realm of teaching and learning, professional development programs aimed at enhancing teachers' PCK need to be instituted, especially in science and technology education.

Local PCK-Focused Teacher Professional Development Efforts. While there were numerous foreign studies on improving PCK, there was not much in the Philippines, more so in science and technology education. The few existing local studies are worthy of consideration because their subject interventions were mainly effective in improving science and technology PCK, and their findings were based mainly on longitudinal and experimental works.

For example, two local studies attempted to evaluate the transferability or replicability of lesson study to a local context. Lesson study is a professional development model for teachers with its roots in Japan. In this model, teachers form small groups and meet regularly to collaboratively conduct systematic inquiries of their practices through peer-to-peer examinations of a particular lesson. Here, every input from group members is considered to develop the lesson into one that will satisfy the lesson's objectives and address contextual concerns.

The first was a qualitative case study by Gutierez (2015) wherein the viability of lesson study as a sustainable professional development program to enhance the inquiry-based teaching practices of 30 local science teachers was evaluated.

The intervention comprised of two phases. The first phase consisted of a five-day seminar-workshop (covering orientations on the nature of lesson study and inquiry-based teaching, collaborative goal setting and lesson plan development, constructive critiquing of lesson plans, and revising of lesson plans), lesson plan constructions by the participants, and lesson plan try-outs with help from trainers. Meanwhile, the second phase was mainly a post-lesson reflection and discussion between the participants and the trainers, with the objectives of arriving at a consensus on how to revise the tried-out lesson plans and determining what further revisions may be done given another series of lesson plan try-outs. The lesson plan try-outs and post-lesson discussions and reflections were spread across the school year, with an interval of five days between the first and second try-outs.

According to Gutierez (2015), the year-long intervention revealed one main result—the participants' analyses of their instructional practices deepened as they engaged continuously in collaborative and constructive self-assessments and discussions. It made them reflect on their practices. Through lesson study, the teachers became very vocal about whom to approach when they had content and pedagogical concerns and wanted to learn more about aligning pedagogy with student diversity. Moreover, Gutierez (2015) noted that the participants did not demonstrate any sign of resistance to modifying their current practices. Instead, they became very open to reflections, constant research, blending theoretical knowledge, and sustainable and systematic professional improvement frameworks.

However, the author noted one primary challenge in the intervention. As conducted indirectly, the post-lesson reflection and discussion sessions were too focused on requiring the participants to express their difficulties in trying out the lesson plans. The participants somewhat became apprehensive about sharing problems with colleagues at times, and with such, the intervention's main premises—teacher collaboration and exchange of ideas—were defied.

Meanwhile, the second study was by Lucenario et al. (2013). It was about the effectiveness of a PCK-guided lesson study in developing the PCK of chemistry teachers at public high schools in Rodriguez, Rizal. The study was of quasi-experimental design where the teacher competencies were compared based on two groups, the treatment group, and the conventional group. The treatment group applied the intervention (PCK-guided lesson about solution concentrations), which involved prototypical steps in conducting lesson studies such as lesson plan design, lesson plan implementation, the conduct of post-conference, implementation of the recommended improvements, and lesson plan revision based on consolidated suggestions from all team members.

Before and after the experiment, both groups were assessed in terms of PCK using two instruments. The first was the Chemistry Teachers' PCK questionnaire (adapted and modified from Jang et al. [2009]), which was intended to measure the teachers' PCK with a focus on subject matter knowledge, instructional objective, and context, knowledge of student understanding, and instructional representation and strategies. The second was the Framework for Science Teacher Education questionnaire, a self-assessment tool constructed by the Department of Science and Technology and University of the Philippines-National Institute for Science and Mathematics Education and intended to gauge the teachers' professional knowledge, practices, and attributes.

It was found that there was a significant difference in the teaching competencies of the two groups based on both PCK instruments after the intervention. The result was attributed to the openness of the intervention. It provided an avenue for the participants to reflect on their practices, thereby promoting new insights into the teaching process and contributing to their reframing processes. The study recommended using the intervention across other chemistry topics and in other science and technology education areas such as biology, earth and environmental science, physics, and mathematics.

Aside from lesson study, another locally popular professional development means to enhance science and technology PCK is online distance learning. This learning platform utilizes information and communications technology (ICT) tools to enhance the learning experience. Such a model uses the Internet, teleconferencing, video streaming platform, short-messaging system, social media platform, learning management system (LMS), and the like to achieve a bridged or extended educational milieu.

Online learning was given attention by Orleans (2010) when he assessed the PCK modifications of physics teachers who were given a month-long, fully online distance training on the subject matter and teaching strategies. The intervention involved nine teachers from a region in the Philippines which had been pre-determined to represent the country's physics teachers demographically. The primary delivery media used were teaching training modules and Macromedia MOODLE as the LMS.

The training modules were developed with the guidance of content and teaching strategy experts: a physics specialist, a physics education expert, and a school's division science supervisor. The modules contained varied learning activities to engage the teachers during training sessions. Alternative learning assessment procedures and sample lesson organization for logical subject-matter presentation (in the classroom) were also integrated into the modules. Online examinations were also administered using the said training platforms.

Before the actual training, the participants were oriented on and exposed to the nature of the intervention's delivery platform. The participants' commitment and their science supervisor were also solicited to ensure cooperation. Pre-training achievement tests and the pre-test for each module were administered online before actual training sessions. During training proper, the teachers were given a week to study the modules and accomplish the requirements. Outputs were submitted, and feedback was delivered online via asynchronous and synchronous discussion using MOODLE, e-mails, and a short-messaging system. A post-test was administered online every end of each module. Test feedback was given right after taking the online learning assessment.

Using a multi-method assessment procedure including achievement testing, concept mapping, lesson planning, and demonstration teaching, substantial modification in two knowledge-based PCK components in science teaching—knowledge about science curriculum and understanding of science—was found to have transpired among the participants. A significant increase in achievement scores, better concept map structure, and corrected misconceptions was also observed post-training. However, not much improvement was seen in the two other skill-based PCK components—knowledge about instructional strategies and assessment in science. Moreover, only a few changes were noticed in the participants' topic-specific strategies and science learning assessment skills.

Orleans (2010) concluded that while online teacher training could benefit professional development, full online mode is inadequate in enhancing all facets of science and technology PCK. He noted that challenges and activities must be hurdled and conducted first to achieve meaningful online learning experiences. Such activities include but are not limited to 1) an extensive pre-survey of the participants' demographic characteristics to know their inclinations and preferences that might be influential to their motivation to undergo rigorous online training; 2) overcoming the participants' anxiety about ICT tools by giving them enough ICT exposure pre-training; and 3) designing suitable learning materials that complement the participants' current competencies per Orleans (2010).

In a case study of how PCK development proceeds in science and mathematics, lecturers of the University of San Carlos in Cebu City, Berg (2010) compared four emerging approaches for science teacher PCK development. The context for the study was the creation of new science teacher education programs that involved faculty selection and development through a series of on-the-job activities and formal degree studies. Berg (2010) was able to monitor, illustrate, and compare the different methods used to stimulate effective PCK development among the faculty members selected for the program, such as 1) through formal studies (acquisition of advanced degrees primarily within USC, University of the Philippines System campuses, and universities abroad), 2) through team-teaching and joint course development (development of primary and science education courses through teacher collaborations), 3) through coaching (having a seasoned faculty member to coach new ones on designing and implementing science education curricula), and 4) through workshops (participation of faculty members to local and international workshops relating science content and pedagogy).

It was revealed that advanced science and science education studies could lead to improved content knowledge and pedagogical knowledge, which are elements of PCK. However, such may or may not translate to enhanced PCK and would depend mainly on the nature of the teachers' theses or dissertations (which must be closely linked to their subject areas of assignment) and how well-supervised they are by their advisers and graduate school professors (they must be very hands-on during the supervision) while pursuing their master's theses and dissertations Berg (2010) noted. Moreover, it was found that team-teaching and joint course development activities can enhance PCK only when conducted intensively. Not all team-teaching experiences work out well, as Berg (2010) noted. Team teaching frequently exposes teachers' weaknesses, and such problems may arise. While some may treat the experience constructively, some may treat it negatively, leading to them withdrawing from the program at times. Similarly, workshops are practical only if they can answer course concerns, result in easily practical suggestions, and are a part of a long-term faculty and course development program, as noted by Berg (2010).

Foreign Approaches to Teachers PCK Development. Unlike locally, there were plenty of foreign studies about PCK development programs for science and technology teachers. The typical intervention themes were ICT-based training, school-based curriculum development projects, school-to-school collaborations, teacher mentoring, and collaborative-constructivist teacher training.

Brooks et al. (2007) reported on the development of and success of delivering 15 PCK-focused web-based chemistry courses for in-service high school teachers in the United States whom their respective state education departments recruited. The materials covered undergraduate or early graduate chemistry and integration of chemistry with other courses. The courses were divided by "topics" representing big chemistry ideas, cross-cutting themes, and related pedagogy. In the system, as with typical web-based open coursewares of today, the participants are required to create their profiles for their basic personal information and record or save their percentage completion of the course. From then on, the participants manage their own learning time and pace. They can choose topics from a coded, indented list on a selector page, where clicking a title brings up a content page with quiz items links that change color once passed (quiz scores are recorded into the system's database to monitor the participant's performance and progress). There were also links to in-depth content, often external to the course and project.

Short-answer quiz item formats include true or false, multiple-choice, fill in the blank, rank, matching, check, select the correct representation, and multiple labeling. The system generates and returns detailed worked-out solutions using problem specifics upon receiving responses. Meanwhile, in essay quiz items, the participants immediately receive a prototypical response after submitting their answers. The essay answers are evaluated by "course mentors" (content and pedagogic experts that the project implementers hired for the project's purposes), who provide feedback.

The project was outright successful in courses completion, 100% per Brooks et al. (2001), but had unique challenges for both implementers and clienteles. The two main issues noted were the participants' varying completion rates and time and technology-related problems. The participants' work was seasonal, with high completion rates during spring and summer breaks, but stagnated over the winter break. Meanwhile, the common technology-related problem was hyperlink failures, where hyperlinked resources had problems loading or sometimes were utterly disappearing.

Another ICT-driven intervention was the 3-C Model for PCK development proposed by Juang et al. (2008). The model, which was implemented through a web-based support system dubbed EDUPLAN, was an ICT-supported school-based curriculum development intervention that revolved around enhancing science and technology teaching via technology lesson plan construction and revision.

The participants were grouped into three in the intervention: class, grade, and schoolteachers having respective tasks. The class teachers were the "typical teachers" and were given the tasks of 1) analyzing lesson planning and implementation conditions, 2) designing detailed lesson plans and instructional materials, 3) implementing lesson plans, and 4) evaluating the adaptability of lesson plans during and after instruction. Meanwhile, the grade teachers included teachers who are skilled at teaching and adopting appropriate pedagogy for specific topics or contexts and were given the tasks of 1) analyzing past conditions of the whole grade level's curriculum design and implementation, 2) designing lesson plan templates based on national curriculum standards, and 3) evaluating curriculum integrity and adaptability. Lastly, the schoolteachers were comprised of teachers who are masters of curriculum development and implementation and were given the responsibilities of 1) analyzing past conditions of the school's overall curriculum design and implementation, 2) designing the overall school curriculum framework, and 3) evaluating curriculum continuity, sequence, and adaptability.

The participants were required to exchange, regenerate, and utilize their knowledge through a software support system called EDUPLAN to develop a consistent curriculum from the top down. The whole process was guided by three mechanisms: creation, collaboration, and communication; thus, 3-C, where each had a corresponding tool or application in the EDUPLAN software. The creation tool allows the participants to incorporate the three stages of curriculum development, namely analysis, design, and evaluation and helps them make frequent revisions in creating knowledge base components. Meanwhile, the collaboration tool allows the participants to link the creation mechanism processes and products to form an integrated curriculum development procedure. Lastly, the communication tool allows the participants to communicate through a group discussion system, reducing the time usually consumed by face-to-face meetings and discussions.

Focus group discussions with the participants revealed that they agreed strongly that the ICT-enhanced 3-C model is effective in developing their PCK due to the following: 1) the intervention allowed them to craft a whole school-based curriculum through integral and stratified curriculum planning with peers, which is improbable when constructing lesson plans individually; 2) the 3-C model affords them of identifying instructional problems with colleagues during lesson plan design and gave them opportunities to learn about instruction methods for overcoming those problems from seasoned peers; 3) the intervention allowed them to develop their PCK, particularly in designing and evaluating instructional activities; 4) the web-based tools which can be used anytime and anywhere enabled them to perform curriculum development more efficiently; and lastly, 5) school-based curriculum development activities placed them under pressure to work with colleagues.

However, because of its complexity in the sense that it is too technology-driven, the intervention poses two pressing challenges: 1) its efficiency can be affected by teachers and school administrators who lack sufficient technical skills and knowledge, and can be significantly hampered even by minor technological issues like poor internet connection and network glitches; 2) the system is too lesson-plan-construction-centered; the other facets of the school and the teaching-learning process such as student behavior coaching, parenting education, classroom management, educational research methods, are somehow neglected in the system.

Indeed, the collaborative and constructivist approaches to science and technology PCK enhancement have been gaining ground in the past two decades. Yeung-Chung (2011), in his case study of a school-based PCK development approach involving two schools, ten science teachers, and a teacher-educator, for instance, found that PCK-focused collaborative professional development activities can be effective in helping teachers embrace inquiry-based science teaching.

Yeung-Chung's (2011) subject intervention pivoted on "collaboration between teachers and teacher-trainers" to develop and reflect upon inquiry-based science lessons. The collaboration process was guided by a teaching cycle model involving three phases: planning, implementation, and evaluation. The planning phase included the following: 1) selection of theme or problems for scientific inquiry, 2) eliciting students' alternative conceptions, 3) setting learning objectives and designing inquiry tasks, and 4) preparing lessons. Meanwhile, the implementation phase comprised mainly of 1) delivering instructions, 2) guiding students to learn through inquiry, and 3) providing explanations. Lastly, the evaluation phase consisted only of the evaluation of teaching and learning. Both the teachers and the teacher-trainers were tasked to apply the model with different foci. The teachers were required to focus on how they could use the inquiry-based approach to teach science using their PCK. Meanwhile, the teacher-trainers were tasked to focus on how in-service teachers can be helped to develop the necessary PCK to teach through inquiry.

The planning stage was found to help elicit and develop teachers' content knowledge. In contrast, the implementation phase was found to be more effective in facilitating their understanding of students' reasoning ability and their development of teaching strategies to further this ability, or simply their pedagogical knowledge. Both are components of PCK.

While the approach successfully improved PCK, there were two significant challenges during implementation. First was the teachers' inability to reflect on their classroom interactions or acute episodes due to limited experience in collaborative professional development activities. Such inability hindered total interactions between them and the teacher-trainers at times. The second was the teachers' dissonance regarding the concept of PCK and inquiry-based teaching itself, which hindered efficient collaborations between them and the teacher-trainers. Indeed, as a personal judgment, participants in this kind of intervention must be first equipped with knowledge about the nature and processes of scientific inquiry and must be re-oriented on their views about PCK before proceeding.

In an assessment of a similar approach of some sort, Appleton (2008) found that training under a teacher-mentoring program can indeed have considerable, lasting changes in participants' teaching practices. His study assessed a professional development program involving two elementary science teachers and a university professor, where the latter served as a mentor to the former, taking the roles of a participant-observer in the classroom, a critique, and a helper, in the course of lesson plan construction, designing of instructional materials, actual teaching, and assessment of learning.

The context of the intervention was to develop the teachers' PCK necessary for them to shift from hands-on science using process skills to outcomes-based science curriculum typified by constructivist-based pedagogy, and with that, develop a new model for science and technology teachers' professional development to replace typical ones where teachers are withdrawn from the school for intensive training with experts. Appleton's (2008) subject intervention was influential in developing the teachers' science PCK but much must be considered before and during its implementation. Per Appleton (2008), there has to be a common understanding of the mentoring process and a sense of mutual respect between the mentor and mentees. Moreover, there has to be a sense from both parties on why the mentoring process must proceed. In this way, the interaction will be productive for both participants in the sense that commitment will be established, and the needs of both parties will be the utmost priority. Lastly, there must be a partnership between both parties because the nature of the mentoring relationship is evolving as necessary as personal and professional growth occurs.

In a somewhat contrasting purpose, Khourey-Bowers and Fenk (2009) found that a constructivist professional development program can enhance chemistry-specific PCK, particularly in terms of scientific representational thinking, implementation of conceptual change strategies, and model development in the classroom through an experiment involving 37 participants (elementary and secondary school chemistry teachers).

Khourey-Bowers and Fenk's (2009) focus intervention was a typical professional development scheme where participants are pulled out of school to join intensive training sessions. The intervention spanned five semesters and was delivered in 11 sessions across six months. The instructional team included a university science educator, a chemistry professor, and two teachers with experience at the secondary and elementary levels. A wide array of constructivist teaching methods, framed within a learning cycle, were used to enhance the participants' PCK.

According to Khourey-Bowers and Fenk (2009), the intervention provided many opportunities for discussion, experimentation, and peer interactions. In training, conceptual linkages were introduced to the participants during each session, primarily via outlines linking chemistry topics with specific collaborative activities. The participants were also tasked to share their laboratory experiences through open inquiry, guided inquiry, and problem-based methods. Moreover, the participants were required to apply inquiry methods and conceptual change strategies in their classrooms through various course assignments, including content reviews focusing on scientific principles, term papers unfolding conceptual change applications, safety inventory of the participants' workstations, and lesson plans for an entire week of science discussions.

Quantitative and qualitative analyses by Khourey-Bowers and Fenk (2009) revealed improvements in the participants' chemistry-specific PCK. Based on interviews, the teachers felt more efficacious in their ability to teach chemistry. The constructivist manner of the training delivery helped them construct more scientific understandings. The training also used different forms of constructivism, like radical constructivism (in model-building) and social constructivism (in alternative conceptions), which led to fruitful learning experiences as the participants implemented their learned chemistry-related strategies in their classrooms. Moreover, through the constructivist methodology, the participants were given opportunities for curriculum decision-making through lesson design, personal reflection, and assessment of their teaching practices.

While there were many benefits documented from the approach, there was one minor setback. There were no groupings involved during the training, and the mixing of participants created some minor problems. Initially, the elementary teachers were hesitant to ask questions or actively participate in some discussions, confiding only their thoughts through some anonymous feedback forms. At times, they felt out of place and intimidated and protested that the strategies employed by the trainers were not suitable for their capacities.

The last subject intervention was a mixed-method approach, which Carlson et al. (2013) revealed to be effective in improving biology teachers' PCK. The multi-faceted

ISSN (Online): 2455-3662
EPRA International Journal of Multidisciplinary Research (IJMR) - Peer Reviewed Journal
Volume: 8| Issue: 4| April 2022|| Journal DOI: 10.36713/epra2013 || SJIF Impact Factor 2022: 8.205 || ISI Value: 1.188

intervention centered on using educative curriculum materials (constructivist materials that are intended to promote teacher learning in addition to student learning) to challenge, deepen, and strengthen high school biology PCK; and was supported by a multi-year, multiple component transformative professional development program that encompassed three parts: 1) a multi-day process in which the participants analyzed constructivist curriculum materials as a way of choosing their program for implementation; 2) an intensive, multiple-week summer experience on a university campus yearly for subject matter knowledge development; and 3) periodic collaborative lesson study sessions for two years.

Quantitative and qualitative data analyses indicated that the complex intervention positively affected the participants' knowledge and practice in general and their PCK in particular. The enhancements were attributed to the nature of the curriculum and to the intensive summer university course works where the conceptual flow graphics method was intensively utilized to identify overarching concepts. The said method helped the participants pinpoint links between activities and lessons and small and big scientific ideas.

One major challenge in the intervention was the participants' varying teaching and learning beliefs, as these did not align well with the nature of the curriculum materials and the goals of the while intervention itself. Some participants did set in the constructivist view of learning—they did not believe that learners could construct their understanding of crucial concepts¬—so often, they get frustrated with the lesson structures. Interestingly, some participants even regard the constructivist approach as an old traditional approach that is obsolete and must not be used.

Prospects for Local Interventions. Developing and enhancing the competencies of science and technology teachers is no easy task, especially in the Philippines, where financial resources are meager, and some culture of apprehension for change and innovation persists in many forms. Despite the many benefits the interventions reviewed can offer, we must weigh in on their corresponding disadvantages. At the very least, we must consider our educational system's seeming demographic, financial, and contextual dynamics in designing, implementing, monitoring, and evaluating our interventions.

Lesson study, teacher-mentoring, and school-based collaborative curriculum development are locally fitting, demographic, and contextual approaches. Their synergistic nature is more meaningful and appealing than the practice of conducting "tell-how-to-teach" in- or off-school type of training that predominated the local scene for so many decades. Their participatory feature can strengthen the cohesion of the faculty because they can provide an atmosphere of active participation and interaction. They are empowering and hence are more engaging.

However, these approaches can accommodate a few beneficiaries only, a setback that we cannot tolerate given our situation. Our performance in science and technology education is way behind many countries, as reflected by past TIMSS results—2003 and 2008—as we know and uplifting the quality of teaching in our schools certainly is one reasonable way of addressing the issue. We need an intervention that is not only effective but efficient at the same time in the sense that it will be encompassing, benefitting more participants. We cannot have interventions that will only cover a handful per school and then expect positive outcomes on a broad scale—which we need—straightaway.

We cannot be efficacious with lesson study and other mentoring- and collaboration-based interventions in their conventional delivery method if we lack the fundamental tools in the first place. What complicates our situation is that we do not have the sufficient number of experts necessary for their effective and efficient delivery. Take, for example, lesson study, which is a research-based approach, and, therefore, will necessitate mentors and participants with above par research competencies upon implementation. The problem is that we do not have a strong research culture in our schools. Research under-productivity is even a significant issue locally in many state- and private-funded universities. Conducting lesson study and the other mentoring-and collaboration-focused interventions without the necessary number and quality of leaders and experts would only be pointless.

The flexibilities of ICT may provide the efficiency that the above interventions cannot afford us. However, we cannot engage totally for a fully ICT-driven approach. So much work must be done first, particularly teacher training in ICT literacy which would necessitate intensive efforts from teachers (for the motivation), school administrators (for the political will), the government (for the financial support), and other agencies concerned. Nevertheless, we can at least have a blended platform and take advantage of ICT's flexibility in providing contexts for collaboration and interactivity.

What this paper is trying to emphasize is that we have to innovate. Curriculum developers can use the findings of this study as bases for framing a financially and contextually justified PCK-focused professional development program that would combine the effectiveness of collaboration-based approaches with the flexibilities of ICT and would take into consideration the drawbacks of both. We need an effective intervention but not too multi-faceted in the sense that it can be implemented in-school only but with high-quality materials and resource persons. Also, we need an efficient intervention in the sense that it is encompassing but not too technology-driven, would not require intensive preparations on the part of both the participants and implementers, and would not exhaust too many financial and human resources.

Such is a daunting task, but curriculum planners can start researching supporting lesson study with online distance learning, for example. Such a blended mode has been gaining ground in recent years because of its advantages concerning access and costs savings and the mobility restrictions brought by the recent pandemic. It can potentially cut expenses (through fewer required experts or mentors hence lower professional fees) and cover a more significant number of participants (the program can employ more groups, thus more teachers). Unlike some of the reviewed interventions, friendlier user interfaces in cheaper and easily accessible platforms can be considered in the delivery, such as the MOODLE mobile application and Google Classroom, which are free and can be run and maintained using smartphones and low-cost mobile data connection.

CONCLUSION

This paper reflects the results of a systematic review of literature on PCK-focused professional development programs for science and technology teachers to provide prospects for local interventions. Overall, lesson study, teacher-mentoring, and school-based collaborative curriculum development are the most locally fitting, demographically, and contextually. However, they can only afford a few beneficiaries. This setback can be offset by supporting any of the three interventions with a partly ICT-driven delivery mode.

Hence, in conclusion, an innovative intervention must be designed for local use, innovative in that it is acceptable to the local situation from planning, implementation, monitoring, and evaluation. It must be collaborative, not too multi-faceted, and flexible enough to use quality materials and human resources without compromising efficiency and effectiveness.

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