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Developing mathematics-enhanced chemistry research lessons through productive lesson study: Insights from in-service teachers

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Abstract

This study explores the perceptions of five in-service chemistry and mathematics teachers in using productive lesson study as a framework for teaching and learning. Introductory professional development workshops on horizontal articulation, productive pedagogy and lesson study were given to teachers at the onset of the project. Teachers were then tasked to produce two research lessons for grade 10 chemistry using the productive lesson study framework. We utilised inductive thematic analysis to identify the themes underpinning the perceptions of the teachers. Findings show that the teachers improved and deepened their knowledge by learning from each other's perspectives. They had also adopted effective strategies for teaching by reflecting on their students' learning, which helped them address the challenges of integrating and relating different topics into one. Furthermore, they became more aware of their students' prior knowledge which enabled them to address misconceptions. Thus, learning was reinforced, broadened and extended. Participating in the study made a transformative intervention in the teachers as they became more focused on the enhancement of their professional practice as teachers.

Keywords

Horizontal articulation; productive pedagogy; lesson study; productive lesson study; chemistry research lesson

Introduction

Education equips an individual with the necessary knowledge and skills to become a functional member of society. In the school year 2012–2013, the Philippine Department of Education enhanced the country's basic education programme by adding two more years to the customary 10 years through the K to 12 Programme. This programme aims to be an additional key to the economic development of the Philippines by producing globally competitive and well-equipped graduates.

The K to 12 Programme utilises a spiral progression approach for science subjects. As a result, biology, chemistry, earth and space, and physics are being taught in increasing complexity in junior high

school (grades 7–10). Hence, there is approximately a one-year gap, each school year, before the continuation of the next chemistry topic. Compounding this is the mathematical nature of chemistry in which mathematical calculations are necessary for exploring important concepts and theories in chemistry (Espinosa et al., 2013). Without basic mathematical skills, students will have difficulty in studying chemistry.

Articulation has a unique relationship with all disciplines, including education. In fact, to have a well-designed curriculum, it should be articulated along three axes: vertical articulation, interdisciplinary and multidisciplinary articulation, and horizontal articulation (Lange, 1982). From these, horizontal articulation targets the coordination of any curriculum across many or several classes that simultaneously attempt to accomplish the same objectives. This is particularly important because interdisciplinary contacts and communication in scientific cognition are an essential prerequisite of scientific development. Furthermore, the connection among the scientific, technical and social dimensions plays an important role in education (Semradova, 2012).

An effective pedagogical practice promotes the well-being of students, teachers and the school community. In addition, it builds community confidence in the quality of learning and teaching (Mazian, 2014). Effective teachers use different teaching strategies because no single, universal approach suits all situations. It seems that different strategies used in different combinations with different groups of students will improve learning outcomes, as some strategies are better suited for certain learner backgrounds, learning styles, abilities and in teaching certain skills and fields of knowledge, compared with other strategies.

In this study, productive lesson study, as the integration of lesson study and productive pedagogy, was used as a framework to address the difficulty of students in tackling mathematical calculations in chemistry to enable them to have a higher achievement in the subject. Productive lesson study was first used by Espinosa et al. (2014) as a tool for lesson planning and as a language framework for classroom teaching reflection. The framework is expected to reflect a collaborative spirit among colleagues by making them work, plan and develop content as well as exchange ideas with each other.

Productive pedagogy (PP) is a balanced theoretical framework that enables teachers to reflect critically on their current classroom practice. The PP was later developed as a research tool for classroom observations (Queensland School Reform Longitudinal Study, 2001). At present, the PP is widely used in Australia and other countries both as a research tool and a metalanguage in teaching (Mills et al., 2009).

Lesson study (LS), on the other hand, is a cycle of instruction improvement where teachers work together to formulate goals for student learning and long-term development. Here, teachers collaboratively plan a research lesson that is designed to achieve these goals. Originating in Japan, LS has been widely implemented across Asia under different names such as “learning study” in Hong Kong, “action education” in China, and “lesson study” in countries that are members of the Asia–Pacific Economic Cooperation (Fang & Lee, 2009). LS is a professional development process that Japanese teachers engage in to systematically examine their practice for increased teaching effectiveness, and it is a process of creating and sustaining a collaborative spirit among colleagues where they work together to plan and develop content, exchange ideas and draft a process that will help address students’ difficulties. LS may change teaching practices and improve student learning, as it involves a backward design that starts with the clarification of the goal or end point of the learning process and then the design of instructional experiences that lead to the goal. Teaching improvement, instructional materials, teaching community and scholarly inquiry are the main reasons that lesson study is worth the time and effort (Cerbin, 2011; Ekawati & Kohar, 2016).

This study aims to align lessons in chemistry with mathematics to help science teachers address the mathematical nature of chemistry and gather the insights of in-service chemistry and mathematics teachers as they develop such research lessons for grade 10 chemistry. Specifically, it seeks to answer the following research questions:

1. What are the perceptions of in-service chemistry and mathematics teachers on the depth of the integration of concepts in chemistry with mathematics using the productive lesson study framework?
2. What are the perceptions of in-service chemistry and mathematics teachers about productive lesson study as a means of professional development?
3. What are the ranges of these teachers' learning as a result of this new pedagogy?
4. What are the perceived advantages and challenges in this new pedagogical innovation?

Three axes of articulation

Articulation refers to how parts are put together to make something whole. In this study's context, it emphasises the interconnectedness of content, curriculum and instruction as they facilitate student learning. A curriculum should be articulated along three axes: vertical articulation, interdisciplinary and multidisciplinary articulation, and horizontal articulation (Lange, 1982).

Vertical articulation "ensures that what students learn from one year to the next takes form as a coherent and logical process that maximally supports student understanding and progression" (International Baccalaureate Organization, 2020, p. 1). Interdisciplinary and multidisciplinary articulation addresses the capability of a second language as a school subject to associate with the other disciplines in the curriculum (Lange, 1982). On the other hand, horizontal articulation is a process or mechanism for aligning programmes across similar levels, such as middle school or high school programmes, or all courses across particular levels, such as first year, second year, and so on. This interdisciplinary contact and interdisciplinary communication play an important role in scientific development. This is highlighted in one of the recommended ideas stated in an analysis about the impact of technology on Hawaii's automotive mechanics: the utilisation of horizontal articulation together with other types of articulation to help automotive technology programmes enhance communication and coordination among professionals and increase schools' productivity (Zane, 1985). For another thing, the increased interest in Foreign Language in Elementary School (FLES) programmes involved horizontal articulation that focuses on teaching objectives, strategies and materials, and aims to maintain the continuity among FLES classrooms at the same level. These facts support the findings of Wilson (1988) that a successful programme results from ongoing communication and cooperation at all levels.

Productive pedagogy

Productive pedagogy is used for teachers' discussions on teaching practices and individual student needs (Chapuis, 2003); to be specific, they are used by teachers: 1) to be able to consider if all their students are involved in a relevant curriculum that challenges their minds in a supportive environment, and 2) to determine whether the method of teaching and assessment assists or inhibits their students' learning. Although the focus of productive pedagogies is teaching practices, achieving high-quality outcomes for students will require more than teachers simply changing their practices within the four walls of a typical classroom. The support of school communities and the systems within which they are situated are also needed.

For a preservice teacher, the language of productive pedagogy is not only useful in developing preservice teachers' critical understanding of teaching but also in helping them recognise that the use of higher-order thinking, connectedness, as well as recognition and engagement with student differences within a supportive classroom, is crucial to improve student outcomes (Zyngier, 2005).

Mills et al. (2009) presented a refined methodology that addresses the importance of the pedagogical process in which it substantiated the inclusion of particular items within the framework; supported a critical approach to issues of differences, including students' perspectives; and recognised the significance of content knowledge in the assessment of quality pedagogy.

Meanwhile, Lingard and Keddie (2013) documented the pedagogies in 24 schools in Queensland, Australia, producing a model that combines Fraser's (2003) concept of the politics of redistribution, recognition and representation, and distinguishes pedagogies to reinforce teaching as a positional good, a good in itself and a good that can improve society. It theorises productive pedagogy's redistributive, recognitive and representative justice possibilities towards fairer results for marginalised students.

The importance of productive pedagogy was highlighted by Sytsma (2006), wherein she stated that productive pedagogy should be more utilised by teachers to improve students' learning. She studied the changing ideas of pedagogy over time and recommended the rise of teachers as productive pedagogy so that teachers can better fulfill their learning needs and those of students and the society, how professional learning communities can aid teachers in teaching and how productive pedagogy in professional learning communities can take the lead in the learning process. Sytsma (2006) recommended that teachers need to have a more radical approach and consider how they might be the creators of their own learning acts in professional learning communities.

On the other hand, Gore et al. (2001) probed whether productive pedagogy provides a feasible alternative to existing frameworks for teacher development. Their study found that the four dimensions of productive pedagogy—intellectual quality, relevance, social support, and recognition of differences—clearly indicate that productive pedagogy attend to both intellectual and social justice outcomes. Webb and Cox (2007) reviewed research on pedagogies associated with the use of information and communications technology (ICT) in primary and secondary schools and proposed a framework for examining pedagogical practices based on an analysis of the nature of pedagogy. Based on this framework, they discussed empirical evidence on the use of different types of ICT in different subjects and phases of education. It also suggested that new affordances provided by ICT-based learning environments should require teachers to undertake a more complex pedagogical reasoning in planning and teaching that incorporate knowledge of specific affordances and how these relate to their subject-based teaching objectives as well as the knowledge they have always needed in planning for their students' learning. Moreover, the article noted that teachers' beliefs about the value of ICT for learning and the nature of successful learning environments are important in teachers' pedagogical reasoning.

Lesson study

In lesson study (LS), the goal of the learning process is first identified, followed by the design of the instructional experiences that lead to the goal. LS provides a deeper, more extensive and more sustainable way of improving teacher practice as it utilises different areas of expertise without classifying any group member as an expert, enabling all group members to continually grow as learners (Lewis et al., 2011). LS is a means of professional development for teachers that started in Japan, and it has been recognised as a key contributor to the enhancement of Japan's mathematics and science education (Stigler & Hiebert, 1999).

Under LS, teachers collaboratively plan a research lesson that will achieve the goals of LS (Lucenario et al., 2016). During the lesson design phase, teachers talk about how students are likely to respond to each element of the lesson. The lesson is taught at a classroom by one team member, while the others gather evidence on student learning and development. A debriefing session is then carried out where teachers discuss and reflect on the strengths and weaknesses of the lesson and use the gathered evidence to refine the lesson, unit and instructions (Perry & Lewis, 2009). Not surprisingly, the debriefing part of LS receives special attention from both teachers who are currently engaged in it and teachers who consider its use (Groth, 2011).

Lewis et al. (2009) proposed a theoretical model of LS that included four LS features, such as investigation, planning, research lesson, and reflection, and presented three pathways through which LS improves instructions, changes in teachers' knowledge and beliefs, changes in the professional community, and changes in teaching-learning resources. This model suggested that the development of

teachers' knowledge and professional community is an instructional improvement mechanism within LS.

The potentials of including the important parts of LS to preservice mathematics teacher education to boost student teachers' facility in carrying out their theoretical knowledge during actual teaching and to raise a certain idea on how LS might be accessed and fostered in preservice teacher education were probed in the study by Elipane (2011). This study raised concerns about the purpose and implementation of student teaching practicum as the beliefs and perceived needs of student teachers must be properly taken into consideration in LS. It noted that the duration of the student teaching practicum and opportunities for rebuilding one's beliefs and classroom practices are among the factors that prevent student teachers from understanding the reform.

Cajkler et al. (2014) found that teachers who are involved in LS gained a better understanding of their students. Furthermore, collaboration fostered a lesser teacher-centred approach and developed a stronger sense of teacher-community. LS also showed that it could be an alternative or complementary model of teachers' learning.

On the other hand, Kanauan and Inprasitha (2013) probed LS and Open Approach that Thailand enacted to understand the collaborative work of an LS team composed of two in-service first-grade teachers and one student intern from Kookham Pittayasan School. The study found that the aforementioned LS team performed the following collaborative work: research lesson design, observation of research lesson, and reflections on teaching practices, which supported how in-service teachers are more likely to work collaboratively with student interns instead of merely supervising them.

Meanwhile, Inprasitha and Changsri (2013) studied teachers' beliefs about teaching practices regarding LS and Open Approach and found that beliefs regarding teaching practices that are related to LS and Open Approach can be classified into three categories—beliefs about teaching mathematics, learning mathematics, and social context. The participating teachers in the study questioned their long-held beliefs, such as teachers must give lectures and explain some concepts or formulas, as they had acquired new teaching practice beliefs, for example, giving the opportunity for students to tackle problem-solving by giving enough time and space.

Productive lesson study

Productive lesson study is a professional development practice where teachers collaborate to plan and develop a lesson plan that will address the key elements of effective teaching. It is a process where teachers engage to exchange and learn more ideas and practices from each other, with the aim to improve student learning. Productive lesson study was first used by Espinosa et al. (2014) in their study, which is in line with the professional development of teachers towards quality teaching through LS and PP. They used productive lesson study as a tool to plan for lessons and as a language framework to reflect on classroom teaching. A detailed description of the framework is discussed in Espinosa et al. (2018).

Methodology

This study used the qualitative research design—a systematic, subjective approach used to describe and give meaning to life experiences. Its goal is to gain insight and explore the depth, richness and complexity inherent in the phenomenon under study (Mason, 2002). In the context of this study, the researchers gather data through interviews and classroom observation. Interview transcripts were analysed through inductive thematic analysis, which was followed by a discussion to identify common themes.

Participants

The participants of this study were five junior high school teachers from a state school in Laguna, Philippines. Two are teaching chemistry while the remaining three are teaching mathematics. All are female participants. The two chemistry teachers have a bachelor's degree in education, major in biology, and handle seven science classes. The three mathematics teachers have a bachelor's degree in education, major in mathematics, and handle seven mathematics classes.

Data collection method

An introductory workshop on horizontal articulation, lesson study, productive pedagogy, and productive lesson study was given to the participants. At the end of the workshop, the chemistry teachers talked about formulating a research learning plan in stoichiometry and gas laws. Then they met with the mathematics teachers to discuss and come up with one research plan about each topic. This research plan presents the alignment of the learning plan on stoichiometry and gas laws made by the chemistry teachers with its related mathematical concepts proposed by the mathematics teachers. A 30- to 55-minute interview with each participant followed to gather insights of teachers about the research plan's application of the four productive pedagogies. This interview was recorded and transcribed as part of the data.

The participants only used the planning stage of the LS to come up with a research lesson to be used by grade 10 teachers in their chemistry class for the next school year. The four productive pedagogies were utilised to create a research lesson that encompasses intellectual quality, connectedness, a supportive classroom environment, and recognition of differences. Presentation and post-evaluation can be used as another form of research regarding productive lesson study.

Data analysis procedure

The transcriptions of interviews and artefacts, such as notes and the learning plan, were used for analysis. Horizontal articulation and the four productive pedagogies—intellectual quality, a supportive classroom environment, recognition of differences, and connectedness—were examined to determine if they were incorporated in the research. The analysis of the interview transcripts involved both deductive and inductive thematic analysis.

Findings and Discussion

Range of integration of concepts in chemistry and mathematics by the teachers.

Interestingly, only one major theme emerged from the inductive thematic analysis. The participants said that they were able to improve and deepen their knowledge, adopt effective strategies in teaching and in reflecting on their students' learning, by learning from the perspectives of their colleagues during the introductory workshop. Furthermore, the introductory workshop made them more aware of the importance of knowing the basic ideas and prior knowledge of their students.

Teacher 1: "We have quickly cleared up previous concepts that were somewhat confusing. We have a greater chance to teach better and more accurately. We are also getting new ideas from each other to find ways to improve our teaching."

Teacher 2: "To better facilitate teaching chemistry to students, teachers need to find out the basic math concepts that the students know. It will be more difficult for our students to absorb the math concepts that will be integrated into our lesson if their knowledge in basic math is poor. For example, in the

conversion of units or the factor-label method, if the students do not know how to convert and cancel units, they will likely have difficulty in chemistry topics such as gas laws and stoichiometry."
Teacher 2's sentiment was supported by Teacher 3, who said: "We can also ask their previous teachers regarding the previous topic that they taught. In this regard, we can easily connect the present lesson with the previous one."

Extent of teachers' adaptation of productive pedagogy

We consolidated the comments and suggestions of the participants. Through deductive thematic analysis, each comment and suggestion was categorised as an improvement of any of the four dimensions of productive pedagogies that include intellectual quality, connectedness, supportive classroom environment and recognition of differences.

Intellectual quality

In the pre-lesson preparation for the research learning plan, the participants analysed the mathematical content that was needed in the chemistry lesson. As they planned for each mathematical concept in the chemistry lesson, they also tried to exhaust some possible responses from their students. As a result, they realised they should allow their students to analyse every topic very well.
Teacher 1 said that making their students think critically will help them have a better understanding, stating, "Let us give our students a chance to think carefully and become active in the classroom discussion. We should train them in HOTS [higher order thinking skills]. We need to encourage them to ask questions about the lesson for us to know if they understand what we are teaching."
Teacher 3 added: "We should not just give students a chance to understand the concept of the lesson. It would be more helpful for them if they realise how it can help them in their daily lives."
Based on these statements, the participants realised the importance of identifying and evaluating if their students had less difficulty in the lessons. These findings stated that teachers should reflect critically on their work and that students should be in a challenging learning environment.

Connectedness

The participants also deliberated on the connectivity of the content of the lesson to their objectives and their background about the lesson. With the difficulty to connect the lesson with the previous lesson, the participants realised that the students were having difficulty in mathematical calculations. Most of the teachers also experienced difficulty in connecting one idea to another due to various factors.
Teacher 2 mentioned that teachers should organise their lessons well: "One reason behind our students' difficulty in understanding our teaching process is our difficulty in connecting and relating the topics from one another. We need to organise the lessons well for our students to find it easy to understand our teaching process."
On the other hand, Teacher 5 said that it was more ideal to give basic examples first before giving complex ones: "To prevent students from having a bad experience, it is better for us to give simple and uncomplicated examples. For instance, in stoichiometry, we should not give complicated examples. Instead, we should start with basic ones for students' understanding. The examples to be given should apply to the students' daily activities."
Based on these statements, the participants realised the challenge of integrating background information and previous lessons to minimise their students' difficulty in the subject matter or lesson and the ways to address this challenge. This finding is supported by Mills et al. (2009) that supported a critical approach to issues of differences that include students' perspective and recognised the significance of content knowledge in the assessment of quality pedagogy. Mills, et al., (2009) further argued that the

realisation of high-quality outcomes for students that will require more than simply changing teachers' practices, and a critical approach to support the issues of differences that include students' perspectives.

Supportive classroom environment

For students to learn more, teachers should build a meaningful and active learning environment. They should let their students discuss the process by which they had come up with their ideas. They should also encourage their students and give them the chance to work with their classmates to promote a good working relationship. In this regard, the teacher only acts as a facilitator. Encouragement and respect for students are needed, as mentioned by Teacher 4: "When giving an activity to students, try to use a group activity. Each student should have a chance to interact with other students. This will minimise the shyness among each student, and the students will always interact with each other and brainstorm during a group activity."

In agreement with Teacher 4, Teacher 1 said: "Students should not feel afraid when teachers are inside the classroom. They should feel at ease every time they see us. They should not be anxious whenever they see us, and they should not be afraid to answer just because they think that their answers are unacceptable."

Recognition of difference

The participants also realised that each student is different, and they should use different strategies for different kinds of students to enable better learning. Mazian (2014) found that different strategies used in different combinations to different groups of students will improve learning outcomes. Some strategies are better suited to one student but not to all of them. Furthermore, some strategies are better suited to teaching skills, whereas some are suited to the learner's background, styles and abilities. Teacher 2 said: "Give a chance to every student. Allow them to analyse and think critically on specific lessons. Not all students have the same thinking capacity; thus, we should use different methods for them to understand the subject easily."

Teacher 3 added: "Give a chance to every student. Allow them to share their ideas about the result of their work. Minimise calling those students who are already active during discussions. Some of the students feel shy. They need to overcome their fear of speaking in front of the class."

As McGregor and Mills (2009) stated, to have high-quality outcomes for students' learning, teachers should not simply change their practices; they should also include in their practice the issues of differences including students' perspectives. It is really important to make students feel that they are socially supported by their teachers (McGregor & Mills, 2009). The support that they get from their teachers can help them engage further in varied and more challenging activities in school (McGregor & Mills, 2009).

Range of teachers' learning that results in productive lesson study

Through inductive thematic analysis, only one major theme can be clearly deduced from the interview transcripts. That is, productive lesson study presents a powerful mechanism that can potentially shape its participants' identities and capacities as teachers. It provides teachers an opportunity to intersect and relate different aspects of teaching and learning, and this might address the complexity of learning to teach mathematics in chemistry to students. It also enables teachers to know their goal in having fruitful learning outcomes with their students. Teachers become professionally competitive through this study, with Teacher 4 saying: "This improves teachers professionally, and they get the chance to think of better ideas that will make it easier for them to teach their students and make them learn." Teacher 5 added:

"It may not be true for all, but it improves the learning of students because teachers get new ideas from one another. Novel activities given by teachers catch the interest of students."

Perceived advantages and challenges of productive lesson study

Based on the inductive thematic analysis of interview transcripts, productive lesson study is advantageous because it can help improve lessons and allow explicit clarifications. It also lets teachers engage in a discussion concerning the value of fruitful classroom instruction to students. As Teacher 5 said: "From this study, we gained good results in teaching the lesson because we received different ideas from different teachers on the process of their teaching and on the way that it will be easier for the students to understand the topic."

However, the participants also noted some challenges and difficulties regarding productive lesson study, such as the concept of cooperation, openness to criticism, time, and power relations.

Teacher 1: "For me, one of the challenges that I will have to face in this approach is the acceptance of the negative criticisms that I might receive concerning my output. I might also be challenged to fully accept their suggestions because, most often than not, those who give suggestions seem to forget the fact that they are also teachers."

Teacher 3: "It is a challenge for a teacher to join in a new kind of activity. They need to give more time. They also need someone who will give enough information about it."

Teacher 4: "One of the challenges that a teacher will face in doing this activity is the allotment of time. It is difficult to make time with other teachers for a meeting about the different matters that need to be done. Because of too much work, they don't have enough energy to collaborate, and they don't have the chance to give better ideas."

Conclusions and recommendations

In light of the abovementioned findings, the following conclusions were drawn. First, productive lesson study can help teachers share and exchange ideas from one another that will enlighten their minds from their practices in teaching. Through collaboration, sharing of ideas and giving of criticisms, they become updated with their practices. Second, knowledge from different teachers can contribute to the growth of everyone's profession. They become aware of new methods or strategies that they can use to get the attention of the students. Third and lastly, from collaborating, teachers gain and learn different things, such as different teaching strategies, methods, and activities. From that experience, it will help them develop the virtue of acceptance, cooperation and patience. By giving and accepting suggestions from others, they can gradually accept the fact that they need others to improve their practices.

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