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Analyzing the Growth of a Pre-Service Science Teacher Community through the Lens of Cultural Historical Activity Theory: The Case of a Three-Year Voluntary Science Teaching Program

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ABSTRACT

This study examines the growth of an innovative pre-service science teachers' (PST) community over a period of three years in a voluntary and informal setting for teaching science to high school students. The objective of this study is to understand the traits and conditions necessary for the learning and development that occurred in the PST group. We describe the growth of the PST group with a focus on the group's endeavor to move from simple laboratory work to a more inquiry-based approach to science instruction. In doing so, we seek to articulate the growth of the group by focusing through the lens of cultural historical activity theory on how its meanings, tools, and priorities were constantly formulated and examined within the community.

Keywords: pre-service science teacher growth, cultural historical activity theory (CHAT), learning to teach science, pre-service teacher education

INTRODUCTION

Recently, researchers of pre-service science teachers have considered more community-oriented means of learning in pre-service education coursework or during the teaching practicum. For example, co-teaching has become increasingly popular as a means of extending the collective knowledge of pre-service teachers by generating critical reflection as they engage in co-planning, co-teaching, and co-reflecting (Bacharach et al., 2010; Eick & Dias, 2005; Scantlebury et al., 2008). Previous studies were focused on effective means of improving pre-service teachers' knowledge and teaching quality, and in this the role of experts was still significant. For example, Gelfuso and Dennis's (2014) study shows that the presence of knowledgeable others, such as experienced teachers and teacher educators, was beneficial to promoting the quality of reflection as a communal process. In the Korean context, mentoring has become an increasingly popular strategy that forges a mentor-mentee relationship between PSTs and experts, such as university professors or teachers serving on the staff of the school where the PST is placed. The mentoring strategy could be adopted in order to yield PSTs' increased knowledge and better teaching performance and quality without consciously addressing the issue of authority between the expert and the PST (Lee et al., 2011). On the other hand, other studies have suggested that a more equal relationship between the expert and the pre-service teacher was possible as they implicitly sought negotiation of their roles (Han, 2010). Although these studies supposed more agency on the part of the PSTs, they still focused on the learning of individuals rather than the growth of the community. Furthermore, their settings still lie within either the PST education curriculum or student teaching, where the most PST experiences of learning to teach are pre-determined, as is the milieu forming the condition of their experiences. One way of overcoming such conditions constraining PSTs' agency and autonomy would be for pre-service teachers to belong to the community in which they collaborate on developing and implementing science teaching in such a way that the community as a whole grows by experiencing success and failure through collective decisions. This idea of PSTs' professional growth presupposes the value of

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Contribution of this paper to the literature

- This work seeks to understand from the CHAT perspective how the professional growth of a pre-service teacher community was possible through its three-year experience.
- It provides an innovative case study showing how the increased autonomy of the PST community led to improved teaching competence by modifying their objectives, tools, rules, and role divisions in order to develop and implement a more inquiry-oriented science program.
- It argues the value of such a practice-based collaborative learning experience distinct from conventional student teaching and initial teacher training systems.

community as the learning environment that enables PSTs to raise issues and take initiatives, rather than follow an expert's guidance or institutional rules in considering and internalizing ideas about good science teaching.

This study reports on an inquiry into the experience of a pre-service teacher group engaged over a period of three years in teaching high school students in a voluntary setting. The objective of this study is to understand the traits and conditions necessary for the learning and development that occurred in the PST group. By doing so, we tried to articulate the growth of the group by focusing on how meanings, tools, and priorities were constantly formulated and examined within the community.

THE RESEARCH SETTING: A UNIVERSITY-SCHOOL COLLABORATIVE PROGRAM FOR LABORATORY-BASED SCIENCE EDUCATION

The education program that was the focus of this study was run collaboratively by Seoul National University and a girls' high school in 2010–2015, with funding from the local district's office of education. The aim of the program was to provide students with a variety of experiences learning science using the university's laboratory facilities in light of the fact that school science labs are usually equipped only with the instruments introduced in science textbooks. Sixteen tenth-grade high school students attended the program, and the program ran over a year, with 10–12 months of instruction sessions on a schedule involving three hours of class on Saturday mornings.

To serve as program instructors, a dozen undergraduate students at the University's Department of Biology Education voluntarily participated. The majority of the participants were members of a student club within the department, Protocol, which had been formed in 2005 by a handful of undergraduates interested in biology experiments and education. The participating undergraduates of the program were eligible for accreditation by the Educational Service Unit, and as this became mandatory for graduation from 2009 on, this link to accreditation attracted other non-member undergraduates to participate in the program. Overall, second- and third-year students formed the majority of the participants in this program. Due to the varying amounts of experience and degrees of commitment, however, the issue of responsibility and leadership for providing quality instruction was a constant issue. Notably, the two institutions—the university and the school—did not intervene directly in the content of the program. The school gave full authority for teaching and learning to the university, and the PST group, under Professor Jeon's supervision, was in charge of the whole process of preparation and implementation. A brief end-of-term survey was conducted to ascertain the students' satisfaction with the program, but there was no formal device to assess teaching quality or the PSTs' own awareness and knowledge gained from their teaching experience. Therefore, program quality relied heavily on individual members' volunteering and motivation, including that of the leader and long-term members of Protocol. Furthermore, rules for managing the program were necessary in order to ensure that responsibility was fairly distributed; however, they were not established well due to the voluntary nature of their participation. For example, the undergraduates decided to take turns preparing the content for at least one of the 10–12 instruction sessions throughout the year in teams of three to four; however, the quality of the prepared teaching content and the actual teaching varied greatly.

The current research project was initiated in this context with the aim of facilitating the professional growth of the PST group by allowing the PSTs increased autonomy over the course of the project. For example, before the research project began, rules were applied loosely to the ways that the PSTs engaged in the co-planning, co-teaching, and co-reflecting processes, as shown in **Figure 1**. In the co-planning phase, the preparation team for each session decided the curricular topics and teaching materials and led pre-sessional lab work that all PSTs were supposed to attend in order to gain the practical skills needed to conduct laboratory work during the actual class. During the actual teaching, roles were divided between the main tutor, who led and taught a whole class, and the mentors, who engaged in small-group laboratory work and discussion. After class, an evaluation session was supposed to be held in order to examine the success of the session from the PSTs' own perspectives. Such a system stemmed from how the program had been implemented over the three years before the current study began. However, whether it actually worked depended heavily on the leadership skills of each year's leader and the preparation team's commitment in each session.

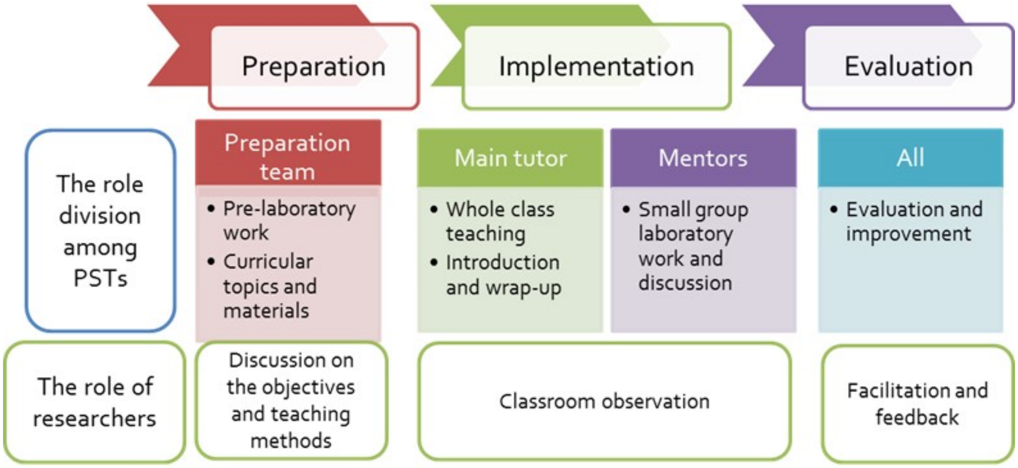

Figure 1. The loose system of co-planning, co-teaching, and co-reflecting

Table 1. The programs that were added, revised, or discarded over three years

Types of instruction	1st year	2nd year	3rd year
Observation	Microscope	Microscope	X
		Drosophila	X
	Chick Development	Chick Development	X
	Fetal Pig Dissection	Fetal Pig Dissection I	Fetal Pig Dissection I
		Fetal Pig Dissection II	Fetal Pig Dissection II
Fun	Secrets of 12 Test Tubes	X	X
	Osmosis	Osmosis	X
	Forensic Science	Forensic Science	Forensic Science
Task/problem-solving			Marvelous Protein: Structure
	Egg Drop	X	X
			Drosophila Genetics
		What Scientists Do	What Scientists Do
Science process skills		Separation of Plant Pigment	Separation of Plant Pigment
			Science Camp (indoors)
Activity (outdoors)	Plant Classification	Plant Classification	Plant Classification
			Marvelous Protein: Function

In this paper, we describe the growth of the PST group with a focus on the group's endeavor to move from simple laboratory work to a more inquiry-based approach to science instruction. Table 1 shows the changes in the instructional foci and themes over the three years of the program. Some content items were taught every year, such as fetal pig dissection, forensic science, and plant classification, whereas others disappeared from one year to the next or underwent revisions if the PSTs judged them to have gone badly. In the early phase of the program, from the PSTs' point of view, experiments showing chemical reactions (e.g., "Secrets of 12 Test Tubes") or confirming a scientific principle (e.g., "Osmosis") were considered the easy choice for teaching. However, the PSTs' increasing awareness of "inquiry-oriented" science instruction made them shy away from such simple experiments in which students did not learn many science concepts or experience genuine scientific methods. Meanwhile, the "forensic science" instruction session survived with its specific content revised to be more like an interesting detective story, which provided students with the motivation to solve the problems using scientific principles, thus representing inquiry-oriented work rather than just fun. Crucially, activity or task/problem-solving types of instruction became dominant over the three years as the PSTs actively pursued "inquiry" as the core objective of the overall program.

THEORETICAL PERSPECTIVES AND METHOD

CHAT as a Lens to Analyze the Growth of the PST Group

In this study, CHAT was adopted as a lens through which to identify the nature of professional growth of the PST group as reflexively constituted through the interactions and tensions within the PST community and between the PST community and the research team. Originating with Vygotsky's sociocultural theory of learning, the CHAT perspective regards the community's activities rather than individual people's actions or motives as the unit of learning (Engeström, 1987). The community's activities occur within a system consisting of subject, object, tool, community, rule, division of labor, and outcome in ways that form and bring together the distinct values, norms, and knowledge of the community. "Expansive learning" can occur as the subjects seek to resolve tensions or problems by redefining and reformulating these components in the activity system, resulting in the transformation of, or a learning experience for, the whole community (Engeström, 1987; Engeström & Sannino, 2010). Since the 1990s, the CHAT perspective has increasingly been employed to describe and intervene in situations where new objectives or activities are pursued in a community in order to enable new learning experiences or educational innovations (Roth & Lee, 2007). More recently, researchers have paid attention to the value of CHAT as a tool to identify and analyze the features and effects of the socio-cultural approach to the PST education. For example, Murphy et al. (2015) utilized CHAT as a tool with which to analyze the complexities of pre-service science teachers' co-teaching experience. In the science education area, Roth et al. (2002) traced a PST's development during her co-teaching experience in a school in the presence of colleagues, including researchers and her teacher mentor. In addition, Saka et al. (2009) looked into the ways in which two beginner teachers' beliefs were transformed as they encountered and tried to resolve dilemmas arising from the school culture. Although valuable, these studies still focused on the individual PST's learning experience within the conventional teacher training system and the actual schooling system.

Therefore, by focusing on the informal, voluntary activity of the PST group, the current study can make a meaningful contribution to the understanding how the increased level of autonomy of the PST group leads to the improvement of teaching competence. Furthermore, taking the pre-service teacher community rather than the individual PSTs as the unit of activity, the study hopes to contribute to developing such a model of the PST education by providing an empirical analysis of the conditions and challenges for the PST community to grow professionally. In this study, the CHAT perspective offers an analytic angle from which to understand how the identity of a pre-service teacher community has been formulated and evolved through its three-year experience of engaging with the co-planning, co-implementing, and co-reflecting processes of the biology instruction program for high school students. Our specific concern was to grasp the dynamic relation and tensions arising from the relationships between the components within an activity system as the PST community made an effort to improve the quality of the program as their experience accumulated.

In this study, the activity system of the PST community can be understood as follows:

- Subject: PSTs with differing periods of participation and motivation.
- Object: To establish the aim, vision, and objective of the program or the PST community's activity.
- Outcome: Revision or addition of the science programs, accumulated teaching knowledge and know-how about the inquiry-based approach, etc.
- Tool: Inquiry-based science education discourse, teaching materials, laboratory equipment, the science curriculum, science education theories, teaching and learning methods, content knowledge, etc.
- Community: PSTs, students, research team, the school, the university.
- Rule: Membership, program attendance, preparation, plans, consensus, etc.
- Division of labor: Turn-taking in the roles of co-planning team, main tutor, chair of the evaluation session, etc.

Research Method and Data Collection

During the three years of the study, the research team was engaged in the overall phases of co-planning, co-teaching, and co-reflection. A variety of data were collected throughout these phases, including recordings of preparation and evaluation sessions, preparation teams' reflective journals, classroom observation, focus group interviews with the PSTs, and group work recordings as the main data sources. As **Table 2** shows, the focus of the research has shifted according to the issues that the PST group was addressing. For example, during the first-year phase, we noticed that the PSTs' reflections often remained only on the level of a description of experiences (Gelfuso & Dennis, 2014), and that issues arising from the discussion did not lead to critical examination into the causes and solutions of the problems. Over the next year, therefore, the research team became increasingly engaged in discussions during the evaluation sessions, so that more concrete ideas were generated and further agreed upon among the PSTs. Along with deeper levels of reflection occurring during the evaluation sessions, in the second year the research focus shifted to the actual classroom teaching, especially the ways in which PSTs interacted with the students and their congruence with the aims of the inquiry-based science program. Later in the project, the groups' main concern shifted towards the systematic and sustainable provision of the program in the future based on the accumulated experience.

Table 2. The foci of research and data sources

Year	Focus of research	Main concerns
1st	• Exploring PSTs' perceptions • Analyzing evaluation sessions	• Low level of reflection
2nd	• Analyzing PST-student interaction patterns as the indicator of improved teaching skills	• Improving evaluation sessions • Clarifying the aims of the instruction sessions
3rd	• Exploring two PSTs' teaching skills • Improving programs based on accumulated data	• Systematic preparation and implementation
Data sources	• Main sources: Observation and recordings of preparation and evaluation sessions; Preparation teams' reflective journal; Classroom observation; Focus group interviews; Group work recordings • Secondary sources: Student interviews and surveys; Program books; PST workshop materials; Research team workshop and meeting minutes; the whole-team (PST and researcher) workshop materials	

Table 3. Forming a community through rule-change

Developments	1st year	2nd year	3rd year
Reformulating membership rules	• The problem of free-rider(s) was raised due to the irregular attendance of some members.	• Rules on attendance became stricter.	• Stricter rules to earn credits for Educational Service applied.
The role of the preparation team	• Teams of four prepared instruction sessions in turns. • Many members did not take part.	• The teams were fixed at the beginning of the program to allow more time to prepare. • The team led discussion during the evaluation.	• The leader rather than the team led discussion during the evaluation, to encourage free opinions from all.

Table 3 shows a more detailed description of the decisions taken by the PST group, which were concerned with the changes in the rules and role-division in the activity system. Overall, the decisions were concerned with promoting the members' commitment and responsibility to the program and with organizing the provision of the program and each instruction session more systematically. In this, the leadership of the leader and some committed members' initiatives were key to translating the decision into concrete actions, for example in annual plans and new program development.

In our other papers, we provided a full account of the cycles of research as the research inquiries evolved according to the PST group's needs and issues, and a detailed analysis of the improved level of the PSTs' reflection over three years which showed the evidence of the professional growth of the PST group (Hwang et al., 2015; Shim et al., 2015). In this paper, we focus on explicating how the growth of the PST group occurred as the members engaged in addressing issues over the three years, with a focus on the changes of the science program that showed the outcome of the group's increasing professional growth. To do so, CHAT was adopted as a lens to grasp the complicated process that the group experienced by modifying their objectives, tools, rules, and role divisions as they pursued developing and implementing a more inquiry-oriented science.

ANALYSIS: EXPANSIVE LEARNING THAT LED TO GROWTH OF THE PST GROUP

Forming and Sharing Object(s): Clarifying the Aim of the Science Program

Over the years, the most fundamental aspect of the learning of the PST community occurred in terms of the formation of the shared object in the activity system, involving the aims of science teaching through this particular laboratory-based biology program. Since only senior-year students learned about theories of science education, the PSTs' use of terms such as "inquiry" and "laboratory work" was neither elaborate nor explicit in definition. In fact, even though the program title included "laboratory work" as the main tool or method for science learning, there had been no serious effort to define the objectives of the program. Actually, the responses quoted below show that in the early phases of the study, the PSTs' perceptions of the need for laboratory work varied. The problem was that the PSTs' viewpoints were not often expressed when there was a need to do so, particularly when the preparation team discussed the content of the next instruction session, and they needed to have an overall agreement upon the core ideas of the purpose and method of that specific session.

R: "Why do you think laboratory work is necessary?"

M1: "Not everything needs to be taught through laboratory work."

M2: "Laboratory work is important at times. But they can learn more things faster if [teaching] is done through lectures rather than lab work."

M3: "I am skeptical about lab work in schools. But I believe it's necessary in this program, because the school does the teaching and we approach the theory based on lab work."

In terms of the activity system, "the object" was only vaguely defined and not well shared among the PST members, and it was the initial intervention by the research team that provided a core theme for co-reflection after each instruction session. In this respect, we tried to understand the PSTs' discourse in the light of theories of science education. For example, "curiosity" was often used when the PSTs argued about the need of laboratory work. The term was meant to refer to students "having fun" or "getting interested" in scientific phenomena. Importantly, in the PSTs' usage of the word, the two meanings were not distinguished, even though having fun does not necessarily lead to interest in scientific phenomena (Abrahams, 2009). For the most part, the PSTs' objectives for the program were concerned with science concepts and science process skills and showed much less focus on inquiry and curiosity (Shim et al., 2013). Also, elementary skills such as observation and measurement dominated the science process skills dimension, with the emphasis on "hands-on" or "not just theories," whereas higher-level, more integrative skills, such as hypothesis-making, interpreting the data, scientific reasoning, and problem-solving, were less focused on.

In the case of the fetal pig dissection, it took place in the first-year program in a content-heavy instruction session in which, because of time constraints, the mentors led the dissection process and allowed the mentees to observe the different organs. In the next year this item ran over two sessions, allowing the mentees more autonomy so that they held a discussion of their own as a group to decide where to start the dissection and how to observe the organs, while the mentors focused on facilitating evidence-based discussion and consideration of how the function of an organ was related to its shape and structure. The issue here then was that, owing to time constraints, giving such autonomy to the mentees was not sufficient to achieve the instructional aim, which in this case was concerned with gaining knowledge about the organs. Thus, in the third-year program, the PSTs found a middle ground between the first- and the second-year approaches by shortening the dissection time while still allowing evidence-based discussion to occur. As the interview below shows, this case was one of many where the PSTs tried to resolve the dilemmas that they constantly encountered in choosing an instructional approach (e.g., more student-led, or more teacher-led), and at the same time to consider how high-priority aims could be achieved (e.g., practical skills or scientific reasoning through taking a specific instructional method).

[Fetal Fig Dissection, 3rd year]

"I was actively doing things myself, I was much more active last year... things took quite a long time because I was doing them all by myself … this time, however, things are done much more efficiently even though I have less amounts of things organized. Students are definitely listening more attentively, though. … but I'm not sure which is better."

Interestingly, the fun-oriented instruction sessions gradually disappeared over time (**Table 1**). In the early phase of the program, from the PSTs' point of view, experiments showing chemical reactions (e.g., "Secrets of 12 Test Tubes") or confirming a scientific principle (e.g., "Osmosis") were considered easy choices for teaching. However, the PSTs' increasing awareness of "inquiry-oriented" science instruction made them shy away from such simple experiments in which students did not learn many science concepts or experience genuine scientific methods. This can be understood further in that the PSTs began to grasp that having fun was not enough to get interested in science (the issue addressed above). Meanwhile, the "forensic science" instruction session survived with its specific content revised to be more like an interesting detective story, which provided students with motivation to solve the problems using scientific principles, thus representing inquiry-oriented work rather than just fun. Crucially, activity or task/problem-solving types of instruction became dominant over the three years as the PSTs actively pursued "inquiry" as the core objective of the overall program. For example, the classic topics of biology instruction such as plant classification went through revisions to give more of an "inquiry" dimension to students' experience. Initially, as in the original plant classification classes, the concepts needed for the classification experiment were taught in class and then the students were led outside to do various plant-related activities. However, in the later years the students were given sufficient time to make their own flora book based on their own observations of plants.

[Plant classification, 2nd year]

"I was also concerned whether I should give the names first in this classification key table when I was making it, or give the characteristics first; I was debating with myself a lot, but efficiency-wise, it is not good. (Letting students heuristically find out without telling them various characteristics)"

As will be seen later, the term "inquiry" referred more to students' active engagement with an activity or task than to the scientific reasoning or evidence-based explanation emphasized in science education theories. Nevertheless, their pursuit of "inquiry" contributed substantially to clarifying, sharing, and realizing the objectives of the community in the activity system.

So far, we have described the growth of the PSTs' group in terms of the formation of the objects in the activity system. In fact, identifying and sharing the objects cannot be understood separately from the resulting developments in the activity system. Thus, we now describe in detail how the PSTs pursued the priority objectives of the program by revising and introducing tools. The "tools" in this case were concerned with the physical and symbolic means of teaching and learning during the instruction sessions. Development of the tools, such as the introduction of teaching slides, activity sheets, and laboratory materials and protocols, occurred to different degrees every time the PSTs co-prepared the next instruction session. In the process, the PSTs examined past materials and came up with new teaching ideas to try, as teachers normally do. In the next section, we focus on the distinctive features of such a process that characterize the meanings and limits of expansive learning that occur in a community.

Inquiry Discourse as a Psychological Tool: Multiple Meanings and Gaps in Actual Teaching

In activity theory, the word "tool" refers not only to physical entities like teaching materials but also to psychological ones like language. Psychological tools are symbolic cultural artifacts—the signs, symbols, texts, formulae, and languages that mediate communication in a community (Kozulin, 2001). In this sense, the term "inquiry" became one of the most crucial psychological tools in this study as the PTSs considered how to realize their increasingly shared object, such as inquiry-based biology education, that could be extended beyond learning science concepts or just having fun. In the first year, the term "inquiry" was almost absent during the evaluation sessions. For example, the PSTs figured out the meaning of inquiry in terms of "being able to apply scientific principles to real phenomena" and "being able to communicate and reason scientifically about how their egg dropped in relation to the way it was designed" (the egg drop program). However, in the overall discussion, this attention to scientific inquiry was overshadowed by the other, dominant purposes of the instruction, such as learning science concepts and handling laboratory equipment. The emergence of inquiry discourse was then stimulated through the researchers' purposeful questioning during the co-reflection, where the question was asked, "What do you mean by 'inquiry'?" or "In what sense do you think the instruction was planned to promote students' inquiry?"

One of the positive outcomes of such intervention was the PSTs' increasing reference to "inquiry" by invoking the knowledge that they had acquired from the teaching methods course. In the second year, the PSTs decided to introduce an inquiry-based instruction session that was specifically focused on inquiry steps, entitled "What Scientists Do." The purpose was to give the students an opportunity to experience the whole inquiry process from observation and hypothesis formulation to theory-building, as this was also included in the first part of the tenth-year science curriculum in Korea. Some senior-year PSTs also utilized such science education theories as "Twenty Things about the Nature of Science and Science Writing Heuristics (SWH)" that they picked up during the teaching methods course. As the quotation below shows, the new instruction session received good comments from the PSTs themselves and from the students. Since the whole session was team-based, the PSTs were able to observe individual students' performances and personalities more closely.

> *[What Scientists Do, 2nd year]*
>
> *"I liked it because the **students participated more actively** than expected. I thought they would not want to do the exercise, but they were actually able to come up with fresh ideas. I think this instruction went successfully compared with others, in some of which they did not participate very well."*

Looked at critically, the session could be criticized for not really teaching any scientific theories and not being well prepared from the point of view of scientific design. However, it was a fruitful learning experience for the PSTs in that they realized that students could be given full autonomy in learning science. This session was revised the next year in ways that focused on the specific tasks to be solved. The discourse on "inquiry" was reformulated to convey multiple meanings depending on the individuals or teams who defined and used the term.

Even though the PSTs began to consider more inquiry-oriented approaches, there were limitations to this approach, especially when the experiment did not yield the planned results. For example, the "Pigment Separation" instruction session was remembered as a "failure" by many PSTs for this reason. To complement the simple pigment extraction experiment, the preparation team refined instructional strategies in ways that invited students to reason why a leaf looks green by linking the principles of color with the observed data. However, extracting

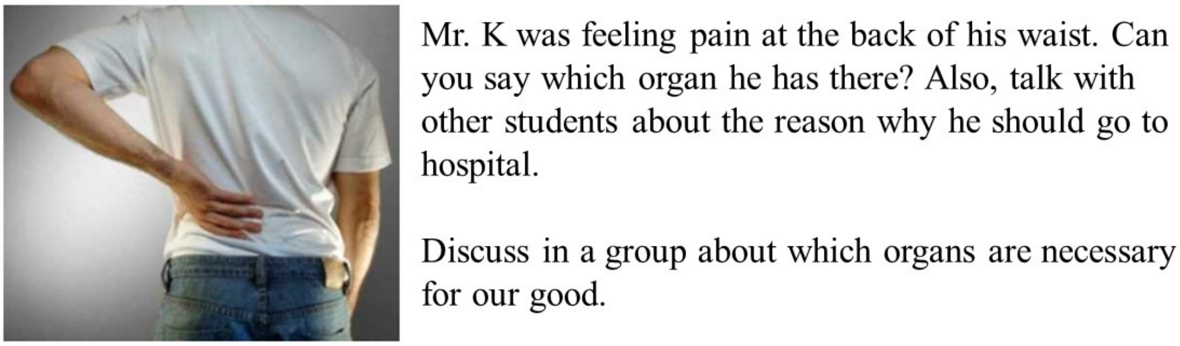

Figure 2. Example of open-ended questions from the activity sheet for "Fetal Pig Dissection"

pigments from the leaves took too much time, and in the end many groups did not obtain results. During the after-class evaluation session, the PSTs actively discussed the importance of continuously asking the students to consider "Why?", and they decided it was excellent to see that the students were able to discuss possible reasons that the experiment went wrong. However, the PSTs still thought the overall instruction session had been a great failure because the experiment went wrong. Consequently, in the next year's program, the session underwent major modifications that reduced it to simple laboratory work focusing on hands-on skills. In spite of the PSTs' increasing efforts towards "inquiry-oriented" instruction, this case shows their limited ability to learn from the failure of the experiment, which is a valuable part of the process of scientific inquiry.

Introducing a New Instructional Tool: The "Open-Ended Question" Strategy

In spite of the ongoing discourse-practice gap in pursuing more inquiry-oriented science instruction, the PST group's endeavors yielded productive outputs in improving the quality of the overall program thanks to the introduction of an annual plan and the initiatives of some passionate members among the group. In addition, the case of the "open-ended question" illustrates another tool change in the activity system through the group's efforts to realize their shared object: inquiry-based science instruction. One major issue was how to find a balance between learning science concepts and doing inquiries, although the two aims of science education were often inseparable. To the PSTs' mind, the dilemma was that allowing more initiative on the part of the students required more time; but on the other hand, focusing on science concepts made the students feel dull and passive. The below vignette illustrates the persisting issue of how to facilitate student's active participation and the PST's lack of ability to do so in the initial phase of the study.

> *[Chick Development, 1st year]*
>
> *"Students were more passive than I thought. When the teacher points things out for them, they say, 'Oh! I see,' but when they were instructed to do it themselves, they would stop in the middle…"*

The idea of the "open-ended question" as a means of resolving this ongoing tension between time management and inquiry came about in the second year. "Open-ended question" refers to a type of question that has no obvious answer and thus might have several different right answers rather than a merely "factual" one. **Figure 2** shows an example of the open-ended questions introduced during the Fetal Pig Dissection instruction session in the third year of the study. Over three years, dissection had been the most popular topic among students since dissecting animal body parts was not practical in school labs due to time and cost constraints. Even so, the PSTs were not fully satisfied with their instructional guidance. The recurring dilemma was how to get students to engage actively with the dissection while facilitating an "inquiring mind." In the second year of the study, the preparation team decided to allow the students in groups of four to decide where to start the dissection and what organs to observe in detail. Although the attempt received good comments during the co-reflection session, some mentors raised the issue of time, as their mentees had difficulty due to their varying abilities in dissection. They then considered the issue further and reached agreement that there was a need to organize the instruction session with the mentor's guidance rather than giving the students full autonomy. Then, during the next year's session the students were guided to pursue their inquiries by focusing on a specific organ system rather than the whole body, and the remaining time was dedicated to thinking over an "open-ended question," as shown in **Figure 2**. Such revision was intended to guide students to "know" the functions of body organs in addition to "observing" them, thus meeting the instructional aims: learning science concepts and doing inquiry at the same time.

The inclusion of the open-ended question in this case resulted in the narrowing of students' focus during inquiries by giving them a specific question rather than supporting them in coming up with their own questions.

Naturally, the decision received both positive and negative comments during the after-class evaluation session: some found it effective in encouraging students to think deeply about one or two questions, whereas others pointed out that their mentees still tended to get the right answers. As the quotations below show, the open-ended question strategy represented the PSTs' continuous efforts to lessen the students' fears about giving the "right" answer rather than just acquiescing to the students' passive learning attitude.

> *[Fetal Pig Dissection 1, 2nd year]*
>
> *"My students tended to obsess about getting the right answer, whether they worked on activity sheets or experiments. I mean, I felt that they were really afraid of getting things wrong. They could have taken more initiative in pursuing their inquiries or whatever, but they didn't."*
>
> *[Forensic Science, 3rd year]*
>
> *"Today's question seemed to require a right answer and the students were afraid of voicing their thoughts. If we kept giving them more creative questions and they understood there was no obvious answer and got used to this, wouldn't they take courage and voice their thoughts?"*

Tension over "The Mentor's Role": An Easy Solution but not a Fundamental One

On the other hand, another case of tool development illustrates ongoing tensions between the other parts of the activity system: rules, division of labor, and community. "The Mentor's Role" refers to an instructional guide distributed to mentors before an instruction session began. The main part of the session consisted of group work, and thus mentor-mentee interaction in the group was crucial to successful laboratory work. However, some mentors were criticized for being unprepared for their role in the session due to their absence from the pre-sessional lab work. In the second year of the study, the PSTs decided to introduce a new tool that they called "The Mentor's Role." The idea was to prepare a guide in which lists of things to do were written down clearly, so that the mentors, even if they did not attend a pre-sessional lab work, would know how to lead the laboratory work in their group once they read the guide. Initially, the intention was to help every mentor to get better prepared by reading the guide in advance, as the quotation below shows.

> *[Fetal Pig Dissection 2, 2nd year]*
>
> *"The whole group atmosphere was very different depending on whether they [the students] were passive or not.* ***If the mentors had prepared a little better by using 'The Mentor's Role,' the difference could have been lessened."***

"The Mentor's Role" received good comments from the mentors. As a result, it became a rule for the preparation team to write a guide for the sessions for the next year. Once developed and used, "The Mentor's Role" was a quick and easy means for mentors to prepare an instruction session, since it included the core concepts to teach, key points to address during laboratory work, and some example questions to ask to assess students' knowledge (see **Figure 3**). However, the issue was raised as to whether the guide needed to be written in more detail, and if so, whether it would actually help improve mentors' teaching competence in the long term. The quotations below show the contrasting viewpoints raised during the co-reflection session.

> *[Fetal Pig Dissection 2, 3rd year]*
>
> *"If we could create it together with an activity sheet, an answer key and mentor comments for each question,* ***would it be more efficient, even though it would take more time to prepare?"***
>
> ***[Forensic Science, 3rd year]***
>
> ***"During the pre-sessional lab work, there were no discussions of what to teach in each phase of laboratory work, so even though 'The Mentor's Role' was handed round in the morning before the session, the mentors were not well prepared."***

1. First Activity: Making the DNA model

✓ The model is fragile. Please be careful not to break it. The tail bone is especially prone to breaking when "taking apart."

✓ The students will do a group presentation upon observing the characteristics of the DNA model. They will be given 5 minutes to make it, and 10 minutes to find the characteristics, so in total it should take 15 minutes. They can be given hints, but do not mention anything directly (for example, "How are the directions of the two arrows?" is a hint, but "There are 2 helixes, so it looks like a double-helix right?" or "The arrows are pointing in different directions so they must be antiparallel" are examples of direct hints).

2. Second experiment: Observing the mutated fruit fly

✓ Including the wild type, there are a total of 7 types: ap (no wings), CyO (uplifted wings), ywsn (yellow body, white eyes, curled bristle), Bar (barred eyes), e (black body), and Antp (Antennapedia: there are legs in the place of antennas).

✓ The students might get noisy because it is their first time observing a fruit fly. Please keep them under control.

The students should first observe the wild type, and then the ap type that most obviously shows the traits, and then e, and Bar, CyO, Antp and then ywsn. Antp and sb (short bristles) are shown together, but observing this is optional. They should be reminded while observing ywsn that many mutations can be seen in one entity.

✓ The observation time should be kept between 20~25 minutes.

3. Thinking Questions

✓ The first question for the students to think about is what mutations can arise in sequence listing. The students would have learned about the scientific definition of a mutation in the "Introduction," so they should be reminded of this in order to solve the problem. Please help them think of insertion/deletion. You can explain to them more details than just about the chromosomes themselves (aneuploidy, polyploidy, deletion, insertion, translocation, and inversion).

The second question is an open-ended question. The students can write freely. This problem is designed to help the students come to the conclusion that the differences in individuals all arise from differences in DNA.

Before the end of class, the students should be asked whether they think positively or negatively about mutations, and watch a video.

Figure 3. An example of "The Mentors' Role" in Drosophila program

In the first quotation, the mentor considers making a greater demand on the preparation team for the sake of the convenience of the other mentors because "The Mentor's Role" relieves individual mentors of the burden of preparing their strategy and role. However, in the other quotation one mentor raised a more fundamental issue: "The Mentor's Role" could not be a "cure-all," and indeed it made pre-sessional lab work ineffective since the mentors felt no obligation to attend. From the CHAT perspective, this indicates that "tool" change is very closely related to the other parts of the activity system like rule, community, and subject. Since the program was run with the mentors' voluntary participation, it was difficult to apply a strict rule, such as dictating that everybody must attend a pre-sessional lab work.

Table 4. Changes in the activity system over three years

Activity system	1st year	2nd year	3rd year
Object (Objectives of the program)	• No shared objective • Low level of co-reflection	• Clarified the aim of each program • Increasingly focused on inquiry-based science instruction	• Tensions still exist between different objectives but were handled more strategically
Tool (Inquiry discourse)	• Absence of "inquiry" talk • Scientific inquiry not explicitly addressed as the aim	• Increasing reference to "inquiry" • Introduced "Open-Ended Questions" • Introduced "Mentor's role"	• More motivation from the PSTs towards inquiry-oriented instruction to develop new curricular topics
Outcome (Adding, revising, discarding the programs)	• Simple lab work	• Revised the existing programs with a focus on inquiry • Developed the "What Scientists Do" unit	• Developed two activity-based instruction sessions, "Marvelous Protein" • Modified "What Scientists Do" unit

Consolidating the Identity of the Community

So far, we have analyzed the ways in which the PST group experienced professional growth by focusing on developments and revisions in the objectives and tools of the activity system. In terms of the community's effort to define its objectives, there was a shift from initially vague and unorganized thoughts about the aim of the overall program towards more focused and specific aims for each instruction session under the umbrella term of "inquiry-based education." Indeed, deliberative thinking during the evaluation sessions became the driving force for fortifying the cycle of co-planning, co-teaching, and co-reflecting in more organized and professional ways, which fits with the argument that integration of teachers' knowledge can arise out of "productive reflection" on their practice (Davis, 2006; Yoon, 2012). In particular, the fortified evaluation sessions—the main activity for the "co-reflection" phase—became the mediating "tool" for establishing a sustainable culture of learning in a community. Through this, discourses about science instruction, such as those dealing with "inquiry" and "student-oriented learning," were formed and examined in evaluating the most recent instruction session and preparing future instruction sessions, and practical decisions and plans were made that would have an impact on instructional practice. Also, along with the stronger leadership, the PST community increased its autonomy and actively reformulated the rules guiding the activity. Overall, the PST group's motivation and commitment to the program was enhanced as co-reflection was established as a necessary part of the PSTs' activity.

Synthesis: The Growth of the PST Group in the Activity System

Based on the analysis so far, this section addresses the conditions and challenges for the PST group to grow professionally. For synthesis, the increased autonomy of the members in making decisions in pursuit of their shared goal was the necessary condition that brought about success, although limited, in improving the programs. In striving to define and realize inquiry-based science instruction in their own ways, the inquiry discourse and the open-ended question strategy became the crucial tools that the PSTs had learned to use and develop in improving the quality of the program, leading to the revision and addition of the programs (**Table 4**). From the viewpoint of science education theories, the PSTs' interpretation of scientific inquiry was limited in that evidence-based reasoning and critical thinking were not actively sought while the program was still activity-based. However, it is also worth understanding that the efforts of the PST group ("subject") yielded various substantial "tools" for seeking the common objective of the program ("object").

Although the quality of the program could be judged to have been enhanced by the efforts the PSTs made over the years, the question of the extent to which individual members' teaching competence was enhanced remains a further issue to be dealt with. In this regard, the research team's suggestions for keeping the PST group's current positive assets and evolving towards a more sustainable learning community are mainly concerned with reorienting the objective toward focusing on individual members' teaching competence. Most crucially, to bring about the desired outcome, the division of labor should be re-conceptualized in ways that promote substantial learning by the PSTs from one another. Indeed, in the absence of a formal training mechanism, it has so far been assumed that the PSTs have learned "naturally" as their program experience has accumulated through co-planning and co-reflecting experiences. For example, the idea of "legitimate peripheral participation" (Lave & Wenger, 1991) can be realized by considering the ways in which experienced members transferred their knowledge and know-how to junior members of the PST community. Along with such an internal mechanism grounded in practical epistemology, more objective perspectives provided by teacher educators or serving teachers can also contribute to enhancing PSTs' professional development. During the project period this was achieved partly through the research team's guidance, and at present continues with developing an instruction guidebook. The idea of providing a "role model" by inviting former members who are now serving teachers has been also under consideration to provide more "objective" viewpoints and knowledge that are also grounded in their own experience of having been mentors of the program.

CONCLUSION AND IMPLICATIONS OF THE STUDY

The current case study was conducted within the unique context of an institutional arrangement between the university and the school. Therefore, the learning experiences and the achievements that the PST group achieved cannot be generalized. Even so, this unique case that shows the PST group's professional growth can inform the ways of developing a more practice-based model in the PST education system. Although due to the informal and voluntary setting of the PSTs' participation, positive changes in the activity system were made slowly, the effective co-reflection, once established, created the key frames—e.g., "inquiry-based" science instruction—through which the PST members considered planning and implementing their programs throughout the whole process. Importantly, such key frames made possible the PST group's continuous effort to keep asking, "What is the aim of this program?" and "How can we achieve this aim?" which are the very foundation of science teaching. As a result, unlike the conventional practicum through which student teachers experience how to become accustomed to schooling culture, this PST group's experience has been about forming their own culture of science teaching as an active and reflective agent for addressing and making decisions about the objectives of each program, instructional tools, role-divisions, and rules within the community. Given that the "practice makes perfect" mantra is a powerful discourse that dominates the realities of student teachers' and beginning teachers' induction into the school culture (Britzman, 2003, p. 4), the growth of the PST community in this study was distinctly concerned with the question, "What makes the practice perfect?"

Importantly, the value of giving more autonomy to the PSTs in ways that enable co-reflection does not rule out the authority of the teacher educators. In the initial stage where the core values or rules are not clearly defined in the PST community, the teacher educators should be able to consider what "objects" are possible, and decide with the PSTs how to prioritize these over the planned period. Since rule-changes and decision-making may sometimes bring unexpected results or side effects, as the current study showed, teacher educators should seek opportunities where their PSTs are engaged in meta-dialogues from their own, or more "objective," viewpoints. In this way, the role of "knowledgeable others" (Gelfuso & Dennis, 2014) could be defined more elaborately. In this sense, the university curriculum needs to be re-considered as a "tool" with which to achieve the objectives of the community with PSTs and faculty alike, rather than a form of objective knowledge. In the cycle of co-planning, co-teaching, and co-reflecting in this study, the inquiry discourse was considered naturally and interpreted actively so that creative teaching ideas were drawn on.

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