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An analysis of STEM/STEAM teacher education in Korea with a case study of two schools from a community of practice perspective

Hunkoog Jho
Dankook University, REPUBLIC OF KOREA
Oksu Hong
Korea Foundation for the Advancement of Science and Creativity, REPUBLIC OF KOREA
Jinwoong Song
Seoul National University, REPUBLIC OF KOREA

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The aim of this study was to investigate STEAM (Science, Technology, Engineering, Arts, and Mathematics) teacher education and to examine the successful conditions for its implementation. This study observed two leading schools that have actively participated in STEAM education since the initial stage of STEAM education in Korea. Through participant observation, we videotaped actual lessons, interviewed teachers, and collected their documents. The data analysis was carried out from a community of practice (CoP) perspective and the CoP dimensions were categorized as joint enterprise, mutual engagement, and shared repertoire. The results show that the two communities shared similar dimensions: open-mindedness and self-innovation as joint enterprise, reciprocal relationship and continuous role exchange as mutual engagement, and educational materials and abundant time as shared repertoire. This study gives some practical implications for teachers' successful engagement with and for their competency in STEAM education.

Keywords: STEAM education, interdisciplinary education, community of practice, teacher professional development, teacher community

INTRODUCTION

Many countries stipulate the significance of STEM and its implementation in education. For example, in the United States there are many efforts to support STEM

Correspondence: Jinwoong Song,
Department of Physics Education, College of Education, Seoul National University, Gwanak-gu, Seoul, Republic of Korea.
E-mail: jwsong@snu.ac.kr

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education (e.g., STEM Coalition, http://www.stemedcoalition.org/) and NGSS (Next Generation Science Standards), which stress science and engineering knowledge and practices (National Research Council, 2012). The United Kingdom has a nationwide network for STEM (i.e., STEMNET), while science coursework in Singapore stresses inventive thinking and activities (Ministry of Education in Singapore, 2012, 2014). The Korean government has driven the integration of school science with other disciplines through STEAM (Science, Technology, Engineering, Arts and Mathematics) education (Ministry of Education Science and Technology, 2011a).

The Korean Ministry of Education, Science and Technology (2011b) emphasized STEAM education as one of the main projects for “The Second Basic Plan to foster and support the human resources in science and technology (2011-2015).” In Korea, STEAM education has been advocated to emphasize students’ capabilities in imagination and artistic emotion as well as understanding of science contents. International studies such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Program for International Student Assessment) have shown that Korean students show high performance but very low interest in science and mathematics (Korea Institute of Curriculum and Evaluation, 2014a, 2014b). Also, the number of highest ability students entering universities for studying natural sciences and engineering has been decreasing recently. To cope with these situations, STEAM education was designed to raise students’ interest in and understanding of science and its application by focusing on linking science with other disciplines, including the arts, and solving problems on a daily basis (Kim et al., 2013)

State of the literature

- STEAM education is one of main goals in scien ce education in Korea, as endorsed in national curriculum documents.
- Basically, STEAM education in Korea premises that teachers from various disciplines collabo rate and encourage students to create output on a daily basis.
- The STEAM initiative has supported a researc h group of teachers to expand STEAM progra ms and enhance teachers’ professional develo pment in STEAM education.

Contribution of this paper to the literature

- This study summarizes various STEAM in-ser vice and higher level training programs in Kor ea that are oriented toward community-based and activity-based programs rather than indiv idual and content-based programs.
- From a community of practice perspective, th e STEAM communities shared common goals f or STEAM (joint enterprise); all members part icipated in decision making in STEAM-related teaching and shared all pieces of work (mutua l engagement); and all members frequently co mmunicated with each other, often using soci al network services (shared repertoire).
- This study suggests that organization of the te acher community is crucial in effective and su stainable STEAM education and that the share d value in the community and devotion of the participants are much more important than ot her concrete factors, like huge investment and enough teaching materials.

In spite of the increase in STEAM education efforts, many researchers reported teachers’ difficulties with STEAM education. Teachers suffer from the insufficient time for and a lack of educational materials for implementing STEAM education in schools (Geum & Bae, 2012; Lee et al., 2012, 2013; Lee & Shin, 2014; Shin & Han, 2011), and feel that there are not enough in-service training programs for teachers, which causes a lack of confidence in STEAM teaching (Lee, 2014; Shin, 2013). STEAM education usually requires collaboration with teachers from other disciplines, and teachers had difficulty in communicating with teachers of other subjects due to the different cultures and natures of the disciplines (Lee et al., 2013; Noh & Paik, 2014). Though such difficulties are engaged to the collaboration, the collaboration is necessary because it is nearly impossible for one single teacher to handle a whole program of STEAM education.

For STEAM education, it is crucial that teachers cooperate with their peer teachers and to develop interdisciplinary (open-ended and creative) instructions on their own. In this vein, it is especially important to organize a group of teachers from different disciplines, to establish effective means of communication with each other, and to cope with problems that arise in the process of STEAM education. Professional subject knowledge and pedagogical knowledge should be integrated appropriately. The socio-cultural perspective on teacher professional development has been long proposed in science education. Education for sustainable development and integrated science teaching with big ideas are also based on cooperative and collaborative teaching (Bang et al., 2013; Mak & Pun, 2015; McNaughton, 2012). Previous studies on teacher education revealed that the support from the peer group is crucial for teachers' professional development (e.g., Jones & Carter, 2007).

From the perspective of activity theory, teaching is an activity performed by teachers (*subject*) in a school (*community*) in order to enhance students' knowledge (*object*) using curriculum, language, and experiments (*tools*) (Saka, Southerland, & Brooks, 2009). For example, Roth and Tobin (2002) analyzed the historical changes of prospective teachers' instruction based on activity theory. They introduced prospective teachers experienced ineffective teaching due to the low expectations at school, unruly students, and lack of rapport and participation. Lee and Jeong (2013) analyzed the contradictions of students in dealing with socio-scientific issues from the perspective on cultural-historical activity theory. Blin and Munro (2008) introduced the resistance to virtual learning environment through the lens of activity theory. Van Alsvoort (2004) also addressed the problem of irrelevance of chemistry in secondary education due to the division between science and society. This indicates that teaching is contextualized under the influence of various social factors such as the negotiation of goal of teaching, norms of classroom, and educational context. Furthermore, constructivist approach supported by many science educators also thinks highly of contextualization by students' taking part in knowledge construction (Traianou, 2006). That is to say, learning in essential is connected to the context and affected by the agent to engage in learning activities. In this vein, Lave and Wenger (1991) proposed the concept of *situated learning* and advocated the significance of learning and teaching as an outcome of communities of practices. A community of practice is a place of learning where practice is developed and pursued, where meaning and enterprise are negotiated among members, and where membership roles are developed through various forms of engagement and participation (Aguilar & Krasny, 2011). In other words, the practice of teachers is an outcome of the teachers' community (Wenger, 1998). For example, Kisiel (2010) analyzed the collaborative works of primary teachers and aquarium instructors from the perspective of a community of practice. The two communities suffered conflicts due to different goals and outcomes, but overcame the problems by sharing their lesson plans and resources (*boundary objects*). A community of practice encompasses not only cognitive and affective domains but also interactions among the members and among the communities. A community of practice shows how teachers set up the goals and values for their works, how they collaborate during the instruction and how they communicate to solve the conflicts or tensions among them. In this light, it would be fruitful to take a look at STEAM education through the lens of communities of practice. Moreover, there have been many studies from a community of practice perspective in science education (Avraamidou, 2014; Howe & Stubbs, 2003; Kim et al., 2012; Kim, Chung, & Lee, 2013; Luehmann, 2007; Roth & Lee, 2004; Thiry & Laursen, 2011; Varelas, House, & Wenzel, 2005). However, it is difficult to find studies concerning STEM/STEAM teacher education from a community of practice perspective.

With this background, this study's aim was to discover the successful conditions for STEAM teacher education by focusing on a case study. First, this study took an overview of STEAM teacher education programs provided by the national initiative in Korea and analyzed them from a sociocultural perspective. There have been many in-service training programs since 2011. Among them, the STEAM research group of teachers (STEAM-RGT) was regarded as the representative of community-based and activity-based programs. In light of analysis of STEAM teacher education in Korea, this study examined the teacher communities participating in the STEAM-RGT project and selected two leading STEAM-RGT for participating in the case study. The researchers analyzed the dimensions of the community of practice (mutual engagement, joint enterprise, and shared repertoire) and examined the successful conditions for STEAM teacher education. This study focused on investigating how the communities coped with the tensions and problems involved in STEAM education. As well, this study intended to give implications for how teachers could overcome these difficulties.

PROFESSIONAL DEVELOPMENT IN STEAM EDUCATION IN KOREA

This study analyzed in-service training programs related to STEAM education, concentrating on the programs driven by the national initiative, KOFAC (Korea Foundation for the Advancement of Science and Creativity). KOFAC is the most representative national institution for STEAM education and for science education as well. Since 2011, the Korean government has continually invested money to support schools, teachers, and students to practice STEAM education. KOFAC has managed STEAM education at a national level as the leading agency. KOFAC has had an annual budget of over USD 5,000,000 to support various projects connected to STEAM education: the development of STEAM contents, the support of STEAM Research and Education (R & E) involving groups of students, the support of STEAM research involving groups of teachers, the development of STEAM outreach programs, and the management of the Teacher Training Center for Cutting-edge Science (Ministry of Education, 2013). Besides, KOFAC has managed several projects, such as STEAM Leader Schools and STEAM In-service Training Programs. Figure 1 shows the structure of STEAM education programs managed by KOFAC (2015b). Among them, the thick rectangles represent STEAM teacher professional development programs analyzed in this study.

KOFAC has operated a three-stage program for in-service teachers: entry, basic, and advanced stages (KOFAC, 2015b). The entry stage is a 15-hour online in-service training program to introduce the concepts, policies, and representative contents of STEAM education. Since 2012, more than 50,000 teachers completed this course. The basic stage is also a 15-hour online program to present specific action plans

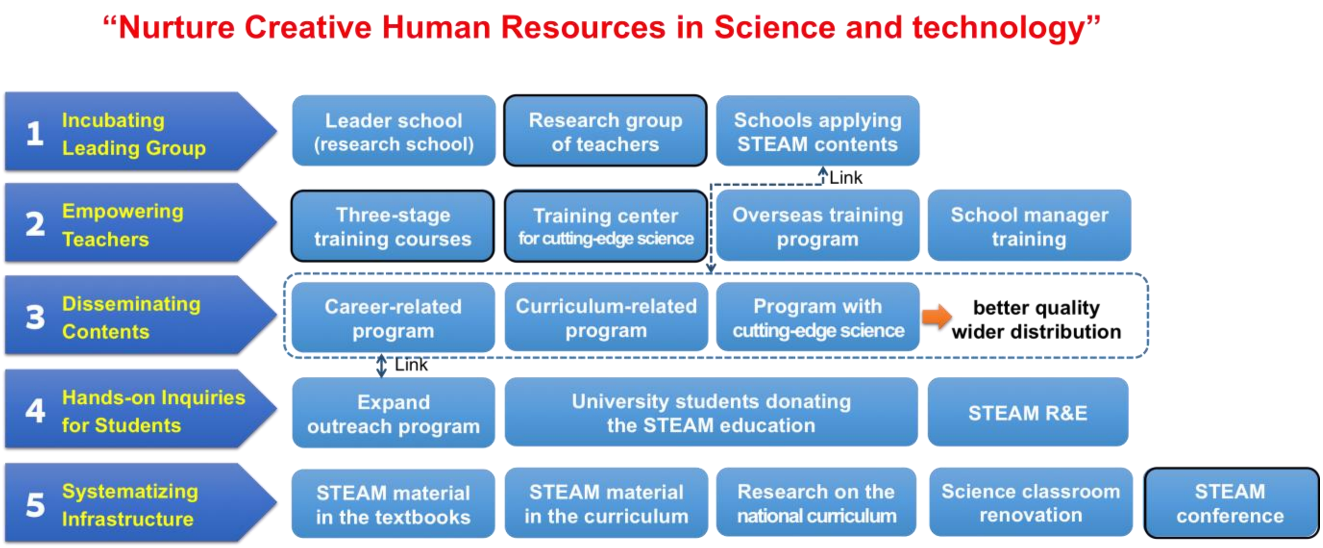

Figure 1. The structure of STEAM education programs managed by KOFAC (2015b)

such as how to link STEAM to after-school programs or to organize STEAM education suitable for school curriculum (KOFAC, 2014c). Both stages are administered at an individual level. Teachers at those levels take lessons and are assessed through an online system. This type of web-based program is suitable for a great number of teachers who are unfamiliar with STEAM education and want to understand STEAM education in a short time at a small charge.

The advanced stage is a mixture of online and offline learning. It consists of about 10 hours of online training, about 40 hours of collective offline training at the Teacher Training Center for Cutting-edge Science, 5 hours of field training, and 5 hours of STEAM fair attendance to share practices (KOFAC, 2015a). About a half of the total of 60 hours is individual oriented (10-hour online training and off-line lectures at the training center), while the other half is composed of collective activities, including the development of classroom-applicable STEAM educational materials, fieldwork, and STEAM fair attendance (community level). The goal of the advanced stage is to encourage teachers to develop and implement educational materials for STEAM education for themselves. Thus, the advanced stage is designed to be relatively activity oriented compared with the entry and basic stages. Teachers are allowed to take the advanced stage after completing the entry and basic stages. Teachers who have completed the advanced stage can then become instructors for in-service training programs. As of 2014, 1,592 teachers completed the advanced stage.

Ryn and Cowan's (1996) two-dimensional framework was adopted in this study to categorize in-service training programs for STEAM education in Korea. Their framework postulates a place for *ecological design*, which prefers a place of everyday life to a deliberate setting for education. It argues that the design based on the engagement of everyday life can establish a sustainable environment for education. *Knowledge* and *learning* are the two dimensions in this framework. First, knowledge construction is categorized into two levels: *individual level* within a community and *community level*. Second, learning differs according to the orientation: *broad activity* or *specific content*. Kim (2011) asserted that teacher professional development needs to become sustainable from the design of preplanned courses that are content-oriented at the individual level to the design of a learning community that is activity oriented at the community level (from the bottom left plane to the top right plane in Figure 2). Relying on this framework, to

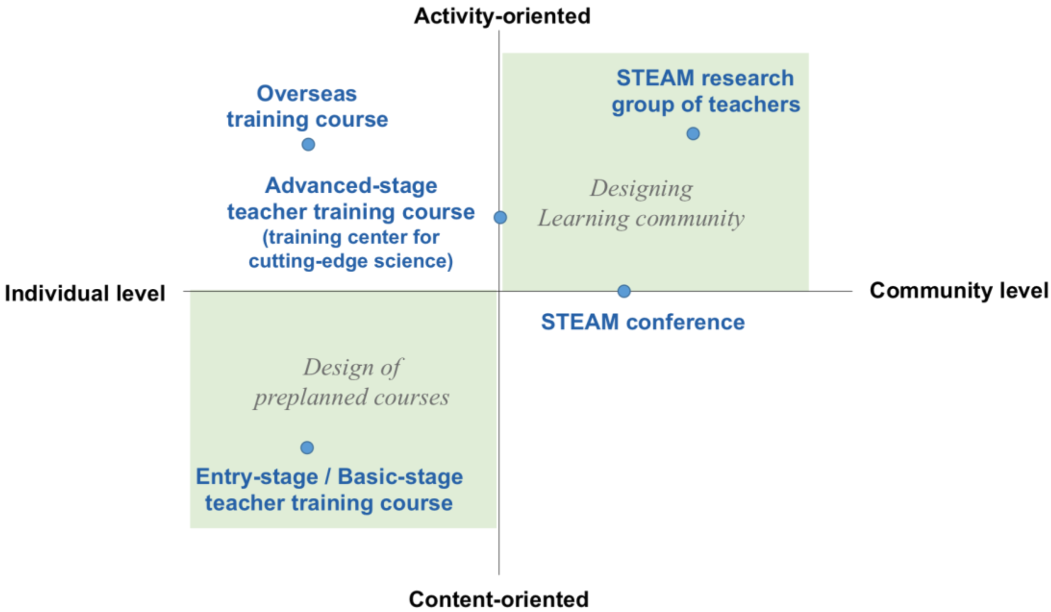

Figure 2. Mapping in-service training programs of STEAM education in Korea

have a good overview, this study tried to map various in-service training programs in STEAM education into the planes as shown in Figure 2.

Besides the three-stage program for in-service teachers, KOFAC operates overseas training programs for teachers with outstanding STEAM education performance in order to enhance their global competitiveness. Through the programs, teachers visit overseas STEM/STEAM education organizations (training centers and schools) and write reports based on their personal experiences. By doing this, they can share their international experience with their peers.

KOFAC also holds an annual STEAM Conference to facilitate action research by in-service teachers and to promote the cooperation of the research community of teachers. The STEAM Conference is also supported by many academic communities: the Korean Association for Science Education, the Korean Society for Engineering Education, the Korean Technology Education Association, the Korean Association of Arts Education, the Korean Society of Mathematical Education, and the Korean Society for School Science. The most recent STEAM Conference was held in Seoul, in which 179 studies by teacher-researchers were presented (KOFAC, 2014b). Through participating in the STEAM conference, teachers had a chance to work with other teachers and form a research community for STEAM education.

In spite of great efforts to promote STEAM teacher education, many teachers have been reluctant to implement STEAM education due to a variety of difficulties: selecting appropriate topics for STEAM education, organizing STEAM contents suitable for the school curriculum, and developing educational materials for STEAM education (Lee & Shin, 2014). According to the report surveying teachers' needs for STEAM education (KOFAC, 2013b), the most frequent request was to support teacher communities for learning and research. STEAM-RGT was designed to encourage teacher communities to conduct research on STEAM education voluntarily and to develop and spread out STEAM educational materials across the nation. This project provides funding to the teachers not as individuals but as a community. Any teacher community in the nation can apply for the project. By its nature, it is activity oriented at a community level. More than 180 groups participate in this project every year with a budget of approximate 5,000 USD for each group (KOFAC, 2014a). The funding is given to the school that the chief teacher of the community belongs to according to the administrative policies. As such, the characteristics of a school may influence the activities of a teacher community.

Among the aforementioned programs, it is likely that STEAM-RGT is the program most likely to overcome the difficulties in doing STEAM education that have been pointed out by many studies. This is because it is based on the collaboration of teachers of different subjects and deals not only with specific contents but also with the whole process of STEAM education. Thus, this study concentrates on STEAM-RGT, hoping to get more practical implications to help teachers in schools successfully implement STEAM education.

RESEARCH DESIGN

Research method

The researchers used a case-study approach to examine the conditions necessary for a community of practice to successfully practice STEAM education (Stake, 2005). The case study focused on two research communities of schools that have led STEAM education in Korea. The 2009 National Curriculum revision had been in effect for two years and STEAM education had been stipulated as the one of the significant goals in the national document in 2011 (MEST, 2011a). Starting from that time, KOFAC has recruited teacher research communities to develop educational materials to be used in the classroom. The aim of one of the projects launched by

KOFAC, STEAM-RGT, was for teachers to develop STEAM contents and teaching strategies, to apply their work in the classroom, and to share the results with other communities. Not all the communities consisted of teachers in the same school but a few of communities were composed of teachers from diverse schools. Teachers who do not belong to STEAM leader schools could apply for the projects and most of the applicants consisted of teachers from various subjects like science, technology, mathematics, and (fine and liberal) arts. Every year, many of the teachers joining STEAM-RGT were selected to attend training programs run by overseas institutions (e.g., Smithsonian Institute, London Science Museum, Arizona Science Center, etc.). Based on these training experiences the teachers developed STEAM educational materials appropriate for the Korean context (KOFAC, 2013a). In 2013, the best two out of the twelve teacher communities that participated in training programs run by the London Science Museum were selected as the successful cases by KOFAC advisors and STEAM experts using network selection (LeCompte, Preissle, & Tesch, 1993). In this study, pseudonyms are used for the two selected schools and teachers.

In October 2012, one of the researchers had an opportunity to meet many of teacher communities in the in-service training and had an interest in the way the teachers communicate and make progression in STEAM education. Accordingly, two other researchers were invited to conduct this research and in December, one of the researchers was involved in STEAM-RGT as a consultant to develop STEAM program for four months. Based on the output of the teacher community, the researchers selected two outstanding communities with the consideration of the advice from the KOFAC and visited the two communities in January and February 2013. Then, we analyzed photographs, field notes, videotapes of actual lessons, and interview transcripts.

This research relied on participant observation (Spradley, 1980). The researchers played non-participation observers in the vignette. In case of Treasury High School, the community was comprised of teachers at different schools. Even more, Treasury High School was located in the middle of other schools. For this reason, the community teachers gathered a meeting and implemented STEAM lessons in Treasury High School where their chief teacher worked. Thus, the researchers visited Treasury High School, observed the classroom and interviewed with the teachers after the instruction. For the triangulation, this study collected research reports and students' homework in addition to field notes (Creswell, 2003). The data analysis was followed by taxonomy analysis (LeCompte et al., 1993).

In regard to the transcript, it was identified as speaker, theme of talk, and the order of utterance. More specifically, the researchers asked teachers at Stony to introduce them to me, and they responded that they had different backgrounds and enjoyed the challenge. To analyze the data, we coded teachers' names, the scene number of the talk (introduction of the organization of the community) and the sequence of the utterance. For example, teacher 2 told me in the following:

> Diverse experiences and different lives… even though we have just lived for thirty or forty years, all of us have different background and it brings about different ideas… [Teacher 2, #1, 3].

In the quote, Teacher 2 means the speaker's ID, #1 means the scene number of the talk, and No. 3 means the third utterance in the theme #1. In this way, we have coded the transcript and analyzed the data.

The research participants were teachers at Stony Primary School and Treasury High School. Both schools have taken part in STEAM-RGT since 2011, the beginning year of STEAM-RGT. Stony Primary School had a great deal of experience in gifted education in science and mathematics. The chief teacher (the leader of the teacher community) was invited as a lecturer in many training programs, including STEAM development. She has supervised STEAM-RGT every year since 2011. In addition, she won commendation from the Minister of Education for her great involvement in STEAM. Treasury High School also had good reputation in education. Since 2010, the school had been selected as a Science Core School, for which the government gives extra funds for a higher quality of science lessons and interdisciplinary science education. In addition, the Ministry of Education named the school as one of the top 100 high schools with excellent curriculum. The chief teacher of this school also participated in STEAM-RGT since 2011, but this was the first time for her to supervise the community. Both schools were selected because the programs they developed received the most favorable evaluation from a group of KOFAC advisors, STEAM experts, and other teachers who participated in the special programs with them (KOFAC, 2013a).

With regard to the research participants, Stony community was composed of 6 teachers and two worked in a different school and rest of them was at the same school, Stony School. The teachers major in science (2), mathematics (2) and technology (2). Regardless of their majors, every primary teacher in Korea should take the course of pre-service education and during the period, they have to learn all subjects in a similar level. As well, they teach all subjects in primary schools. In this vein, the teaching subject is not that meaningful in the primary level. Treasury High School consisted of four teachers who majored in mathematics, chemistry, biology and earth science. Unlike primary teachers, pre-service education in secondary level concentrates on specific field of science. For example, student teachers in physics learn general physics, mechanics, thermodynamics, electromagnetism, modern physics and quantum physics as well as pedagogical theories and physics curriculum. As a result, physics teachers are not that knowledgeable about other fields of science (chemistry, biology and earth science). In secondary schools, many teachers prefer to teach the contents related to their majors rather than to teach all contents in the textbook. For example, physics teachers teach force and motion and chemistry teachers teach matter and interaction in the 7th grade science classroom. That is to say, they seldom have an opportunity to collaborate with other teachers even with science teachers. Hence, STEAM education encourages science teachers to work with each other.

Theoretical lens: Communities of practices

A community of practice can be described as “a set of relations among persons, activity, and world over time and in relation with other tangential and overlapping communities of practice” (Lave & Wenger, 1991, p. 98). A community of practice involves a unique system of *joint enterprise* through negotiated meaning, *mutual engagement*, and *shared repertoire* (Wenger, 1998). *Joint enterprise* refers to how members negotiate their response to the conditions and goals of the community of practice; *mutual engagement* involves the sustained interaction of people within a community of practice and the roles and relationships that arise from this interaction; and *shared repertoire* consists of the signs, symbols, tools, and language that are used as resources and have meaning specific to the community (Aguilar & Krasny, 2011; Kisiel, 2010; Wenger, 1998). For example, purpose of practice and evolution of practice can be regarded as joint enterprise, membership, engagement, participation and roles of the members can be as mutual engagement, and symbols, tools and language within the community can be as shared repertoire (Aguilar & Krasny, 2011). All dimensions work together to determine the practice, and the practice, in turn, works to refine the dimensions.

Moreover, there are various kinds of relations between different communities and a member in any community can also belong to a different community. For example, a teacher belonging to a school community can at the same time be in a local citizen movement and/or leisure activities. This means that there can be an overlap between different communities and that overlap participation of members in a community bring about the change in their communities of practice. According to Wenger (1998), the connection is made through *boundary objects* and *brokers*. *Boundary objects* are overlapped enterprises, documents, terms, and artifacts that help to organize interconnections between communities of practice (Kisiel, 2010). *Brokers* are those people who facilitate connection by introducing aspects of one practice to another.

This study intended to examine the three dimensions (mutual engagement, joint enterprise, and shared repertoire) and overlapping participations (broker and boundary object) associated with the two communities (Stony Primary School and Treasury High School). In addition, this study examined how they coped with the problems in the process of STEAM education (planning, implementing, and evaluating/reflecting) and how the five aspects of community of practice were connected to problem solving in the STEAM process. Table 1 shows the guiding questions used in classroom observation and interviews in terms of the dimensions of the community of practice.

Table 1. Dimensions of community of practice and guiding questions for classroom observation and teacher interview

Community of practice dimensions	Observation and interview
Mutual engagement	How do teachers participate in activities and discussion?
Membership	In what types of roles are teachers engaged?
Engagement	What does full membership look like?
Participation	How do teachers form identities?
Roles	How do teachers interact during the process of STEAM education?
Joint enterprise	What are the purposes, goals, values, activities and common practices of the community?
Purpose of practice	Who determines these things?
Evolution of practice	How do teachers make decisions/resolve problems in the process of STEAM education (plan, implementation, and evaluation)?
Shared repertoire	What artifacts, symbols, and documents are used to give meaning to this community (Especially in STEAM education)?
Tools	
Languages	

CHARACTERISTICS OF THE TWO COMMUNITIES

Stony Primary School: Joint enterprise, mutual engagement, and shared repertoire

The researchers determined the aspects of the community of practice as shown in Table 2. Through fieldwork, teacher interviews, and the produced documents, this study identified joint enterprise, mutual engagement, and shared repertoire in the teacher community using the questions in Table 1.

Joint enterprise

The community at Stony Primary School was formed with a desire to strengthen public school education. Many students in Korea are attending private education (cram schools, private tutoring, online schooling, etc.) and the school principal was eager to enhance the competitiveness in school education and to provide all students with high quality education. The principal invited excellent teachers in the vicinity and some of teachers moved to Stony Primary School. A mathematics teacher with 30 years of teaching experience took charge of developing special programs for science and mathematics education and organized a community to enhance pedagogy of science and mathematics in the school. Later, they applied for STEAM-RGT and she became a chief teacher in the project. All members of the

Table 2. Community of practice dimensions of Stony Primary School

Community of practice dimensions	Stony Primary School community
Joint enterprise	The goal of the community was the contribution to enhance the quality of public education. They aimed at learning about science teaching and then decided to participate in the STEAM-RGT for their passion.
Mutual engagement	They stressed open-mindedness in order to be able to accept plural viewpoints and thoughts. Self-innovation was a great motivation for this community. Also, they had no fear or anxiety about reform and change of their education. They were ready to abandon the way they had worked to accept better ideas. Based on those values, they invited devoted teachers who were familiar with each other and had different backgrounds and a variety of views. Each of them played roles matching their talents, and their roles were switched over time. In this way, they became familiar with all of the processes of STEAM education. In addition, everyone had an opportunity to serve as leader and to discuss any topic. They helped each other frequently.
Shared repertoire	Project outcome (educational materials, reports, etc.), time

community were eager to learn new pedagogies and teaching strategies and wanted to enhance the quality of school education.

> As mentioned before, [the principal] had a desire to make school education competitive and wanted to give ordinary students the same thing as the gifted students… [Teacher 1, #4, 11]

Later, they became interested in STEAM education and participated in many projects related to STEAM education. However, money was not the first issue but they wanted to engage with STEM-RGT because STEAM can give students to more chances to learn science and mathematics and the teachers wanted to learn "new ideas". They were ready to spend all of time for what to do.

> Every day we are forced by the school security guard to leave the school… Money is not a big deal. Sometimes we have to work [even when we go home] and we share the work with others at night and everyone does it… The budget is very small. However, everyone did not want to move out of the community. [Chief Teacher, #5, 1-3]

Mutual engagement

The teacher research community in Stony Primary School consisted of six teachers, two of who taught at different primary schools. When the community was first organized in the school, the members were all at Stony Primary School. Over time, however, they decided to change the members because "if we remain still for a long time, our thoughts will remain standing and after-all be near-sighted." They believed that different backgrounds and careers helped them to flourish new ideas and more creative. In the beginning, the novice teachers in the same school were reluctant to spend much time to participate in the community. Thus, the two new teachers in other schools were invited to join the community and had a different kind of experience from the rest of the team: they had worked in electronics companies.

The teachers were invited through the overlapped participation of the existing members. A member in the community met the two new teachers in the in-service teaching programs for the gifted and observed them for six months to see whether they could work together. They were offered the chance to join the community because they could spend much time for the community and passion for the learning.

> We've known each other for only two years. We met the two newcomers in the gifted education programs. After we observed them for six months, we believed they would match our team and invited them to join. [Teacher 3, #5, 8]
>
> They are different [from novice teachers in my school] because they really wanted to learn whatever they could. When we said, "let's do

> something," they worked very hard because nobody had cared about them before. [Chief Teacher, #6, 25]

It was intriguing that they kept changing their teaching and their products. They asked their students to guess what would be inside the opaque boxes. For the several days, they tried to find out the appropriate box that can be helpful to stimulate students' interests and to flourish students' ideas. First, they used aluminum boxes but they found that the students' responses were not that diverse due to the similar sound when shaking the boxes. Thus, they took use of many boxes with different materials: paper, snack box, and plastic. On the day the researchers observed the classroom, they applied their materials to the classroom and the teachers found that sand came out of the boxes and they discussed new materials and proposed to use a case for a float. In the next classroom, they used float cases instead of snack boxes. After the instruction, the teacher who taught students in the classroom and two other teachers observing the classroom discussed what should be changed for the better understanding. In this ways, they discussed problems and tried to come up with answers. When they developed the first prototype and used it to teach students, they found something missing and changed it the next time. In terms of teaching, they were willing to listen to anyone and opened their classroom to outsiders. Also, they welcomed anyone who wanted to learn from them. They mentioned "self-innovation" as an important value of the community. This means that they wanted to break up their existing standards and tried to hold new viewpoint about teaching. They revised their educational materials repeatedly until they found satisfactory outcomes and effects.

The way teachers worked in STEAM education was reciprocal. For example, a new teacher had worked in an electronics company and then became a primary teacher. He was knowledgeable about physics and addressed the problems related to physics. While developing educational materials, the division of labor relied upon each member's strengths. A teacher who was good at making something took charge of developing educational materials, another with presentation skills made a presentation file, and another teacher taught students while the rest of the members observed the classroom and reported the pros and cons of the developed materials. Moreover, they exchanged the roles with each other in order to avoid possible biases.

> At first, we divided ourselves into two groups: people who are good at framing the aim and objective of a lesson and those who were not… Duties were then switched because if we do only one thing, then it's apt to regard anything from one single viewpoint. In the next phase, such as developing teaching tools, we changed our roles… for example, if teachers who established action plans enter the classroom and teach students and teacher who made materials take analysis of their peers' instruction… [Teacher 1, #9, 1-3]
>
> When we ran out of time, we divided the work and each took a part. However, we wanted to discuss the whole thing as always. [Chief Teacher, #9, 6]

Shared repertoire

The community spent a lot of time participating in this government-funded project. They ran several projects related to STEAM education and STEAM-RGT was one of their works. The main outcome of the projects was educational materials: experiment kits, activity sheets, presentation files, and teacher guidelines. The outcomes played a significant role in their community: that is, the outcomes were their main concerns and all activities focused on them. As well, the outcomes helped the members to engage with other community such as STEAM in-service teaching program. Moreover, they spent a lot of time studying STEAM. To develop educational materials for a one-hour lesson, they met twice a week, usually for five or six hours, for two months. In addition, they shared their ideas by e-mail at home. In this community, time was not only individual property but also a social asset as a significant resource for communication.

The project outcome was useful for their overlapping practices. The teachers had a chance to speak to other teachers as lecturers and introduced what they accomplished and how they developed the educational materials. In addition, the output gave them chances to meet other teachers and opportunities to invite other teachers interested in their work.

> When I gave a speech, many asked me how they could create a research community, how I created this outcome, and where they could learn about such things… Even graduate schools called me and wanted to have some tips for teaching STEAM education. [Chief Teacher, #5, 7]

Treasury High School: Joint enterprise, mutual engagement, and shared repertoire

The researchers determined the aspects of the community of practice as shown in Table 3. Through fieldwork, teacher interviews, and produced documents, the community was examined as a community of practice using the questions in Table 1.

Table 3. Community of practice dimensions of Treasury High School

Community of practice dimensions	Treasury High School community
Joint enterprise	The goal of the community was to have fun and learn about STEAM teaching and they wanted to give impacts on ordinary schools.
Mutual engagement	They met in in-service training programs and decided to create the project in order to work together. Due to the distance issue, they could not often meet face to face. Instead, they frequently communicated with each other on the internet. They made important decisions together and the work was divided between them according to their expertise. Everyone could play a leader role in the community and was open-minded to everyone so that they could point out and criticize their works. They spent a great deal of time doing or learning things.
Shared repertoire	Project outcome (educational materials, reports, etc.), time, SNS

Joint enterprise

The members of the community at Treasury High School were not all at the same school. Except for the chief teacher, they were from different schools and lived in various places in the Seoul metropolitan area. They came to know each other in in-service training programs and wanted to have a fun of sharing something. That was the first reason they participated in STEAM-RGT. But at the same time, they were very interested in applying the programs they developed in ordinary schools. While reflecting on their practice, they discussed the extent that their programs would be effective in other schools.

> If we bring this to ordinary schools, the atmosphere would not be better than here. [Teacher 101, #109, 30]
>
> When the program is brought to ordinary schools, it is likely that a teacher will apply it alone. So, we decided that one of us would teach using it. [Teacher 101, #18, 3]

Mutual engagement

Unlike the Stony community, the teachers in the Treasury community were at all different schools. Before they joined in the community, they were at different schools and met each other in different meetings. They were involved in in-service teaching programs as lecturers and classroom observation projects as consulting teachers. Over time, they became acquainted each other and decided to gather together to do something valuable. Even though their teaching experience ranged from 5 to 20 years, their ages were similar and they found it easy to find common interests in science education.

> I was involved in the province institute of science education and participated in teacher training as a lecturer. While doing this I became acquainted with these people and became close with some of them due to teaching consulting. [Teacher 105, #104, 16]

Since Treasury High School was the most centrally located of the members' schools, they met mainly at Treasury. In meetings they discussed the topics to be developed and decided what each of them should do. When they selected a topic, they tried to develop one topic that contains everyone's thought through collaboration instead of each individually proposing a topic. Once a topic was selected, they suggested various methods to implement it in the classroom. They handed it over to others after they added some comments on it. After they decided what to do, they assigned individual duties and shared their works each other by e-mail and online messenger (e. g., Skype). In spite of fewer meetings, they often had video chatting at night. When a teacher finished one part, another teacher looked at it and made comments. It was handed then over to another colleague who did the same thing. They were able to speak unreservedly. Unlike other communities, they had no leader but all were leaders.

> First, after we attended the training program (run by the London Science Museum), we had a meeting at a hotel to set up a goal. Any ideas were accepted. We agreed that it was not better to work separately. Instead, we decided to work together and combine our ideas… When met all day long, from morning to evening. [Teacher 108, #116, 6]

Although they could not meet frequently, they spent a great deal of time on STEAM research. Like the Stony community, they also shared their ideas and continuously changed their products. After they met to discuss the topic to be developed, they worked on their own and shared their parts by e-mail, online messenger, and Social Network Service (SNS). Due to geographical constraints, they could not meet as frequently as the Stony community did. If needed, they had to meet at Treasury High School in the early morning. However, they were always in contact through SNS. To check out if their programs could be implemented in other classrooms, the programs developed were applied in multiple schools and then modified based on the results of the application. The programs were then implemented multiple times in various schools. While doing this, they listened open-mindedly to each other's comments.

> Actually, I am not good at teaching using debates. Mine is making materials for experiment. But I was caught up… I really wanted to do that but I was not confident because I have never done it before. [Teacher 102, #17, 16-18]
>
> We just decided [to join STEAM-RGT] because we wanted to work together. [Teacher 104, #4, 19]

Shared repertoire

Basically, Treasury also had a similar shared repertoire. They discussed and negotiated their opinions in order to create educational materials (i.e., experiment kits, activity sheets, presentation files, and teacher guidelines). They also spent a great deal of time in developing one kit for a one-time lesson. In addition, time was regarded as a communal asset because they had to stay focused on the project. But the difference was the use of SNS. Due to the distance issue, it was hard to see each other frequently. Instead, they shared their ideas and adjusted the output by SNS and e-mail.

> We cannot often see all face to face because everyone is busy and it's difficult to set up the schedule. So, at night, we do collaborative work through the web… In this way, we all know about everything that each of us is doing. [Teacher 2, #116, 12]

Successful conditions of two communities in STEAM education

In spite of different school levels and different ways of communication, there are similarities between the two communities with respect to the dimensions of community of practice. Both of the communities responded that they did not have trouble with or feel uncomfortable about participating in the project (STEAM-RGT). Using the questions in Table 1, this study investigated how the communities solved the problems or conflicts that may happen in communities of STEAM education. We investigated the way the two communities were run according to the steps of teaching: conception (setting a goal or objective of a lesson), plan (constructing teaching strategies and materials), implementation of planned instruction, and reflection (feedback for revision of instruction) (So & Watkins, 2005).

First, regarding the conceptions of teaching STEAM education, the two communities had no conflict about the objective of STEAM education. Both communities aimed at enhancing the quality of school education and students' understanding of basic concepts in science.

> Many teachers asked me, "STEAM education is careless about learning basic concepts of science and mathematics, isn't it?" Rather, I focus on the basic concepts while teaching students to STEAM. I ask myself, "What should students have in their minds?" or "What should they know?" After all, STEAM education is based on the basic concepts… it is important that students would be interested in STEAM lessons but more important thing is to understand the contents. [Teacher 2, #18, 8-10]

Usually, most teachers have different opinions about the role of STEAM education. For example, one may regard STEAM as a motivational tool for learning science while others may view the goal of STEAM to be facilitating students' creativity. It is hard to set up a shared goal among teachers and different interpretations may cause serious problems in developing and implementing STEAM education. It is therefore important that a team or community have teachers with similar goals and views on STEAM education. However, in many cases, teachers are gathered from one school because it is convenient to have close contact with each other. In spite of the long distance, the teachers in Treasury were happy to participate in STEAM-RGT and had no conflict about the goal of education. It is not necessary that members of a community should belong to one school. Rather, the teachers should share the same goals and values, and a close relationship can be a basis for mutual engagement in the community. The distant issue can also be overcome by online communication.

Second, one of the most difficult points in planning is to select appropriate topics for STEAM education. Each of the two communities solved that issue by discussing topics together and trying to respect all opinions as much as possible. The reason that this type of communication worked in their communities was the equal distribution of power. There was a leader teacher in the community but the role of the leader was limited to being the coordinator in the project only. From the beginning to the end, everyone was able to have a chance to lead and organize the work done in the community and was able to be open-minded to each other's comments. Grace (2009) argued that a group with a high quality of decision-making is democratic: no leader, equivalent relationships, and information vigilance.

> We were asked to examine third and fourth grade. We looked into the curriculum and each of us selected two or three content items. We then decided what could be developed by discussion. [Teacher 3, #6, 31]
>
> This [community] is different because there is a leader in most communities. Except a few of members, others usually try to step back from the work. But, that's not the case in this community… My other community consists of nine teachers but only two do all the work in the community [Teacher 101, #117, 3]

One of the difficulties in STEAM education is collaboration with other teachers. This is because in Korean schools teachers usually plan, implement, and even make assessments of instruction themselves. However, STEAM education necessarily involves collaboration. However, teachers of different subjects may have different approaches to goals, teaching strategies, and assessment of STEAM education. In this study, the two communities respected the strengths of each teacher and continuously exchanged roles so that the members could understand the whole process, and be accustomed to doing any part of it.

Third, many teachers hesitate to implement STEAM education because they have insufficient teaching experience with it. However, teaching in a community helped to relieve teachers' anxieties because they had peers and experts to support the new teaching strategies. In addition, allowing experienced teachers to observe classes helped the teachers become familiar with new approaches to science education. In the Stony community, the teachers opened their classes and especially gave novice teachers a chance to take a look and learn about STEAM. This can be called *legitimate peripheral participation* in the teacher community (Wenger, 1998). In the fieldwork we found that a chief teacher's peers assisted her and video-recorded the lesson while teaching students. Such participation encouraged teachers to be familiar with new pedagogy and freely participate in discussion. In addition, open-mindedness helped them to be actively involved. New members or teachers outside of the community could discuss their teaching with them and they continued to revise their educational materials as well as their instructions.

Last, after the instruction in STEAM education, teachers may have trouble in terms of revising instruction because if they are alone they are not able to get comments from others and cannot come up with solutions even if they discover any problems in their teaching. The two communities in this study were familiar with continuous revisions and had frequent discussions. To make revision possible, teachers should be open-minded but also devote sufficient time to finding solutions.

DISCUSSIONS AND IMPLICATIONS

This study analyzed the characteristics of STEAM teacher education in Korea and identified two STEAM communities from a community of practice perspective (Wenger, 1998). The results of analysis on the in-service training programs for STEAM education show that the direction of STEAM teacher education is heading to the community-based one. While the entry and basic stages were individual and content-oriented, the advanced stage was relevant to community and activity-oriented. Thus, this study selected the outstanding groups among the teachers participating in STEAM-RGT that encouraged teachers to organize a community and develop STEAM education programs. The researchers analyzed the selected communities from a community of practice perspective. In terms of joint enterprise, the two communities aimed at enhancing the quality of public education and learning interesting pedagogies. As for mutual engagement, the teachers were closely connected with each other and shared values of open-mindedness and devotion. They did their work in a democratic and circular way. In the two communities, the project outcomes as well as SNS were viewed as shared repertoire.

The results of this study indicate that there may be some characters in the successful community of practice in STEAM education. First, the community shared a common value for the aim of practice. In this study, the teachers shared a clear objective of education and they let some teachers out and invite others who could consent the aim of practice. In some cases, it is difficult to organize a community within one school. That is because "capable teachers want to be get promoted and have no time." Sometimes, it would be better to recruit teachers from other schools. For example, teachers can meet peers in the local teacher meetings or in the in-service teaching programs. The communities in this study also invited new teachers in this way. In this light, shared repertoire such as the project outcomes could play a role of boundary objects that allowed them to participate in the other communities and attracted other teachers. The development of excellent materials and successful management of STEAM education gave them opportunities to serve as instructors in other in-service training programs. Thus, the teacher education agency should foster the overlapped participation by providing teachers with opportunities to have connections with other peers and to organize communities outside of their schools. Through the teacher communities, novice teachers can learn how to implement STEAM education and the members can be encouraged to implement STEAM education by the supports of the peers. It is especially important to support the formation of communities to create a sustainable system of teacher professional development.

Second, the community should develop a mood that teachers can freely talk about their opinions. In this study, the existing members in the community provided new members with a chance to have legitimate peripheral participation in their classes by encouraging them to observe them. Besides, the new members could criticize the senior's teaching in spite of less experience about STEAM education. They wanted to hear new ideas from the newcomers. Such an attitude (open-mindedness) is helpful to enhance teachers' professional development in STEAM education.

Third, it is important to adjust the balance of power among the teachers and to prepare the sound decision process. In this study, the two communities encouraged the teachers to take their duties according to their strong points but also exchanged their roles so as to be able to understand all the work done in the community. There was also nobody given the authority to make decisions alone on the issues emerging in the community.

Fourth, to develop STEAM education in Korea and enlarge the territory of STEAM education, teachers of non-science subjects should collaborate with science teachers in doing STEAM education. Ahn et al. (2013) address similar points to the results of this study. They argue that group-centered teacher activities and an innovative atmosphere in the community are necessary conditions for integrated science education. Along these same lines, in-service training programs should not be based on teachers' majors but should focus on the cooperation of various subjects and communities. Moreover, teacher education should be shifted toward teacher professional development as a community. Recently, the STEAM initiative has run a consulting service, which sends experts to local schools. In order to better achieve STEAM education, the national initiative needs consulting by expert teacher communities rather than individual experts because STEAM education requires thorough teacher collaboration and experience from other communities is more helpful to teachers with insufficient experience with STEAM education.

This study implicates that the perspective on teacher professional development should shift from individual competencies to collective competencies. Although it may not be appropriate to generalize the results of this study, the demands on interdisciplinary approach on education is growing attention, especially in Korea. The 2015 Revised National Curriculum of Korea concentrates on the integrated thoughts of different disciplines (MOE, 2015). As well, there is a growing demand on combination of science with technology in the classroom: embedded kits with Arduino (Jamieson, 2010), the maker movement (Peppler & Bender, 2013), and education with 3d printer and Internet of things (IoT). To satisfy the urgent need, teachers should collaborate different subject teachers and collaboration will relieve teachers' burdens and save more time to acquire new pedagogies.

Especially, a teacher community can be a starting point for educational progression in Korea. In general, Korean students intend to keep silent in the classroom not to give the wrong answers and respect their teachers (Chang & Song, 2015; Ho et al., 2008; Ryu & Cervero, 2011). Receptive attitude of students are good to acquire information and knowledge but may play an obstacle role in enhancing students' creativity. Similar phenomenon can be found among teachers. Science teachers appreciate the tentative nature of science but intend to teach "correct" knowledge of science not to fail (Kim, 2014; Kwak, 2002). Both teachers and students are afraid of failure in teaching and learning. They may not be concerned about the value of failure. With the anomalous or unexpected results, teachers can facilitate students to find out the cause of them and students may learn the nature of science and the joy of achievement when they finally solved the problems. It is likely that school education still concentrates on the cognitive domain although STEAM education emphasizes emotional touch in the classroom. Through the community, teachers can cope with many problems in teaching and be more open-minded about the issues that they are unfamiliar with. To adapt the rapid change in educational environment, teachers should hold an attitude of "self-innovation" and a community is helpful for teachers to be more innovative. Innovative teaching may bring about change of students' attitude in science and help students throw away the fear about failing in the classroom. After all, the organization of teacher communities should point to the reform of science classroom in Korea.

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