An Exploratory Study of the Experience and Practice of Participating in Paper Circuit Computing Learning: Based on Community of Practice Theory

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The purposes of the study were to investigate the participation of artists in paper circuit computing learning and to conduct an in-depth study on the formation and development of practical knowledge. To do this, we selected as research participants six artists who participated in the learning program of an art museum, and used various methods such as pre-open questionnaires, participation observation, and individual interviews to collect data. The collected data were analyzed based on community of practice theory. Results showed that the artists participated in the learning based on a desire to use new technology or find a new work production method for interacting with their audiences. In addition, the artists actively formed practical knowledge in the curriculum and tried to apply paper circuit computing to their works. To continuously develop the research, participants formed a study group or set up a practical goal through planned exhibitions. The results of this study can provide implications for practical approaches to, and utilization of, paper circuit computing.

Keywords: Design-based learning, Computing learning, Paper circuit computing, Community of practice

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Introduction

The maker movement is called the new industrial revolution and it is becoming a global trend. This movement refers to a process in which not only professionals but also laypersons create various artifacts in physical or digital form and share such processes and outputs with others (Halverson & Sheridan, 2014). In particular, these maker movements are booming for artists who want to develop their artwork into interactive works. As a result of this macro trend, it is argued that the maker mindset should be cultivated in art education (Peppler & Bender, 2013). Therefore, the importance of software education and hardware education is being highlighted around the world. Consequently, programming education that is now becoming more emphasized becomes a training that makes the learner a maker rather than a user of software.

This kind of programming education that is being actively studied as a block-based programming tool such as Scratch, has been developed recently. A block-based programming tool provides a visual-based development environment for a programming language that is difficult and complicated (Park, Choi & Lee, 2013). However, current programming education is not able to train learners to become makers, and it is beyond the limit of the virtual environment in the computer. This is because there is no alternative to the complex electronics of the hardware compared to the development of software programming tools. However, maker education is rapidly emerging as conductive pens and tapes including various assembled tools for hardware construction are developed.

One example of maker education is the paper circuit. Paper circuits are electronic circuits made on paper using conductive copper tape, conductive paint, LEDs and a power source such as a coin-cell battery (Makerspace, n.d.; Sparkfun, n.d.). Paper is cheap and light, and can be folded, bent or cut, so it is a material that is not burdensome to use for educational purposes (Siegel, et al., 2010). By enabling learners to construct paper circuits using paper, they can understand electrical
circuits and creatively make their own circuits (Qi & Buechley, 2014). In addition, the paper circuits constructed by learners can be connected with block-based programming tools such as Scratch to control the lighting of the LEDs, the sound from the speaker, and so on. In other words, learners can see the working principle of the software they have implemented through a physical craft that is the paper circuit. According to the constructivist point of view, learning is the learners’ formation of their own knowledge structure. In other words, learning can occur effectively when learners create tangible artifacts to achieve their goals (Papert, 1980).

In this context, software education using paper circuit computing, which is a visible artifact such as a paper circuit, enables learners to understand the results of computing, and to understand the interaction between the computing environment and the real environment. In addition, it can facilitate learners’ problem solving in real contexts and help them express creative ideas (Przybylla, & Romeike, 2014). In this study, therefore, the authors had designed and implemented computing education as Design-Based Learning using paper circuits. This feature of paper circuit computing is particularly helpful and practically feasible for designers or artists seeking to create interactive art.

However, our understanding of paper circuit computing is actually very limited. There are very few studies that have examined the reality of how paper circuit computing learning can be practiced and applied to learners. Researches on paper circuit computing focus more on the developer’s viewpoint of designing and making educational content. Therefore, application research is still in its infancy.

In this study, we selected an art museum that is a leader among paper circuit computing classes in Korea as a case study with the consent of artists participating in a learning community. The purpose of this study was to investigate how artists took part in the learning of paper circuit computing and how to develop practical knowledge through this learning. More specifically, this study tried to examine various ways in which participants took part in the learning of paper circuit
computing with what bases of practice, what meaningful activities occur during learning, and how those activities contribute to the development of individual works based on community of practice theory. The community of practice, a group of members who share the same interests, forms and develops practical knowledge in a specific area. Therefore, we have decided that community of practice theory is appropriate for analyzing the process of formation of the learning community of artists who have needs to reflect new technology in practical work and the process of learning practical knowledge in such a community (Lave & Wenger, 1991; Wenger, 1998).

Thus, we aimed to contribute to a deeper understanding of the practice of paper circuit computing, and to help shape and develop practices in the field of education. The research questions of this study are as follows:

First, how did artists become involved in paper circuit computing learning?
Second, what do artists experience while participating in paper circuit computing learning?
Third, does participating in paper circuit computing learning affect the work of an artist?

**Theoretical Background**

**Computing education as Design-Based Learning**

The maker movement, which is becoming a global trend, refers to the flow of creating creative artifacts in physical or digital forms as well as experts and non-experts, and sharing the process and output with others (Halverson & Sheridan, 2014). As a result of this social trend, it is argued that art education should cultivate a maker mindset (Peppler & Bender, 2013), emphasizing the
importance of programming education around the world. The recent emphasis on programming education can be said to be a lecture that sees learners as makers, not as users of software.

In other words, recent programming education is a kind of design-based learning that cultivates creativity and an attitude of inquiry through the activities of learners designing circuits. Design-based learning refers to a teaching-learning approach that actively engages in the process of inquiry and reasoning into education to create creative artifacts or systems (Puente, van Eijck, & Jochems, 2013). Previous studies have proven the effects of design-based learning. Learners have shown improvements in reasoning, self-directed and collaborative skills, creativity, and scientific inquiry skills (Chen, & Chiu, 2016; Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004). In particular, Ke’s (2014) study showed that learners were able to develop their abstract and quantitative reasoning abilities as well as formulate positive attitudes toward mathematics and activate reflection through the use of Scratch to design games related to mathematics. Thus, computing education as design-based learning is expected to have various kinds of educational effects.

In addition to Design Based Learning, programming education can include content such as principles of creative computing (Brennen, 2011) or promoting Computational Thinking. This study is based on the principle of creative computing that is more suitable for a computing environment that is contextual and produces realistic output. The principle of creative computing has three objectives. The first is to provide learners with opportunities to create and practice to participate in design and production rather than just listening, observing, and using them. The second is to provide learners with the opportunity to personalize and participate in meaningful activities so that they can think about their connection to their work. Third, it provides the opportunity for learners to share their work within the learning community and interact with others as viewers, coaches, and co-producers.
Paper circuit computing

Although programming education is emphasized as a part of maker education, the programming education that is currently being implemented is often beyond the limits of virtual environments in computers. Recently, a variety of techniques have been proposed as a methodology to move beyond the limits of a virtual environment in a computer and to induce learners’ immersion more effectively. An example of this is a paper circuit, an electronic circuit made on paper using conductive copper tape, conductive paint, LEDs and a power source such as a coin-cell battery (Makerspace, n.d.; Sparkfun, n.d.). Paper is cheaper and lighter, and can be folded, bent or cut, making it less expensive to use for educational purposes (Siegel, et al., 2010). By allowing learners to design paper circuits using these papers themselves, they can understand the electrical circuits and use them to create their own circuits (Qi & Buechley, 2014). In addition, the various types of paper circuits designed by learners can be linked to block-based programming tools such as Scratch to control the lighting of the LEDs, the sound from the speakers, and so on. In other words, learners can not only design a physical craft like a paper circuit, but also visually confirm the working principle of the software they have programmed.

However, there is a lack of research on how paper circuit computing can be practiced and applied to learners. Research on paper circuit computing focuses on how to design teaching tools with developers’ perspective (Qi & Buechley, 2014). Therefore, the advantages of paper circuit computing based on Maker-oriented computing education are as follows. First, it is worthwhile to make it possible for children, elderly or non-specialists to practice with electrical circuits and computing, which were considered unsuitable because of the risks and complexity of the technology (for example, Leduc-Mills, Dec & Schimmel, Lin & Chang, 2014; Rogers et al, 2014). Next, paper circuit computing can be taught at a low cost, thereby relieving the burden of the high cost of electronic teaching tools, which has been pointed out as a limit, and the excessive cost incurred in the early stage of
education. Finally, paper circuit computing makes it easy and safe to learn computing without the need to assemble complex electronic components by simply painting and attaching copper tape on a piece of paper.

According to the constructivist point of view, learning is the learners’ formation of their own knowledge structure. In other words, learning can occur effectively when learners create tangible artifacts to achieve their goals (Papert, 1980). In this context, software education using paper circuit computing, which is a visible artifact such as a paper circuit, enables learners to understand the results of computing, and to understand the interaction between the computing environment and the real environment. In addition, it can help learners solve problems in real contexts and express creative ideas (Przybylla, & Romeike, 2014). In this study, therefore, the authors had designed and implemented computing education as Design-Based Learning using paper circuits.

Community of Practice (CoP)

A community of practice as proposed by Wenger (1998) is based on situated learning theory (Lave, 1991). From the viewpoint of situated learning theory, learning is a continuous social practice. The newcomers learn the language, values, and norms of the community as they engage in legitimate peripheral participation, and achieve complete participation. In other words, learning is a social process in which people become aware of the tacit understanding of the community’s specific perspectives, capabilities, and practices as they are participating in the community (Lave & Wenger, 1991).

The community of practice refers to a group of people who share the same interests and set of issues, passion for a topic, and deepen their knowledge and expertise in a particular field through a process of constant interaction (Wenger, McDermott, & Synder, 2002; Yang, 2011). Wenger (1998) explained the community of practice in three dimensions: mutual engagement, a joint enterprise, and a shared repertoire. First, mutual engagement is the relationship between the participants
that is required to maintain the community. Second, a joint enterprise is the result of interaction among the participants and is determined during the work process between the participants. Third, a shared repertoire is an asset that the community of practice needs to drive their concerns.

The formation process of the community of practice can be explained in the following stages: potential, coalescing, maturing, stewardship, and transformation. In the potential stage, people start networking, discover common interests, and identify the common knowledge needs. This requires maintaining a balance between discovery and imagination. During the coalescing stage, members build relationships in earnest and build trust based on common interests and needs. The maturing stage is the stage for the community of practice to grow and become sustainable, and in which the focus, role, and boundaries of the community should be identified. The stewardship phase is the development of community ownership while maintaining openness. At this stage, the community usually experiences tension to maintain its up-to-dateness. The final stage, the transformation stage, is a stage in which the community is either radically transformed or dissolves due to some factors.

Going through each stage, the level of energy and visibility changes dynamically (see Figure 1). The process of developing a community of practice is an appropriate framework that can explain the dynamic process through which artists who want to apply a new technology like paper computing to their practical activities, develop a
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community with those who share similar interests.

Methods

Case selection

This study used the case study method to explore in depth the practical knowledge formation and development of the paper circuit computing learning community. The selection of the case started with the recognition of the practice community learning paper circuit computing in Korea. The community of practice was chosen based on knowledge sharing centered on learning, sustainability, and practicality. This study was conducted with six learners, adult artists who participated in paper circuit computing learning conducted in September 2016 at S City Museum in Korea. As shown in Table 1, the participants each work in the arts as illustrators, western painting artists, a calligraphist, and a book artist. They were from their late 20s to 50s. Five majored in an art field related to their current job, while the other's major was engineering, but none had any computing experience.

<table>
<thead>
<tr>
<th>Name</th>
<th>Sex</th>
<th>Age</th>
<th>Degree</th>
<th>Major in college</th>
<th>Current job</th>
<th>Computing experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Song</td>
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<td>27</td>
<td>Bachelor's</td>
<td>Art</td>
<td>Illustrator</td>
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</tr>
<tr>
<td>Jung</td>
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<td>28</td>
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<td>Illustrator</td>
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<tr>
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<td>42</td>
<td>Bachelor's</td>
<td>Art</td>
<td>Book artist</td>
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<tr>
<td>Kwon</td>
<td>Female</td>
<td>59</td>
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<td>Art</td>
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</tr>
<tr>
<td>Park</td>
<td>Male</td>
<td>30</td>
<td>Bachelor's</td>
<td>Engineering</td>
<td>Calligraphist</td>
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</tr>
<tr>
<td>Lee</td>
<td>Female</td>
<td>54</td>
<td>Bachelor's</td>
<td>Art</td>
<td>Contemporary artist</td>
<td>none</td>
</tr>
</tbody>
</table>
Data collection

This study used various collection methods such as observing the paper circuit computing learning community, collecting photographed various products of community members, to explore how practical knowledge is formed and developed in paper circuit computing learning. Details of the collection of data are as follows.

In this study, open questionnaires were given before paper circuit computing learning was carried out, so that students were free to describe what they would like to achieve and what they actually expected to achieve through the learning. Demographic information of participants was also collected through a preliminary questionnaire. One of the authors observed the participants’ paper circuit computing learning activities and collected document data. Some participants naturally showed their portfolios and other workbooks during the learning activities. These documents and participant observations were used to enhance understanding of the participants and their work activities.

After the learning program, the authors collected data through interviews with each of the 6 learners. The interviews took place where they could talk comfortably without being disturbed in the museum where the learning activities were carried out. The interviews were conducted on the basis of semi-structured interview protocols produced by the researchers on community of practice theory. For the main questions of the interview, the learners were first asked about their motivation and expectations of the program such as “How did you know about this learning program?”, “Was there anything you wanted to learn in this program?” then were asked about their personal experiences and feelings during the learning program such as “Did you have any special memorable experiences during the program?”, “Did you have any difficulties during the program?”. The authors also asked participants about their intention to put into practice what they learned such as “Did you get ideas for various applications during the program?” “Do you plan to apply what you learned in this program to your own work?” Participants were able
to talk freely about their experiences and feelings and ask questions, and the authors also answered the questions about the software programming or electrical circuit design. The authors and participants made an effort to recognize each other as colleagues who respond to questions while sharing and exploring experiences (Witz, 2006).

Data analysis

The analysis of the data was based on observations, interviews, and output of community members, and analyzed through the process of organizing original data, code generation based on community of practice theory, and topic creation.

First, we started by organizing the original data and transferring the preliminary open questionnaires and interview data. The data analysis began by transcribing the responses to the open-ended questionnaires that were implemented before the program and interview data. The researchers read the transcripts several times to use them as the main data of the analysis to have an overall image of the participants while overlooking subjective elements such as intonation, tone and gesture in the interview.

Second, we examined the data and generated codes that can explain practical knowledge formation and development based on community of practice theory in the paper circuit computing learning environment. For the initial analysis, the codes to extract based on community of practice theory were POT (potential), COA (coalescing), MAT (maturing), STE (stewardship) and TRA (transformation).

Third, after examining the cases of each research participant, the researchers conducted a cross analysis of the code generation for all cases and found commonalities. As a result, the codes extracted from the second-order crossover analysis were POT, C&M (coalescing and maturing), and STE in the practice community of paper circuit computing learning.

Fourth, through discussions among researchers, we created a topic that can
explain the overall formation and development of practical knowledge of the paper circuit computing community from the generated codes. The following topics were generated based on the code. In the potential stage, subjects such as “community of practice formation and practice base in paper circuit computing learning” were selected. Then, topics such as “obtaining practical knowledge of the community of practice in paper and circuit-computing learning” were selected during the coalescing and maturing stage. Finally, in the stewardship stage, topics such as “development and sharing of practical knowledge in paper circuit computing learning” were selected.

**Paper circuit computing learning**

To implement paper circuit computing learning for artists, 12 lessons were planned based on the Design-Based Learning Model and Principles of Creative Computing (Brennan et al., 2011). The program was designed to enable learners to apply and utilize paper circuits computing to their own artwork. Details are shown in Table 2 below.

<table>
<thead>
<tr>
<th>Lessons</th>
<th>Contents</th>
<th>Design-Based Learning principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to paper circuit computing</td>
<td></td>
</tr>
<tr>
<td>2, 3</td>
<td>Methodology to make paper drawing instruments</td>
<td>Immersion</td>
</tr>
<tr>
<td>4, 5</td>
<td>Methodology to make paper circuits</td>
<td></td>
</tr>
<tr>
<td>6, 7</td>
<td>Methodology of paper circuit computing</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Connect with one’s own work</td>
<td>Human needs</td>
</tr>
<tr>
<td>9</td>
<td>Ideate and design</td>
<td>Ideate</td>
</tr>
<tr>
<td>10, 11</td>
<td>Prototyping</td>
<td>Prototype</td>
</tr>
<tr>
<td>12</td>
<td>Evaluate and share</td>
<td>Share &amp; Reflect</td>
</tr>
</tbody>
</table>
In the 7th lesson of the program, the concept of paper circuit computing was introduced at the “immersion” stage of Design-Based Learning, and the conceptual learning and practice about specific application methods were concurrently conducted. Specifically, the learners practiced the drawing on paper and making a paper circuit that produces sound when touched in the 2nd and 3rd lessons. Then, the learners practiced making a paper circuit with twinkling LED lights when touched in the 4th and 5th lessons. Finally, in the 6th and 7th lessons, the learners learned computing by using paper circuits with which they practiced from the 2nd to 5th lessons such as how to produce the sound they want, and how to vary the sound and light output according to the touch method.

Next, in the “human needs” stage of Design-Based Learning, the learner discussed the possibilities of how to combine their own work with the new methodology learned from the program; and then they were guided to come up with detailed ideas for work for the next lesson. In the 9th lesson, which is the “ideate” stage of Design-Based Learning, they specified and designed individual ideas for prototyping, and then created their own prototypes in the 10th and 11th lessons. Lastly, in the “share and reflect” stage, which is the last stage of Design-Based Learning, the learners demonstrated and presented their own works to the peer learners.

The program was designed to follow the principles of creative computing (Brennen, 2015) as well as Design-Based Learning. First, the authors tried to provide learners with opportunities to create and practice by participating in design and making rather than simply observing, understanding, and using. Second, the program allowed learners to participate in activities that are meaningful to them so that they can think about how such methodology is connected to their work. Third, the program provided learners with the opportunity to share their work in the learning community and interact with their peers as audiences, coaches, and co-producers. Finally, the authors tried to give learners opportunities to reconsider and reflect on their creative practices.
Potential: Community of practice formation and practice base in paper circuit computing learning

The potential stage is a time when the community is formed. It is possible to explore the formation of the community of practice by understanding the opportunities of the community. In this study, we analyzed the potential stage of
the community of practice through the interviews and questionnaires of the members who made up the community of practice for paper circuit computing learning.

Except for one, none of the artists who participated in the program had ever participated in a learning program about electrical circuits including programming education. Park is a 30-year-old male who majored in engineering and is currently working as a calligraphist. After graduating from college, he worked in an art-related field that had nothing to do with his major. He said he had some experience with electrical circuits in his college years, but he could not remember it, and said he had no programming experience at all. Compared to other students, however, he had little prior knowledge, but a high level of computer literacy and basic knowledge of electrical circuits. Park recently watched the phenomenon of sounding when someone touched the picture in a wall on the YouTube video, and thought that he wanted to use it for his calligraphy work. In particular, Mr. Park said that he had commuted for 3 hours in each direction to learn because these kinds of skills were not taught in his neighborhood.

Song, as a female illustrator in her late 20s, said that she had applied for the program because she thought it would be fun as it is different from the illustration work she had already done. Song said that she knew various learning programs were offered in museums, looked at the on-going learning programs in nearby museums, and became interested in this one. Since then, she has searched for related topics using various search terms including paper circuits on the Internet. Song was particularly interested in how the drawing becomes a musical instrument, and decided to enroll in the program with high expectations because there was not enough production method content online. Song said that she wanted to satisfy her curiosity about the principle and production method through the program. Park is a female illustrator in her late 20s like Song. After Song recommended she take the
learning program, Park found she was interested in the combination of music and art. Park also said she would like to learn new methods to create her own work. Song and Park did not have basic knowledge about electric circuits, but they were highly computer literate and especially good at collecting data by searching related content.

Sohn is a female book artist in her 40s who is planning a private exhibition in December and lectures on book art. Sohn saw the announcement for this learning program during the exhibition at the museum. Recently, Sohn was interested in a sounding book, so she decided to enroll in the program. Although she cannot make all of the book artwork sounded in the exhibition scheduled in December, she enrolled in the program with the expectation that she would be able to make one sound book among the exhibitions. Sohn wanted to learn how to make sound in a painting through this learning program, and she wanted to apply it to make her own work.

Kwon said that she does not live near the museum where this learning program was implemented, but came to this area by accident and learned about it. She said that it was difficult to know exactly what she wanted to learn, but she decided to take a course with the vague expectation of doing something new. Kwon is a female contemporary artist in her fifties and enrolled without hesitation because she wanted to join the trend of the rapidly changing era and get ideas. She said she wanted to spend meaningful time in this program. Lee, a 50-year-old female contemporary artist, is a friend of Kwon. Lee received a phone call from Kwon and heard about the program, canceled a planned overseas trip, and enrolled in the course. She canceled her trip abroad and decided to learn because she thought that she could use it for her work. Lee is an artist who mainly working with fabrics, and said that she recently was craving something new because she fell in love with Mannerism while making cloth work. Kwon and Lee are both contemporary artists who have no basic knowledge of electric circuits. They rarely utilize computers and are even unfamiliar with basic functions such as keyboarding and mouse clicks. But
they had a strong desire to add new technology to their own works.

**Coalescing & Maturing: Obtaining practical knowledge of the community of practice in paper circuit computing learning**

Coalescing, the second phase of the community of practice, is the step of maintaining the community as the members of the community form a sense of intimacy and acquire practical knowledge that they share and that shapes their values. Members of the community of practice have the freedom to leave the community if the practical knowledge they seek and the value of the community do not match. However, no one withdrew from this study. Maturing, the third period of development of the community of practice, is a time when communities and members grow and develop as members of the community, sharing information and knowledge through the community. Coalescing and maturing of community of practice in paper circuit computing learning was as follows.

All of the artists formed a community by participating in paper circuit computing learning. They were in the same art fields, sharing their anxieties, and naturally introducing and showing their work. Sometimes they looked at the works of other learners, asked each other about the process and methods, and shared ideas. Most of the learners who participated in the study through this learning program have experienced immersive participation in the community, and have actively and voluntarily demonstrated their potential and built up their knowledge beyond simply experiencing new technology or acquiring knowledge. In other words, the participants tried to make the knowledge in learning activities more than merely understanding specific technologies, accumulating information, or performing specific actions. This was because most of the learners participated in this learning program with a clear purpose for practice. For this reason, they have actively participated in paper circuit learning activities and found meaning in practicing. For example, once a topic has been learned, participants have been constantly studying...
how to use it in connection with their work. The following response from Lee shows this.

*Lee: I am a little too manneristic about what I'm doing with cloth, so I need to develop a bit more… I found that there was such an educational opportunity. In the case of my work, it is not touchable or a circuit. But it is a three-dimensional <work>… In my case, people want to keep touching the works because it is made with a cloth. But I do not allow them to touch them because they can be ruined.*

*Instructor: Oh, I see. So, if you apply it <the paper circuit>, will people be able to touch it?*

*Lee: Yes, they can touch it because it is made with a cloth. I can deliberately say "touch it" here. Deliberately, yes. So when people are passing by and they touch it, when the sound comes out, they will say, “Oh, uh ...”… Then I can make one or two things like this <paper circuit work> with other works.*

*The authors added content in < > to help with understanding.*

Lee has been influenced by Mannerism in the production of her work, and she had a strong desire to find new ways of making her artwork. Following the program, Lee has been constantly wondering how to apply it to her work. She was able to acquire practical knowledge with precise and clear goals to produce one or two works with paper circuit computing which are exhibited along with other works of her own. Sohn, another participant who has the same goal as Lee, has already scheduled an exhibition in December. She had a goal in the exhibition to make and present one small piece of work like props using paper circuit computing. In fact, Sohn created prototypes of small props for her exhibition in the last lesson, and she used to ask questions of the instructor after lessons.

*Instructor: So, when you do the exhibition, are you planning to mix works that
use paper circuit?

Sohn: Yes, yes... Small as props. Or if I install a part of the center… And if it makes sound when someone touched it, I think it would be fun. I think it would be nice to have something that I had not intended… There are a lot of works people are participating these days… I wanted that kind of things, the program was just for me.

* The authors added content in < > to help with understanding.

Calligraphist Park also wanted to show works using paper circuit computing in a personal exhibition scheduled next year. He said that he wanted to exhibit almost all of his works using paper circuit computing, unlike Lee and Sohn. Park also made a prototype for personal exhibitions in the last lesson. Because Park had solid basic knowledge and was highly proficient in using computers, he volunteered to help Kwon and Lee who rarely use computers, and formed a community of participation. Kwon, who was the eldest learner, participated in the program as the most active and voluntary participant among the research participants and showed an active attitude to ask questions for applying what she learned. She had no planned exhibition to utilize it, but her enthusiasm to learn was stronger than that of anyone else. Finally, illustrators Song and Jung are actively working on online rather than offline exhibitions. They photographed and filmed their works in class and sometimes photographed each other’s works. They also shared the works through SNS and shared positive comments and feedback online in class.

**Stewardship: Development and sharing of practical knowledge in paper circuit computing learning**

Stewardship is the period when community learning outcomes spread out. In the latter part of the program, they shared the location of their studios and promised to visit each other. In this way, learners formed social relations with their peers,
shared the same purpose, and constructed practices. Practice involves objectification that yields products that give shape to a participation and practice (Wenger & Snyder, 2000). In other words, the learners made a more meaningful experience for themselves by sharing their works, i.e., practices, which utilized their paper circuit computing while forming a network of artists and relationships. In this way, practice and intention in learning programs appeared as willingness to continuously practice paper circuit computing, and the learners actively asked the instructor about various application and utilization methods that could be used in the future. Most of those interviewed said that they would continue to study paper circuit computing after the program ended.

Sohn: Because I want to show various things in the exhibition… Well… If I am interested in doing this <paper circuit computing>, I can continue to develop and learn more. If it can make various sounds… In a page <of book art>, when a drawing of chorus comes out and when touch it, a chord comes out… Once the light <LED> came out… I was thinking about it, but I have to keep studying…

Lee: The LED was fun… I… If I apply the LED to this… Anyway, you might able to rip between here <cloth>.

Instructor: Ah… So is the light coming out of the torn cloth?

Lee: In the shape of a square <cloth>, sewing this <on canvas>… When the LED comes on through the whole shaded… When the light comes out (demonstrating)… Doing this (laugh)… It still seems difficult to do like this… So if I do this and it works better with my work, then I have to do more research.

* The authors added content in < > to help with understanding.

In addition, the learners showed much interest in the various application examples presented by the instructor, requested the museum to continue offering
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the program, and requested individual tutoring to learn more. Since then, Kwon, Lee, and Sohn have set up a small community to study paper circuit computing, and have requested some additional lessons from the instructor. They also asked questions about how to find more research materials in Korea and shared ideas for future work. Following the learning program, most of the research participants requested additional materials from overseas, as illustrated in the following example:

Kwon: People like us need to know this to work on it… Then how can I learn <more>? When the situation becomes… There are a lot of people interested in these things these days. First, I will do what I have learned… And I hope I have a chance to learn more. Is there any advanced program I can make own work? I’m going to do it, so if I keep thinking about how to make it, I think I know now. But just now I can do only what you taught. If I want to use it, I need to learn more. Could the museum extend this educational program a little more? If the museum cannot do it, couldn’t you do the advanced course for us?

* The authors added content in < > to help with understanding.

As the learners showed active and persistent intention to learn consistently, the researchers determined that there would be difficulties in utilizing and practicing paper circuit computing. So far, physical computing learning using electric circuits has had complexity and difficulties in implementing the technology. Paper circuit computing learning, however, has the advantage of expanding the scope of the learners to minorities such as children, the elderly, and the disabled. The participants in this study did not simply aim to accumulate experience and knowledge of new learning opportunities but had the purpose of applying it practically. Therefore, in the process, 12 lessons for 4 weeks were somewhat short and insufficient, and most of the learners gave the following responses to the
question of the difficulty of the learning program.

Sohn: Well… I did not think it was difficult because I could do following you in class. I don't know what to do for my own work using this. (laugh) So I think… (Describe her diverse ideas)

Kwon: No. It's vague, rather than difficult overall. I know it as a whole, but I really have to work on it to get it to myself. I tried to work like real artwork, so it becomes vague. How to organize this… What I wanted to do was… making three-dimensional person. Because it has to reflect light, I can use acrylic or cloth. It's not just making it, but trying to breathe it. So, it is difficult to do with this.

Jung: Well, I feel something lacking because the period is short. No, I'm personally very pleased, but it's a little short. A little bit more… It's okay to do this in a day, but overall, it would be better if it was longer.

* The authors added content in <> to help with understanding.

Discussion

The purpose of this study was to investigate opportunities for artists to participate in paper circuit computing learning and to conduct an in-depth study of practical knowledge formation and development based on community of practice theory. For this purpose, we selected as a case artists who participated in the educational program of an art museum that is the leader of paper circuit computing learning in Korea. In the paper circuit computing learning, we tried to explore how the practice community developed based on the development stage of community of practice theory. In other words, the research participants tried to understand what kind of practical bases in which they participated in paper circuit computing learning at the potential stage, what meaningful activities occurred during the
educational program at the coalescing and maturing stages, and how these activities contributed to the development of individual artwork and practice community at the stewardship stage.

As a result of the study, in the potential stage, the participating artists were passionate about various aspects of their work, such as the material of the work, communication with their audiences, and the interactivity of the work. Artists have become involved in the learning of paper circuit computing, either locally or by chance. They had a deep desire to use new technologies and methods to interact with the audience, but they had no prior knowledge of, nor did not know how to approach them. The easy approach of paper circuit computing makes it possible for a learner who lacks computing experience and computer literacy, to compute without cognitive overload. This feature of paper circuit computing has led and challenged older learners and those with no prior knowledge to participate in computing education. In addition, insatiable curiosity and the lack of related educational opportunities motivated one individual to commute more than 5 hours round trip to the museum.

In the coalescing and maturing stage, participating in paper circuit computing learning, the learners in this study worked with others who had a similar thirst for practical knowledge. Learning participants had a clear sense of purpose to apply paper circuit computing to their work and create new interactive art. In addition, learners had concrete action goals to showcase work that applied paper circuit computing to existing exhibitions or online space. Therefore, research participants not only acquired new knowledge but also gained practical knowledge and shared their works and concerns through this education. In this way, participants were thoroughly immersed in education and built practical knowledge voluntarily and actively.

In the stewardship stage, participants showed satisfaction and achievement, and continuously engaged in research and demonstrated a willingness to put into practice what they learned. Participants tried to communicate by revealing the tacit
knowledge of the individual's bases of practice, and shared practical knowledge such as being evaluated on social networking services. Through the process of forming and sharing practical knowledge, the participants sought to continuously develop practical knowledge of the community as well as themselves through study group formation. As far as shortcomings, the researchers mentioned the lack of related information, lack of related education, shortage of study time or lack of advanced courses in the process of applying what they learned.

In this way, the artists participating in this study took part in paper circuit computing learning based on the desire to learn new technologies or methods of producing interactive artwork for interacting with the audience. Participants have traditionally struggled alone to build up practical knowledge and to move away from the culture of isolation. Through this education, practical knowledge has been shared and developed together. Paper circuit computing learning offers accessibility to artists who would like to take up the challenge of creating interactive art but have no prior experience with it. Therefore, it is most necessary to provide active support such as network formation and communication, and related data, according to the needs of artists interested in paper circuit computing learning. Based on this study, the authors hope that various and rich educational programs will be developed and implemented to promote research on and discussion of practical approaches to, and the utilization of, paper circuit computing.
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