Science Teachers' Technical Difficulties in Using Physical Computing and the Internet of Things into School Science Inquiry

Seok-Hyun Ga, Changmi Park, Hyun-Jung Cha, Chan-Jong Kim

***Abstract*— Data collection is an essential process of securing evidence to support students' arguments in conducting a scientific inquiry of problems students are interested in. However, as schools are not affordable to be equipped with various measurement instruments, students are only offered limited options, leading to possible limitations in choosing their inquiry topics. Arduino can be suggested as a solution for the issue of deficiencies in measurement devices at school. Through Arduino, students can make various measurement devices by connecting various sensors to Arduino, customize devices to suit their inquiries, and implement remote sensing using the Internet of Things. However, great technologies do not necessarily guarantee any of their potential to be utilized as great tools for science classes at school. Due to technical difficulties, teachers and students have shunned many promising technologies, failing to assimilate great technologies into school curricula. This study examined three different cases of adopting Arduino by three teachers from educational institutions: a gifted education center, autonomous club activity in middle school, and a local community center. We found four major difficulties; (1) Selection of proper technologies; (2) credibility issues with information from the Internet; (3) technical complexity due to the intervention of multiple variables; and (4) compliance issues with related acts and regulations.**

***Index Terms*— Arduino, internet of things (IoT), physical computing, scientific inquiry, scientific measurement, technical difficulties**

I. Introduction

The importance of scientific inquiry has long been emphasized. Through scientific inquiry, students understand the importance of evidence, evaluate multiple explanations of phenomena, communicate with others, and learn how to justify their scientific decisions [1]. However, Chinn & Malhotra [2] criticize that school inquiry is too simple inquiries activity that just follows the procedure presented by the teacher. In simple inquiry, because the inquiry procedure is very straightforward, students simply imitate it and fail to develop their literacy. In the authentic inquiry, students draw their own research questions, design, and conduct research, and interpret the results to draw conclusions. Because the authentic inquiry is not fixed, students' literacy, such as knowledge of science, nature of science, and understanding of doing science, are promoted [3], [4].

With the recent emergence of the Action-Oriented Science Curriculum (AOSC), the importance of authentic inquiry has been further increased. The AOSC includes not only understanding scientific phenomena and learning how to perform science but also the practice of sociopolitical action to create a change to a better world [3]. In AOSC, it is essential to perform well-designed authentic inquiry [3], [5], [6]. Students investigate socioscientific issues in their community, prepare countermeasures to solve them and take action directly through authentic inquiry. Since scientific inquiry in AOSC varies depending on which topic a student is interested in and how students to design research, it is not easy to prepare for all possibilities in a controlled environment. The school environment, which has limited measurement devices, restricts students from dealing with various topics of inquiry.

Measurement tools are lenses looking at the natural world, which are an essential part of scientific inquiry because they allow humans to observe the natural world, which has not been seen with the naked eye [7], but few studies have focused on measurement tools, and researchers focus instead on the concepts, ideas, and structures of labs [8]. Therefore, researchers need to pay more attention to the role of measurement tools in inquiry and find ways to solve the limitations due to measurement tools.

Recently, there are many attempts to using the Arduino into school scientific inquiry [9], [10]. Arduino is an open-source platform that includes Arduino boards, a hardware part, and Arduino Integrated Development Environment (Arduino IDE), a software part [11]. Physical computing was hard-to-access

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technology because it required advanced knowledge in electronic engineering and a high level of computer programming skills. However, after the emergence of Arduino, designed in a way that even non-professionals could easily make devices, the threshold for physical computing was significantly lowered [12]. By using Arduino to school science inquiry, students can make measurement devices that can measure various targets and that can be customized to fit their inquiry designs. In addition, wireless telemetry becomes possible if the Internet of Things (IoT) is implemented by attaching a cellular communication module to the Arduino [13]. Since Arduino uses the same 5V power supply as cell phone chargers or other USB devices, we can make mobility devices by connecting widely-used portable chargers to Arduino.

Although using Arduino in school science inquiry has many advantages, these advantages alone cannot guarantee that Arduino would be smoothly integrated into school education as one of the supporting tools for student learning. There have been many efforts in vain to introduce new ICT (Information & Communication Technology) in the learning environment, and schools have not changed as much as the world changes [14]. Teachers' perceptions are positive about introducing ICT in education [15], [16], but are less positive about applying them extensively in their classrooms, and far less positive convinced its potential to improve instruction [15]–[17]. In addition, teachers only view ICT in education as an auxiliary element but do not think of it as a critical element to be used in education [17]. Teachers' computer use in schools has increased, but most teachers use ICT to search for information, produce class materials, and process administrative tasks , but have not used it well to help their students in classroom [15], [18], [19].

Despite the positive perception of ICT, being passive about ICT use is due to the technical problems using ICT [20]. The experience of technical problems during their classes reduces teachers' confidence in using ICT and makes them reluctant to use ICT in future classes [21]. Teachers who have difficulties using technology sometimes blame their lack of competence, but they raise questions about whether technology is effective in education [22] and resist changes to adopt technology into their classes [23]. Therefore, for ICT technology to be well integrated into classrooms, it is essential to examine the technical problems experienced by teachers and provide appropriate support to teachers [24]–[27]. If Arduino, which is also one of the ICT products, is introduced into the education field without giving careful thought to possible technical issues that may arise with teachers, it would be hard to achieve the expected effectiveness through Arduino.

In previous studies, Ga *et al.* [13] compared and analyzed several technologies adapting Arduino into the science education field and proposed an appropriate technology configuration. There were many teachers who were interested in our ideas, and some of them put these ideas into practice with us. But the teachers all faced a lot of technical difficulties. Teachers have found solutions to problems on their own or solved them with our help, but sometimes they have given up on using new technologies. However, there have been no studies on the difficulties teachers face in the process of using Arduino into their classes. Revealing the technical problems faced by teachers, we conducted a retrospective study of the cases of teachers.

II. Methodology

In this study, the technical difficulties of using Arduino into science classrooms by field teachers were examined, and how they dealt with these difficulties together with the researchers was described in detail. The purpose of this study is to help field teachers and science educators who want to use Arduino to understand problems that may occur to them in advance. Since the difficulties using technologies into school classroom have common characteristics regardless of the gender or age [28]–[30], the difficulties revealed through this study are likely to occur to others as well. If they identify problems that are likely to occur in advance, they can prepare for them in advance.

This study retrospectively examined the experiences of applying the idea proposed by Ga et al. [13] to actual classrooms which are the cases of three teachers Ahn, Bae, and Cha. These three cases are not independent of each other. We applied our idea first to Ahn's class, improved the technical problem in Ahn's case, and applied it to Bae and Cha's class. Because this study is a retrospective study, each case is not in equivalent settings. However, since the purpose of this research is to find out teacher's technical difficulties based on several actual cases, the non-equivalence of cases is not affect to achieve the research purpose.

This study was designed following Generic Descriptive-Interpretive Qualitative Research (GDI-QR) presented by Elliott & Timulak [31].

A. *Research Question*

"Open-ended and exploratory research questions, which then guide the study and begin to define domains of investigation," are posed [31]: What kind of technical difficulties do field teachers face when using Arduino into their science classrooms?

B. *Data Collection*

We "collected open-ended (nonnumerical) verbally reported experiences or observations to answer these research questions" [31]. To find out technical difficulties facing teachers, we interviewed three teachers who using Arduino in their classes. The interviews were conducted as a semi-structured interview, and the following questions were asked. The questions started with open-ended questions and gradually moved on to concrete questions. We asked the teachers questions, such as:

1) Tell me how you felt during class.
2) Can you tell me about technical difficulties you experienced while planning and conducting your class?
3) How did you handle those difficulties? If you failed to handle them, what are possible solutions that you can think of now?
4) What support do you think should be provided for general science teachers to introduce Arduino in science inquiry classes?

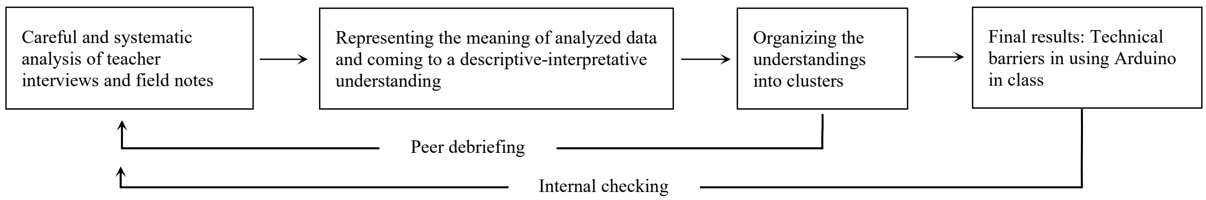

Fig. 1. Process of Data Analysis

In addition, we wrote field notes to keep a record of class progresses, any difficulties facing students and/or teachers, and their solutions to technical issues.

C. Data Analysis

According to the stage of GDI-QR, we "committed to the careful, systematic analysis of" interviews of three, and came "to a descriptive-interpretive understanding of experiences and observations by carefully representing their meaning," and organized "these understandings into clusters of" similar difficulties [31]. The clustered results were peer-debriefed with two science education researchers, and the final results were re-checked with teachers [32]. The overall data analysis process is shown in Fig.1. Although the analysis process was linearly described, the actual analysis starting from the data collection process was conducted nonlinearly [33]. In addition, the categorized results were continuously revised throughout the entire study.

D. Research Context

This study investigated the technical difficulties that appeared in the process of applying the device proposed by Ga *et al.* [13], the first author, to their own classes by three teachers. Three teachers were interested in the device proposed by Ga and hoped to use it in their classes. For the three teachers, Ga provided different levels of technical support. This is because the three teachers had different environments, such as the distance between the field and the researcher, the teacher's wishes for technical support, etc. Three teachers, who participated in this study, are as follows: Ahn working for action-oriented science education programs run by gifted education centers affiliated with science high schools, Bae leading students in student autonomous clubs at school, and Cha teaching for training programs run by local governments.[1] They are all common in that they taught middle school students, but the environments where each teacher taught classes were quite different (Table 5). Such heterogeneous cases were chosen to reveal various difficulties in different environments where science inquiry classes using Arduino are conducted.

Ahn

Ahn is a female teacher in her 40s with ten years of teaching experience and works as an earth science teacher at a science high school in Seoul, at the same time working as a lecturer at gifted education centers; one affiliated with the science high school and the other affiliated with the Provincial Office of Education. Since she has been working at a science high school for three years, she has many experiences guiding the 'Student Research Project.' She usually uses various technologies such as Padlet and Google Sites in class. Ahn instructed five (5) second-year middle school students at the gifted education center affiliated with the science high school to use Arduino for their 'Student Research Project.'

The program at the gifted education center consisted of 85 sessions (50 minutes per session) for one year, among which the 'Student Research Project' was organized in 16 sessions. There were forty (40) 2nd-grade middle school students in the program. The students organized individual groups for their research, with maximum five members per each, and chose their advisors who suit their research needs the most. Ahn told the students in advance that only the students who would do scientific activities using Arduino should choose her as an advisor, and a team of four boys and one girl chose Ahn as an advisor. Student Research Project intended to encourage students to design and conduct their research by themselves, avoiding depending on teachers' unilateral instructions. In this way, students were also given opportunities to learn how to use Arduino by themselves. Ann's decision to use Arduino in her class was drawn from her academic cooperation with Ga, the first author of this paper. Ahn heard that Ga tried to adapt Arduino into science education and asked Ga for help with introducing Arduino in her class. Ga informed Ahn of the related components for Arduino and a website where she could purchase them. Since Ga did not select specific components in detail, Ahn selected and purchased the components by herself referring to Ga's advice.

Due to the spread of COVID-19, all classes were conducted in real-time in a contactless manner. Ahn sent the students an Arduino kit containing a basic Arduino manual by courier. Students learned basic skills of Arduino, such as hardware circuit connection and installation of development tools, by themselves referring to the manual without any in-person lectures. One student was interested in programming, but the rest had little programming experience and showed no interest. Students programmed with text coding through Arduino IDE. A device to measure the concentration of carbon dioxide was manufactured using Arduino to find out 'changes in the degree of greenhouse effect according to carbon dioxide concentration.' Since the IoT was not used in Ann's class, students read the data directly through a serial monitor and recorded it in Microsoft

[1] The names of the three teachers have been pseudonymized to protect their privacy.

Excel.

We found that in Ahn's class, the teacher had a lot of difficulties selecting appropriate components, and the students had a lot of difficulties performing the text coding. Therefore, Ga made a list of recommended components based on the difficulties of Ahn's class and developed mBlock 3-based expansion blocks for fine dust sensors, carbon dioxide sensors, and Wi-Fi modules so that these components can be used only by block coding.

Bae

Bae is a male teacher in his 20s with three years of teaching experience, working as an earth science teacher at a girls' middle school in Seoul. He graduated from a science high school and majored in earth science education in university. When he was a science high school student, he dabbled in programming using the language C, but he had never developed any software using the knowledge learned from high school. Bae opened a student autonomous club named 'Fine-dust Inquiry Club' as an extracurricular activity to examine environmental issues related to fine dust. There were 17 sessions (40-45 minutes per session) for the club activities. He recruited 2nd and 3rd graders students, and 17 students voluntarily applied. The club activities were conducted after school, and Arduino used to measure the concentration of fine dust. He used components in the list provided by Ga, and taught with block coding based on mBlock 3. The sensors collected data which was transmitted to the IoT platform, ThingsBoard, through a Wi-Fi module connected to Arduino. Students were given access to the IoT platform to read and analyze data. The initial plan was to conduct all sessions offline, but due to the rapid spread of COVID-19, some sessions had to be delivered online via Zoom.

Cha

Cha is a female teacher in her 30s with four years of teaching experience, working at a middle school in Seoul and at the same time working as an instructor at a local community center in Gyeonggi-do Province. Not long ago, Cha had no experience in programming except when she used MATLAB to do her projects for a major class during her university years. Later, when she attended a 4-week training workshop for teachers, titled 'Arduino Utilization in Scientific Inquiry,' conducted by Ga, she first learned about Arduino. At the workshop, she learned how to do text-based coding for Arduino, and even after that, Cha further asked Ga to teach her how to do block-based coding through mBlock 3 and 5. Cha designed an 8-week program with 16 sessions titled 'Convergence Science Education for Middle School Students: I Am an Active Citizen Scientist' at a local community center. Participants are six (6) ranging from 1st to 3rd graders at middle school. Ga organized Arduino kits for the club activities and provided them to Cha. Ga developed extension blocks of fine dust sensor (Winsen ZH03B), carbon dioxide sensor (Winsen MH-Z19B), and Wi-Fi module for mBlock 5, a block-based coding platform. The sensors collected data then transmitted to the IoT platform, *ThingsBoard*, through an LTE module connected to Arduino. Students were given access to the IoT platform to read and analyze data.

III. Results

To understand the technical difficulties in applying Arduino to scientific inquiry, we represented various technical difficulties based on teachers' interviews and the researcher's field notes and categorized them. At first, we classified teachers' difficulties into seven categories; (1) selection of proper technologies; (2) reliability of measured data; (3) credibility issues with information from the Internet; (4) difficulty in dealing with problems; (5) language barrier; (6) knowledge requirement in various fields; and (7) compliance issues. Through the peer debriefing process, similar classifications are integrated and recategorized into four categories; (1) selection of proper technologies; (2) credibility issues with information from the Internet; (3) technical complexity due to the intervention of multiple variables; and (4) compliance issues (Table 2). Finally, to confirm our misinterpretation of the interviews, the interviewer reaffirmed the analysis result. There was no change other than simple errors, such as the name of the club and the number of participating students.

The three teachers complained of various technical difficulties even though they received technical support from Ga. Arduino, which was initially adopted as an auxiliary tool to support students in scientific inquiry, seemed to lose its focus. With more and more technology-related problems raised during class, it seemed that dealing with those problems properly and promptly was the most powerful deciding factor to determine whether the science inquiry was successful or not.

> Bae: It is meaningful to dig deeper technically, but I thought it was more meaningful for students to concentrate on scientific inquiry. Technology is sort of a supportive tool... Of course, the deeper our understanding of technology, the better outcome we may expect. But since it's just supposed to play a supportive role ... However, as this has a more significant impact on the success or failure of the project, I thought it would be nice to have a way to solve it quickly. (Bae's Interview)

A. *Selection of Proper Technologies*

When selecting a development board, programming language, communication module, sensor, etc., it took a lot of time to determine which one was appropriate to use. Among them, choosing a sensor was the most difficult task. Various types of sensors are needed depending on science inquiries designed by the students. Even sensors measuring the same target have different principles (electrical, optical, chemical), accuracy, measurement range, operating voltage, and data transmission protocol (Analog, PWM, UART, SPI, I2C), so right sensors should be selected to serve the purpose of each student's scientific inquiry.

TABLE I
RESEARCH CONTEXTS

	Ahn (10-year career, 40s, female)	**Bae (3-year career, 20s, male)**	**Cha (3-year career, 30s, female)**
Instructors' Major	Earth Science Education	Earth Science Education	Earth Science Education
Target	Five (5) 2nd Graders at Middle School	17 2nd to 3rd Graders at Middle School	Six (6) 1st to 3rd Graders at Middle School
Place	Gifted Education Center affiliated to Science High School	Student Autonomous Club	Local Community Center
On/Offline	Online (live)	Offline + Online (live)	Offline
# of Sessions	16	17	16
IDE	Arduino IDE	mBlock 3	mBlock 5
Contents	• 1-4 Session: Scientific method, Orientation of the 'Student Research Project' • 5-8 Session: Research Design, Preparing Materials • 9-12 Session: Making CO_2 measurement device using Arduino • 13-16 Session: Implementation, Feedback	• 1-2 Session: Introduction to citizen science and air pollution issues (Online) • 3 Session: Arduino Basics (Online) • 4-6 Session: Practicing using Arduino making measurement devices and Planning a research project • 7 Session: Presenting and sharing their research project plan (Online) • 8-9 Session: Making measurement devices for their research project • 10-11 Session: Analyzing data and writing report • 13-15 Session: Preparing action as a citizen scientist • 16-17 Session: Sharing action plans and receiving feedback	• 1~2 Session: Introduction to citizen science and air pollution issues • 3~6 Session: How to make measurement devices using Arduino • 7~8 Session: Preparing research project including data collection • 9~10 Session: Checking their data collection plan • 11~12 Session: Analyzing collected data • 13~14 Session: Preparing action as a citizen scientist • 15~16 Session: Sharing action plans and receiving feedback
Technology	• CO_2 concentration measurement using Arduino • Data Analysis using Microsoft Excel	• Fine dust concentration measurement using Arduino • Publishing telemetry data to ThingsBoard using wireless communication • Data Analysis in ThingsBoard	• Fine dust and CO_2 concentration measurement using Arduino • Publishing telemetry data to ThingsBoard using wireless communication • Data Analysis in ThingsBoard
External Support	• Introducing Arduino and related sensors • Providing information on how to buy materials • Selecting sensors and coding are done by Ahn and her students	• Providing materials in the form of Arduino kit (Arduino UNO, grove shield for Arduino UNO, grove connectors, fine dust sensor, Wi-Fi module, etc.) • Developing mBlock three extension blocks for fine dust sensor and Wi-Fi module.	• Providing 4-week training sessions about Arduino • Providing materials in the form of Arduino kit (Arduino UNO, grove shield for Arduino UNO, grove connectors, fine dust sensor, carbon dioxide sensor, LTE module, etc.) • Developing mBlock 5 extension blocks for fine dust and carbon dioxide sensors and LTE modules.

TABLE II
TECHNICAL DIFFICULTIES FACING TEACHERS

Categories	Ahn	Bae	Cha
(1) Selection of Proper Technologies	Experienced difficulties in choosing CO2 sensors	-	
(2) Credibility Issues with Information from the Internet	Followed example codes found online for newly bought CO2 (MG811) sensors, with none of the codes working properly	-	Followed example codes found online for newly bought CO2 (MG811) sensors, with none of the codes working properly
(3) Technical Complexity due to the Intervention of Multiple Variables	Difficulties in finding a cause for any issues encountered	Difficulties in finding the cause of the failure to access the LTE router	Difficulties in finding the reason for errors that occurred during compiling even when block coding did not have any flaws.
(4) Compliance Issues with Acts and Regulations	-	Not available to use Wi-Fi in school due to the security reason	Difficulties in dealing with regulations related to the usage of LTE communication modules, such as USIM registration and conformance evaluation under the Radio Waves Act.

Ahn had students choose sensors to use for their inquiries. No specific guidelines were provided for sensor selection. Students selected sensors sold at domestic online shopping malls in Korea. At an online shopping mall, for instance, there were five types of carbon dioxide sensors: MH-Z19B, MH-Z14, MH-Z16, MG811, and SH-300-NDC. Students thought it would be easier for coding to select a sensor with a lot of information provided on the Internet. They decided to use an MH-Z19B sensor. However, the delivered sensor was not soldered with pin headers, so students without a soldering iron could not use them. The teacher rebought the MG811 sensor and sent it to the students.

> Ahn: We didn't choose the sensor for no good reason. Because I was not familiar with Arduino either, I just let students choose any sensor they wanted. If the sensor they picked was within the acceptable price range, I bought it for them. (However), when I got the sensor delivered, I found that it was not soldered with pin headers, which I couldn't predict at all. (Ahn's Interview)

Since it was the first time Ahn used Arduino, she could not give any special advice on sensor selection. Ahn only checked whether the price was reasonable before purchasing the sensors chosen by the students. Although the seller's website had a product photo showing the pin header not soldered with, Ahn could not notice it. This problem could have been a simple solution for those sensors if Ahn had been experienced enough to find a proper solution. Instead, Ahn thought those sensors were flawed and decided to get a new one, which took a considerable amount of time before it was finally delivered to students.

Ga informed Ahn that fine dust or carbon dioxide concentrations can be measured through Arduino and informed websites where information can be obtained and where she can purchase components. According to Ga's advice, Ahn chose Arduino without considering other options such as Raspberry Pi or micro:bit. However, she had difficulties in selecting sensors or coding because she didn't get any advice. Through Ahn's difficulties, Ga thought it was necessary to provide more detailed guidelines on sensors, communication modules, coding implementation methods, etc. to teachers, and gave Bae and Cha the recommended technology configuration (Table 3).

TABLE III
TECHNOLOGY CONFIGURATION PROVIDED TO TEACHERS

	Bae	Cha
Development Board	Arduino UNO	Arduino UNO
Development Environments	mBlock 3	mBlock 5
Wi-Fi module	ESP-01S	ESP-01S
LTE module	Using a portable LTE router	SIM7600E
Sensors	ZH03B (fine dust)	ZH03B (fine dust) MH-Z19B (carbon dioxide)
Others	mBlock 3 Extension block	mBlock 5 Extension block

B. *Credibility Issues with Information from the Internet*

After connecting modules or sensors with Arduino, students develop the program for working physical devices. The passive infrared sensor (PIR) simply outputs the case of having or not having objects to 1 and 0, so it can be read as a simple digital signal. Proximity sensors output voltage at an intensity of 0-5V to see how adjacent things are, so simply read them as analog signals. But the sensors used in scientific inquiry are not so simple. For example, Winsen ZH03B, a fine dust sensor, outputs many kinds of data such as PM1.0 (Particulate Matter under 1.0μm), PM2.5, and PM10 at the same time, and it outputs the value in the form of a digital signal consisting of 0 and 1 according to specific rules. Generally, UART (Universal Asynchronous Receiver/Transmitter), I2C (Inter-Integrated Circuit), and SPI (Serial Peripheral Interface) protocols are used in Arduino. It is difficult for users to process these signals directly and convert them to the target value. With Arduino, which is so popular that most sensors have libraries and example codes, there is no need for us to consider complex signal processing. On the other hand, many errors were found in information posted online, which later turned out to waste students' time in unnecessary struggling with technical problems.

Ahn's students initially copied and used the code from the sellers' blog where they purchased the sensors. However, it did not work. They searched online to find other example codes for the sensors, which did not work either. Neither Ahn nor the students had much programming knowledge, so they could not find the cause of the problem. Without knowing the reason, they searched for other examples from the Internet and tried them until they found something that worked properly.

> Ahn: I've never used that sensor before ... The problem is that it didn't work well even with the sensor code from that blog ... The code provided by the vendor didn't work either. ... When we were prompted for missing libraries, we tried to find an appropriate library again and again. ... Without knowing why it didn't work, we repeatedly tried different things. (Ahn's Interview)

Before teaching the local community center class, Cha participated in a 4-week training workshop by Ga about adapting Arduino into scientific inquiry. Cha learned how to write text code in Arduino IDE. During the workshop, Cha made a device that measured temperature and humidity through DHT11 sensors and transmitted measured data to the IoT platform. It was not difficult to follow Ga's class, but when she was programming alone without Ga's help, she realized that she could not deal with any technical problems at all. After the training workshop, Cha made a device that can measure carbon dioxide using an MG811 sensor. As she learned how to find guidelines for a new sensor at the training workshop, Cha tried to develop the device using the information from the Internet about an MG811 sensor. However, the information on the Internet was different from each other, making her confused with which one she followed. Because she did not have enough experience or knowledge to discern useful information, she had no choice but to try everything. When the device didn't work well and she couldn't figure out why, she moved on and tried to find other sources of information for retrial.

> Cha: At that time, when I was text-coding for a CO_2 sensor, I referred to data from the blog. According to the blog, I needed to set a voltage value for accurate calibration. Even though I followed what they said, I could not get concentration values from the sensors. So, I kept trying in many different ways, and then suddenly, values measured from sensors came out. But I was not sure the values I got were reliable or not.
>
> Cha: The content on the Internet was different for each post. I was confused and not sure about which was correct. I just tried one by one until I found something working properly. Even though the values came out, I didn't know if the values were reliable. (Cha's Interview)

To solve this problem, Ga decided to use a block coding tool, mBlock, instead of text coding and developed extension blocks for Wi-Fi, LTE modules, fine dust sensors, and carbon dioxide sensors. While mBlock 3 was applied to Bae's class, mBlock 5 was applied to Cha's class. After using mBlock for coding, teachers or students did not need to search online to find how to do coding. However, since the extension block is not a form that general users can easily modify as the code is grouped into blocks (Fig.2), there was no way for the students to cope with malfunctions.

> Cha: Block coding itself is easy because Ga made all the extended blocks. However, problems sometimes occurred during the uploading process. As the code is packed in blocks, it was not possible to find what caused those problems on my own. All I could do was simply check the circuits' connection, so I felt ashamed and helpless. (Cha's Interview)
>
> Bae: In class, we coded with the expansion block developed by Ga. Even though I studied Arduino before, I found myself not capable of solving technical malfunctions. Expansion blocks were packed together, making it hard for me to modify them independently. (Bae's Interview)

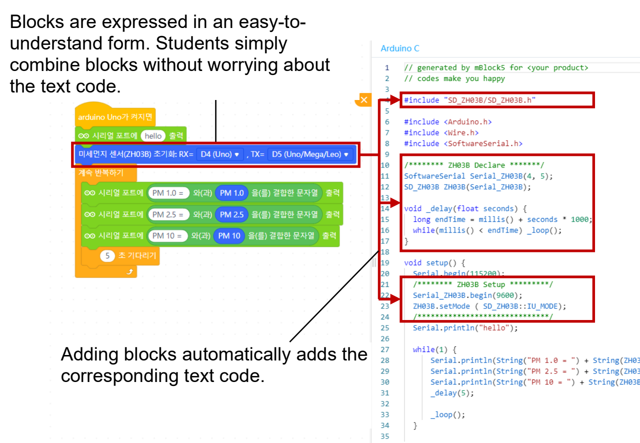

Fig. 2. An example of block coding

C. *Technical Complexity due to the Intervention of Multiple Variables*

In using Arduino into scientific inquiry, students faced many technical problems. Teachers tried to help the students with those problems but often failed to resolve them. Since there were many variables affecting those technical problems, it would be impossible for someone with insufficient background knowledge and experiences in diverse fields to apprehend the problems.

Ahn also had difficulties in coping with the problems. Students requested the purchase of the MG811 sensor to measure carbon dioxide, and Ahn purchased the sensor and sent it to the students. However, many students complained that the sensor did not work properly.

> Ahn: I've never used a CO_2 sensor before. ... Even though I used the example codes from the seller's blog, it didn't work well. Most of those errors reported by the students were actually not related to the sensors. One day, the students said that the development board was not working, so I changed Arduino UNO, including modules and sensors. But the problem was the connection between sensors and the board. (Ahn's Interview)

Ahn, who did not know what caused such problems with Arduino, had no other choice but to start all over again.

> Interviewer: So, did you find out the cause of the problems?
> Ahn: No. Each time I encountered a problem, I tried to search for solutions online and modify this and that until I finally saw something changed and have different outcomes... I am not sure I really solved the problem or not... Sometimes I used the same code that worked well before, but it didn't work on another student's device.
> Interviewer: How did you solve it?
> Ahn: I took it out, put it back on, uninstalled the software, and reinstalled it ... I didn't know the cause of the error, so I was doing everything I could do…Then, one day, it finally worked, but no one knew what exactly the problem was and how it came to work. (Ahn's Interview)

The students tried to find a solution by doing whatever they could do without clear guidelines given to them. When the device seemed to work properly in the end, they thought they solved whatever the problem was, but it does not mean that they understood the technical issues they encountered.

In Bae's class, students accessed the Internet using an LTE router that converts LTE signals to Wi-Fi. However, their Wi-Fi modules failed to access LTE routers frequently, which frustrated Bae who did not know how to find a solution.

> Bae: I hope to solve the problem right away, but I can't do it, which frustrated me. (Bae's Interview)

Bae thought there was a problem with the LTE router and temporarily tethered Wi-Fi on his mobile phone, but the connection was still unstable. Some students needed to use LTE routers because they designed their inquiry that required measuring while walking on the street. As LTE became unavailable, they gave up measuring data through Arduino and modified their plan to use fine dust meters provided at school. These fine dust meters needed to be carried around by users for accurate measurement, which thus inevitably eliminated the possibility of telemetry. Students had to give up their initial inquiry plan to measure the concentration in the fixed location for a long time. Due to technical problems, Bae felt sorry for the students not being able to carry out their original plans.

> Bae: I think it's essential to operate the machine well without malfunctioning. Arduino did not work properly, frequently breaking down, which caused students to lose interest in Arduino and abandon their original exploration plan. Witnessing them helplessly give up their project broke my heart. Technology issues are critical for the success of student science inquiry. (Bae's Interview)

Ga conducted a technical analysis to solve Bae's problems with LTE routers. There were already many Wi-Fi APs installed near the classroom. Approximately 10 SSIDs were found in the 2.4 GHz band. However, the installed AP in the school was not compatible with the ESP-01 module used for Wi-Fi communication in Arduino. In addition to that, about six to seven more LTE routers were brought into, making the frequency in the 2.4 GHz band saturated and causing problems. Eventually, Ga changed the technology configuration from LTE routers to LTE modules and applied it to Cha's class for the first time.

Cha used the LTE module instead of the LTE router, which helped her prevent the same technical problems Bae encountered from recurring. Still, she had different technical issues to deal with. Many problems emerged, such as faulty components, compiling errors, connection failure to the server, etc. Cha could not find causes for those problems and tried whatever she could, including simply reconnecting the device, replacing components, or reinstalling the software. Even though she solved any of the problems, she did not know exactly which solution she chose was effective. Cha told in her interview about how she felt when she tried to tackle the technical issues as follows:

> Cha: It felt like kicking a broken vending machine and making it operate. (Cha's Interview)

Cha expressed her concern, saying, "Because it was solved without knowing the cause, I may not be able to solve the same problem next time."

D. Compliance Issues with Related Acts and Regulations

Bae's class used LTE routers instead of Wi-Fi AP installed in the school. The reason for this was that the in-school AP was set up as WPA2-Enterprise, following the security regulations of the Provincial Office of Education [34]. Still, the Arduino library (WifiESP v2.1.0) used to code for the ESP-01 module did not support WPA2-Enterprise.

Bae belatedly discovered the Wi-Fi problem when preparing for classes with Ga, and Ga urgently replaced it with an LTE router and provided it to Bae. However, it also caused many technical problems as it was hastily applied to the field without sufficient technical review and support.

> Researcher: School teachers don't know the detailed security regulations of the Office of Education. We tried to use a module other than ESP-01S, but if we use another module, new mBlock extension blocks and Arduino libraries must be developed again, so they cannot be applied immediately. So, we replaced Wi-Fi AP with an LTE router, but even that didn't work well. (Field notes)

IV. Conclusion and Implications

In this study, we examined three teachers who using Arduino to scientific inquiry and found technical difficulties they experienced. Since technical issues they encountered were not something that teachers with insufficient expertise can overcome independently, the teachers complained of various technical difficulties. Teachers' technical difficulties can be dealt with in various ways. The first strategy is to develop the ability of teachers to deal directly with technical difficulties. This requires that teachers have the skills of physical computing and general computer programming. However, since it requires a lot of knowledge, it is unreasonable to expect general science teachers to put such an effort into just using tools. A second strategy is to design technology so that teachers do not face technical difficulties. In this study, the latter strategy was mostly chosen. Ga eliminated the possibility of technical difficulties for teachers by providing them with a list of recommended parts in advance. The change from text coding to block coding reduces the difficulties teachers may face in the coding process. By choosing LTE instead of Wi-Fi, the possibility of Wi-Fi connection problems caused by school security regulations is eliminated. However, this strategy is not a panacea. Block coding is less flexible than text coding, there are restrictions for teachers to use Arduino in more diverse ways. There is no single best answer coping with technical difficulties. Since all the classes in this study used Arduino as a ‘tool’ for scientific inquiry, it was important to minimize technical complexity for teachers and students to focus more on science teaching and learning. Therefore, the second strategy was mainly used to cope with their technical difficulties.

Recently, the use of Arduino in the science education is increasing. Science teachers are attracted to the Arduino but are not fully exploiting its potential. For teachers who are not technical experts to use technology, the occurrence of technical problems is the biggest cause of limiting the use of technology. Nevertheless, there have been no research on the various uses of Arduino and the teachers’ or students’ difficulties using Arduino. For Arduino to become a powerful tool to support science education, further research related to this needs to be conducted in the future.

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