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## Developing a Low-Cost Microcontroller-Based Model for Teaching and Learning

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**Abstract:** Recently, as low-cost microcontrollers such as those developed by Arduino and Raspberry Pi have become widely available, the term maker education has emerged as a hot topic in education. Teachers are increasingly using low-cost microcontrollers in their classes, but conducting a class that focuses on using a microcontroller may cause difficulties or problems, for the learner or for the instructor. To solve these problems, it was necessary to design a teaching and learning model for the use of low-cost microcontrollers to be applied at school sites. Accordingly, this study aimed to develop a teaching and learning model for using low-cost microcontrollers. As a result of this study, the author proposes a teaching and learning model that consists of six stages: topic selection, exploration of implementation methods, experimentation, production of teaching and learning materials, implementing lesson plans, and improvement. According to this procedure, teaching and learning materials were created and applied for the subject matter of a middle school unit on “Making Arduino Automobile.” The model developed in this study may provide a guideline for teachers who want to apply low-cost microcontrollers in their classes.

**Keywords:** *Arduino, automobile, low-cost microcontroller, teaching and learning model, technology education.*

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### Introduction

With the advent of the Fourth Industrial Revolution, our society is dealing with technologies that we have not experienced in various fields, such as Artificial Intelligence (AI) in automobiles, the Internet of things around us, and big data impacting our lives. The emergence of these technologies is changing the overall structure of our society, showing that products in the Information Technology (IT) field, though formerly reserved for professional engineers, are now opening the field for interested members of the general public. At this stage, anyone can produce Do It Yourself (DIY) built goods and sell them through social-based online platforms or at offline marketplaces, suggesting that the paradigm of our industrial structure (in the form of production and consumption) has changed.

Reflecting these changes in the times, maker movements are actively taking shape in countries around the world, to cultivate makers and spread maker culture. Here, “maker” means someone who makes something for himself. The “maker movements” in question refer to a culture in which people supply their own needs rather than rely on consumer goods (Dougherty, 2012). Makers use new digital technologies related to the recent Fourth Industrial Revolution. These maker movements have also affected the field of education. Makers’ activity—designing and producing goods of their own choice, using various digital tools and materials—has emerged as an educational paradigm (Martin, 2015). This emphasis on the educational value of maker activities has come to be called maker education. Maker education, creating a new educational environment for sharing their ideas, allows students to create from their own imaginations what could not be realized before (Halverson & Sheridan, 2014).

Low-cost microcontrollers have played an important role in the emergence of the maker movement and maker education. A microcontroller is a computer that performs a specific function by integrating a microprocessor and an input-output module into one chip. It has a CPU core, memory and programmable input-output devices. Microcontrollers have been programmed for use in a variety of electronic devices’ performance of their functions. Until some years ago, microcontrollers were devices that only specialized engineers could handle in the field of electrical and electronics. However, after the most recent decade’s introduction of low-cost microcontrollers such as those made by

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Arduino, the general public can use them to easily implement the functions they want (Halverson & Sheridan, 2014). This popularization of low-cost microcontrollers has been the main driving force of the maker movement already mentioned.

Several researchers have already conducted a variety of studies that have applied low-cost microcontrollers in the field of education. They have highlighted such educational effects as improvement of creative problem-solving ability (Kim et al., 2016; Yoon & Kim, 2018), improvement of academic effect (Bae & Hong, 2016), improvement of positive subject matter-related attitudes (Shin & Lee, 2017), and improvement of positive creative-fusion thinking (Choi & Kim, 2016). However, implementing microcontrollers in the classroom learning environment has faced a few problems (Booth & Stumpf, 2013). First, learners do not know how to operate the boards, or they can do what they wanted but do not know which tool to use. Second, learners may know what tools to use, but they do not know how to use them correctly. Third, a learner may know roughly how to use a microcontroller without understanding the exact method or meaningful content. Fourth, the learner may have an idea or hypothesis concerning a program's failure to work properly, but verifying such hypotheses can pose another challenge. Fifth, instructors faced difficulties including the cognitive burden of hardware knowledge concerning microcontroller, of the difficulty in preparing teaching tools, and of the lack of teaching and learning materials. These difficulties are due to the short history of the introduction of low-cost microcontrollers in education, where no guidelines can easily be referred to when developing lessons based on such objectives. For this paper, the author proposed developing a model that could be used as a reference when introducing low-cost microcontrollers in class.

The research questions of this study were as follows.

First, what are the components of the teaching-learning model using a low-cost microcontroller?

Second, what activities occur at each stage of the teaching-learning model using low-cost microcontrollers?

### Literature Review

In this study, the author identified various teaching and learning models to develop low-cost microcontroller-based teaching and learning models, using Google Scholar's academic search engine and a Korean academic search site ("www.riss.kr"). The author searched using keywords such as "maker education" and "software education" in order to find related teaching and learning models directly related to low-cost microcontrollers.

The following was determined from the literature survey of teaching-learning with low-cost microcontroller application. First, the process of student making was assessed. For example, according to the model published by (Hwang et al., 2016), in the Tinkering stage, students freely performed activities using various materials and parts, while in the Making stage, they took the ideas derived from previous stages to make products. In the model developed by (Gerstein, 2016), in the Copy stage, students imitate the outputs that others have already succeeded in making, and in the Advance stage, students progress to the making activity that is more advanced than that of the Copy stage. The models of Martinez and Stager (2013) and of Loertscher et al. (2013) also described students' process at the Making, Tinkering, and Experimenting stages.

Second, the teacher's demonstration was investigated; this was appears as a demonstration of production or as the operation of the finished product. Through this demonstration process, students imitate the teacher's demonstration, which helps to form the basic knowledge necessary for the creation of future creative works. In the case of a low-cost microcontroller, it is necessary to acquire a basic concept of connection between various electronic components or a programming. This basic concept is formed by knowledge through repetition and practice, and the demonstration process of the teacher is presented for this purpose.

Third, the improvement process was examined; it was seen from the student's perspective and the teacher's perspective. From the student's point of view, improvement was related to the students' reflection on the result of the completion of work (Hwang et al., 2016; Martinez & Stager, 2013). This stage was intended to ensure that students did not repeat the same mistakes or encounter the same difficulties as they passed to new making activities. In some studies, the improvement process has been described from the teacher's point of view (Kim & Im, 2019). In this mode, the teacher analyzes and reflects on students' reactions, outputs, and class progress after certain class activities.

Fourth, the sharing process was included. This was expressed as students sharing the process or outcome of creating a work (Hwang et al., 2016; Lee & Ham, 2018). One of the main reasons that low-cost microcontrollers are used in education is to introduce sharing concepts such as open hardware and open source. There are a variety of ways to take advantage of low-cost microcontrollers for use in class that are available from internet sources. Sharing contents and methods with a class can help teachers wishing to conduct similar classes.

The analysis of several teaching-learning models related to low-cost microcontrollers led to the following implications. Most models did not include activities that required pre-class preparation from the teacher. In other words, these activities can apply to the process of making teaching and learning materials for using low-cost microcontrollers in the classroom. Most models discussed here include activities focused only on classroom activities, while low-cost

microcontroller-based teaching and learning activities have a lot of difficulties in pre-production of related materials by connecting circuits and coding programs (Eom et al., 2016). Therefore, the low-cost microcontroller-based teaching and learning model needs to suggest a process for selection of subject matter, experimentation, and testing. Therefore, based on previous studies, the teaching and learning model developed here can now consider the specificity of low-cost microcontroller applications.

## Methodology

### *Research Goal*

The purpose of this study being to develop teaching and learning model using low-cost microcontrollers, the author proceeded to develop a comprehensive teaching and learning model and components, first seeking to validate the model's developing outline. Afterwards, the research method permitted construction of a specific, finalized teaching and learning model (Richey & Klein, 2014).

### *Previous Literature Analysis*

Relevant literature was analyzed to develop a model for this study, using search engines such as Google Scholar, a Korean site for scholarly research ([www.riss.kr](http://www.riss.kr)), and the website of the Education Resources Information Center ([www.eric.ed.gov](http://www.eric.ed.gov)). These are databases of educational papers, and many studies that have developed teaching-learning models have also used these resources to assess previous work in this area (Kim & Lim, 2019). The literature review focused on teaching and learning models directly related to low-cost microcontrollers, and on cases of classroom use of low-cost microcontrollers. Search keywords regarding teaching and learning models included "maker education," "software education," and "physical computing." The author reviewed various items such as teaching strategies, educational effects, materials used in class, and difficulties in class, analyzing the implications.

### *Internal Validation of Teaching and Learning Model*

The teaching-learning model, first drafted through the review of literature, next underwent an evaluation for internal validation. A total of three internal validations involved two primary school teachers and five secondary school teachers, each with a master's degree or more and at least ten years of teaching experience. All the teachers in this study had experience in using low-cost microcontrollers for more than two years, and some were educational experts who had written papers on low-cost microcontroller-applied classes. They examined the author's teaching and learning model for its validity and adequacy on each topic, and for its applicability in an actual class.

### *External Validation of Teaching and Learning Model*

After the author's first use of this study model, an external validation process was offered by an elementary school teacher. In the first stage of this external validation, the project involved first-grade students making an adder using Arduino. In the second stage, fifth-graders observed the direction of the wind blowing. The author analyzed the strengths, weaknesses, and improvements suggested for the teaching and learning model, as resulting from these two external validations.

## Results

### *Low-cost Microcontroller-based Teaching and Learning Model*

Based on the review of literature, the researcher developed a teaching and learning model consisting of six stages as shown in Figure 1, with details shown in Table 1.

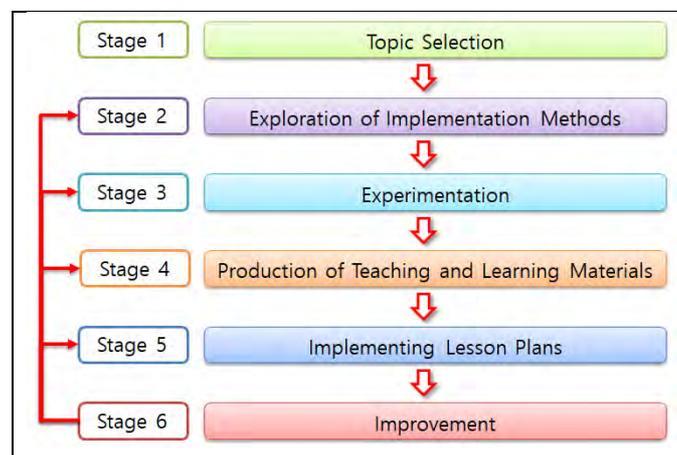


Figure 1. Low-cost microcontroller-based teaching and learning model

Table 1. Details of low-cost microcontroller-based teaching and learning model

	Stage	Major activity
1	Topic selection	<ul style="list-style-type: none"> <li>• Confirmation of needs in class</li> <li>• Selection of topics inviting low-cost microcontrollers into textbook and curriculum context</li> </ul>
2	Exploration of implementation methods	<ul style="list-style-type: none"> <li>• Adaptation of contents from major books, textbooks, and teacher guidebook</li> <li>• Searching and analyzing of theoretical papers</li> <li>• Researching implementation for selected topic involving low-cost microcontrollers</li> </ul>
3	Experimentation	<ul style="list-style-type: none"> <li>• Purchase and preparation of experimental materials: low-cost microcontrollers, circuit connections for each component</li> <li>• Programming</li> <li>• Simplifying as much as possible the kit, circuit configuration, source code, etc. for presentation</li> <li>• Tinkering, copying, making, investment</li> </ul>
4	Production of teaching and learning materials	<ul style="list-style-type: none"> <li>• Preparation of ppt slideshows</li> <li>• Preparation of example programming source code</li> <li>• Preparation of example program completion file</li> <li>• Preparation of pilot teaching and learning materials</li> <li>• Preparation of complete model</li> <li>• Upload of teaching and learning materials to Internet sites (e.g., YouTube)</li> <li>• Purchase and preparation of class materials</li> <li>• Check for any problems with class materials</li> </ul>
5	Implementing lesson plans	<ul style="list-style-type: none"> <li>• Presentation and demonstration of teaching materials (e.g., video content)</li> <li>• Presentation of a finished product model</li> <li>• Copying, making, investment</li> </ul>
6	Improvement	<ul style="list-style-type: none"> <li>• Identification of problems with the lesson plans and suggestion of improvements</li> <li>• Preparation to repeat steps 2–5 for improved application of knowledge gathered</li> </ul>

- *Stage 1: Topic Selection*

The first stage was topic selection: determining how low-cost microcontrollers could help to demonstrate curriculum content. A teacher's grasp of textbook and curriculum contents will allow them to determine whether it is reasonable to use low-cost microcontrollers in the classroom—whether as the teacher's demonstration material or as the students' learning material.

- *Stage 2: Exploration of Implementation Methods*

The second stage involved exploring how to implement teaching and learning contents using low-cost microcontrollers—through in-depth study of the selected topic for a fuller understanding of the available sourcebooks, textbooks, and teachers' guidebooks.

Note that the process of searching and analyzing the theoretical basis is necessary. Analyzing theses and research papers enhances a teacher's expertise in the production of teaching and learning materials, although this process is not strictly necessary, and is only recommended for teachers who have the expertise to evaluate such works. If the teacher has professional knowledge of the content, they need to explore how to implement the selected topic concerning low-cost microcontrollers. They can find ways to operate low-cost microcontrollers using media such as YouTube and the Internet at large, as well as related books.

- *Stage 3: Experimentation*

The third stage was an experiment. At this stage, a teacher may replicate actual experiments implementing knowledge gathered in the previous stage. They first need to purchase experimental materials and prepare for the experiment. Once the materials are prepared, a circuit can be constructed and programmed using a low-cost microcontroller, along with the other electronic components and wiring, to perform the required functions. This process involves the

tinkering, copying, making, and improvement suggested by Hwang et al. (2016), Gerstein (2016), Martinez and Stager (2013), and Loertscher et al. (2013), integrated into the proposed teacher's preparation as follows.

- Tinkering: Teacher draws on existing teaching and learning materials
- Copying: Teacher incorporates teaching and learning materials that lend to using the low-cost microcontrollers on the market
- Making: Teacher creates the lesson plan to be implemented
- Improvement: Teacher improves existing contents so that they can be applied optimally in class

In other words, the teacher experiments with low-cost microcontrollers to test various making activities in order to select the topic and process to be introduced in class. Naturally, the teacher should explore the activities that best apply to his or her class. In addition, existing kits and activities may consist of overly complex programming sources or unnecessary components, which the teacher needs to analyze and convert to as much simplicity as possible. Additionally, if the existing kit consists of standardized materials, it is necessary to check for this and use the simplest possible set of materials.

- *Stage 4: Production of Teaching and Learning Materials*

In this stage, the results of the previous stage's experimentation are produced as teaching and learning materials, preparing basic materials such as work sheets or ppt slideshows as prepared in general teaching and learning courses. Example programming sources or complete files, as required for the classroom use of low-cost microcontrollers, are to be prepared in advance. Arduino features a text-oriented programming method incorporating sketches, and a graphics-based programming method for Scratch. The text-based program will not work with even the simplest of input errors so, given the teacher's difficulty in checking a large number of students' entries, it is necessary to prepare pre-written programming source. Graphical programming will involve fewer typing errors, but the teacher will also need to prepare a complete example file in order to prepare students for errors they should monitor.

The implementation of low-cost microcontrollers requires wiring with several components. Demonstration materials should be prepared in order to guide this. Low-cost microcontrollers and other components are small in size, making it difficult to directly demonstrate their wiring. It is therefore necessary to record the process using images. In some cases, pictures alone are inadequate and it will necessary to take a video (e.g., using a screen capture method with a simulation program such as "Fritzing" to show connecting lines). This preparation can lead to more efficient teaching.

The author suggests posting a video (or other teaching material) on a website. If students can access such a resource, they should be able to reduce unnecessary wastes of time during the classroom lesson. For example, video footage of wiring work can reduce students' confusion. In particular, sharing videos on YouTube and similar sites can contribute to the development and sharing of results that (as products) are emphasized in the maker education (Martin, 2015; Schön et al., 2014). It is additionally necessary to make a complete model using a low-cost microcontroller. This can be a goal in helping students identify the topics they need to in order to successfully create in class.

Finally, it is necessary to purchase and prepare materials for the lessons. Kits to be used in class should be prepared in advance. The author recommends that teachers organize their own kits rather than purchase and use those commercially available because (as already mentioned) kits on the market may involve overly complicated assembly processes, or contain unnecessary parts, adding to the classroom challenge. Recently, the increase in opportunities to use 3D printers and laser cutting machines can allow the teacher to prepare a kit with only the necessary materials for the class.

- *Stage 5: Implementing Lesson Plans*

The fifth stage is to use low-cost microcontrollers in the lessons prepared earlier. This requires such activities as distributing handouts, presenting practical learning materials, and presenting finished product models. The author summarizes the three factors such as copying, making, and improvement, as present in teaching and learning models in the existing maker movement. The three elements are:

- Copy: An activity in which students copy what is suggested by the teacher or other medium
- Making: In which students arrive at the design or the to be implemented
- Improvement: Students make their own improvements by adapting the given materials

In this way, students make their own works by making copies and making improvements using low-cost microcontrollers according to the subject of the lesson.

- *Stage 6: Improvement*

Stage six involves improving what has been supplied in class. It is the process of finding problems and suggesting improvements based on the activities conducted in the class. The teacher verifies problems that appeared during the

lesson as applied to the available low-cost microcontrollers, and then modifies the teaching and learning materials that supplement them. After that, the process of applying the lessons is repeated using this revised teaching and learning material.

Even if the teacher's preparation has progressed through various stages in developing the lesson, unexpected problems may yet occur during the actual class. The improvement stage allows and compensates for these problems. However, because low-cost microcontrollers come in new versions every year, new parts are released, and the types of low-cost microcontrollers themselves are increasingly diverse. Therefore, once developed, teaching materials should periodically be updated to reflect the latest contents. In this process, the teacher returns to steps two through five above, and proceeds with the improving process—reviewing, revising, and applying the teaching materials (Hsu et al., 2017; Martin, 2015; Martinez & Stager, 2013).

#### *Application Examples of Low-cost Microcontroller-Based Teaching and Learning Model*

The following process is a practical example of applying the teaching and learning model devised by the author.

- *Stage 1: Topic Selection*

The author wanted to apply a low-cost microcontroller at a Korean middle school where students were to encounter the topic of automobile making. The rationale for this theme's inclusion in the curriculum is that automobile making activities appear frequently in the typical curriculum technology education at junior high schools (Deal, 2010; Jones & Bartholomew, 2019; Mahoney, 2013; Roman, 2011). In addition, automobile making activities using low-cost microcontrollers are widely shared on the Internet. In the formal curriculum, however, textbooks did not introduce activities to build cars using low-cost microcontrollers. Korean educational policy is turning to maker education and software education, and various studies that apply Arduino to the existing curriculum have been reported (Lee & Ham, 2018; Shin & Lee, 2017). For this reason, "Making an Arduino Automobile" was selected as a topic that could be performed using Arduino in the context of this middle school technology education curriculum.

- *Stage 2: Exploration of Implementation Methods*

At this stage, more in-depth research and analysis focused on the selected topics. First, the author reviewed textbooks that show automobile making activities. In Korea's middle school technology textbooks, there is a unit called "Transportation Technology." The problem-solving activities in this unit featured automobile making, as presented by eight of the 12 publishers shown in Table 2.

*Table 2. Problem-solving activities presented in the Transportation Technology unit of the Korean middle school technology textbooks*

No.	Representative Author	Publisher	Main Activity
1	Choi, Y.	Gyomunsa	* Hybrid automobile
2	Lee, B.	Gyohag book	Condenser airplane
3	Jeong, S.	Gyohagsa	* Solar amphibious automobile
4	Jo, G.	Geumseong	Vibrating automobile
5	Wang, S.	Dong-a	* Electric automobile
6	Yun, I.	Milaeaeen	* Electric automobile
7	Kim, J.	Bisang	* Solar automobile
8	Chae, J.	Sam-yang media	Condenser airplane
9	Moon, S.	Ssimaseu	* Electric automobile
10	Kim, K.	Wongyojaesa	* Solar automobile, Drone
11	Choi, Y.	Jihagsa	* Electric automobile
12	Lee, C.	Cheonjae textbook	Condenser airplane

\* *Automobile making activities*

The specific contents of textbooks and guidebooks on the selected topics showed that, in automobile making activities, automobiles gained power from motors and transferred this power to gears, axles, and wheels in order to move. The power supply was either a battery or a solar cell, and the activity was usually made up of the activities of constructing a circuit and decorating the appearance of the automobile. In other words, there was no special function for control of the automobile. It was a simple automobile that could not reverse, simply moving forward. Applying Arduino to these existing electric automobiles can enrich the variety of activities, including control of the automobile's movement or interacting with the surrounding environment. Considering the contents of the textbook and the capacity of middle school students, the author limited the plan to "Activities for Controlling Electric Automobiles Using Arduino," and the subsequent process was carried out.

• Stage 3: Experimentation

The author purchased a kit related to the Arduino automobile, and analyzed its contents, finding several problems. First, kits on the market were expensive. The cost of an automobile kit was \$30 to \$60, and would be costly distribute to many students. In addition, the kits consisted of bolts, nuts, and standardized boards, all of which required considerable time in reading the assembly instructions. Finally, the source code was difficult, consisting of very long lines that would make it difficult to figure out what it does. The author worked to understand the basic structure and principles of these kits and the meaning of the source code.

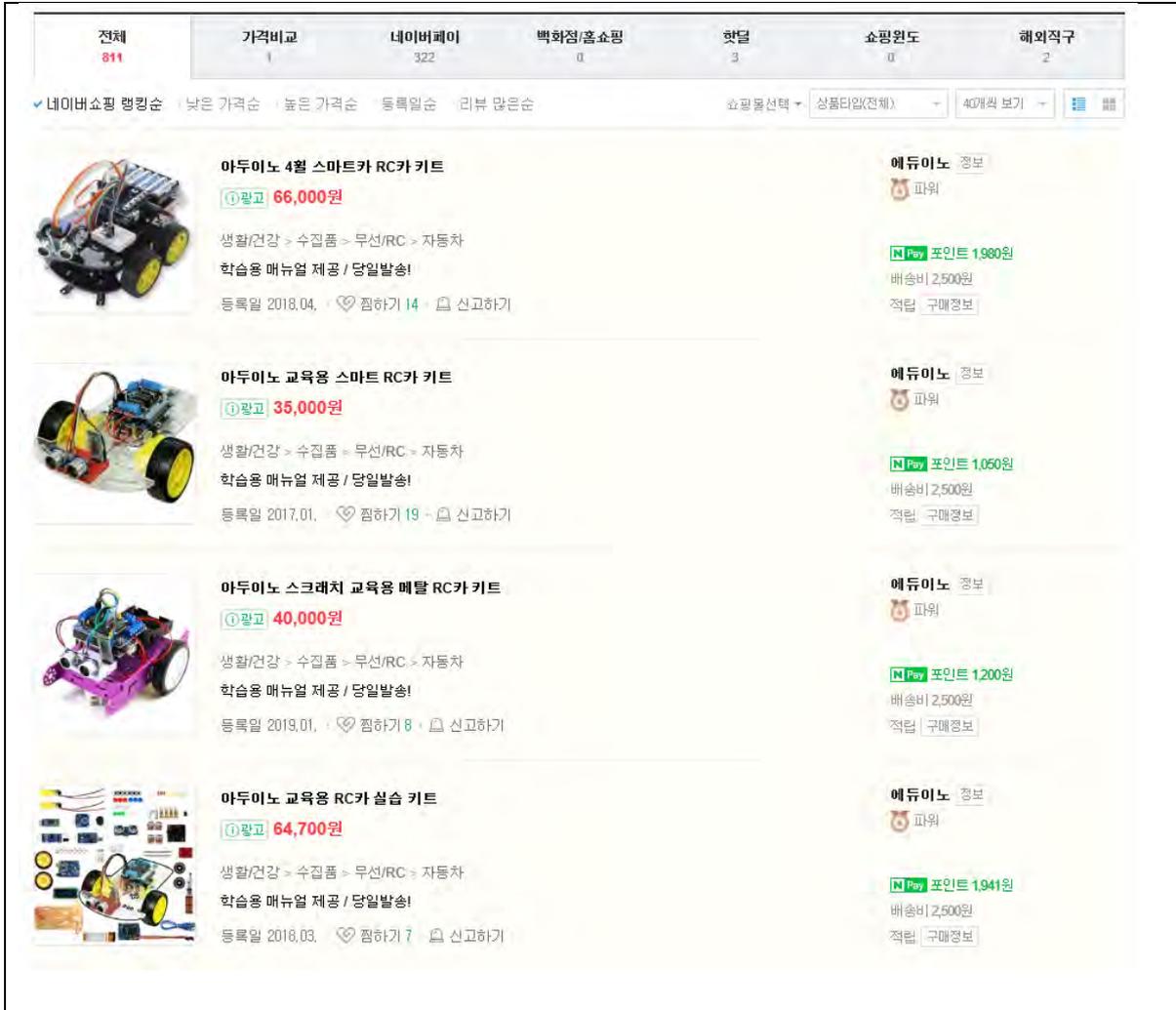


Figure 2. Arduino automobiles sold on Korean Internet web sites (selling for \$30–\$60)

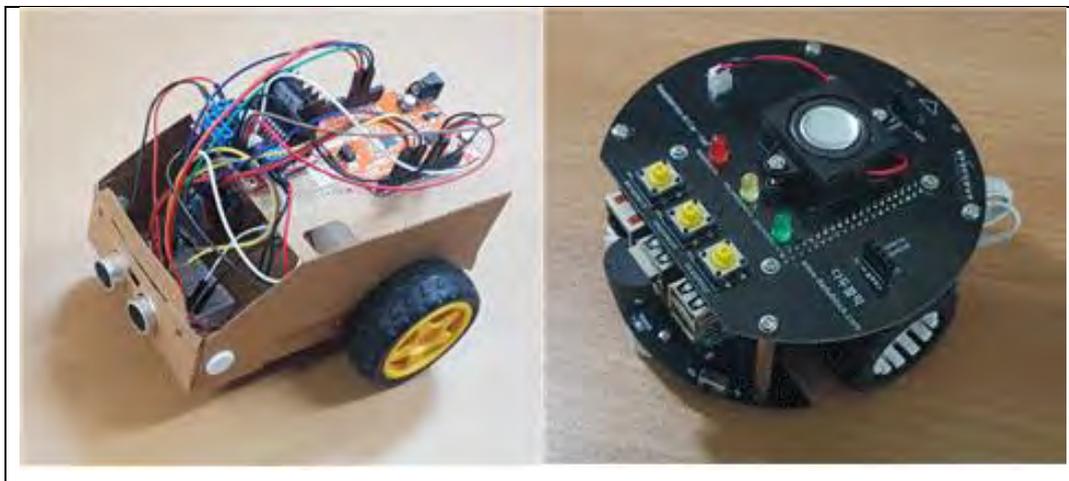


Figure 3. Assembly examples of Arduino automobiles sold in Korea

The author searched the Internet to understand how Arduino cars work. The key components of the Arduino car are motor drive modules, wheels, and Arduino program code which controls the motor drive module determining the rotational speed and direction of the wheels. The author evaluated how to make Arduino circuit connections and related components as simple as possible, so that tinkering, copying, making, and improvement were all part of the teaching preparation stage.

- Stage 4: Production of Teaching and Learning Materials

The class topic developed in this study is the creation of an automobile using Arduino, a motor driver module, wheels, and other components, and the task of carrying out the mission given by the automobile. The given mission is to program a particular route using a sketch program. This topic is about 3 hours of activity.

The author produced teaching and learning materials for the class. First, a ppt slideshow was created to more easily explain the process of connecting circuits between components (Figure 4). This teaching material was printed and distributed in a separate study sheet so that students could easily apply Arduino automobile making activities in class. The author also created a sample programming source, and saved it as a separate file (Figure 5). Text-based programming is only rarely encountered by Korean middle school students. The source code provided by the researcher is a simple code that of only 10 lines, but changing only a few constants in it allows the student to easily control the direction or rotation time of each wheel. Using this source code, students can easily implement Arduino in a car-making activity. In the connection between Arduino and each circuit, students could be confused, so a demonstration video was posted on YouTube (Figure 6). In addition, as shown in Figure 7, a model of the finished product was produced to explain the structure of the automobile to be make this time. Finally, various materials needed for the class were purchased and prepared.

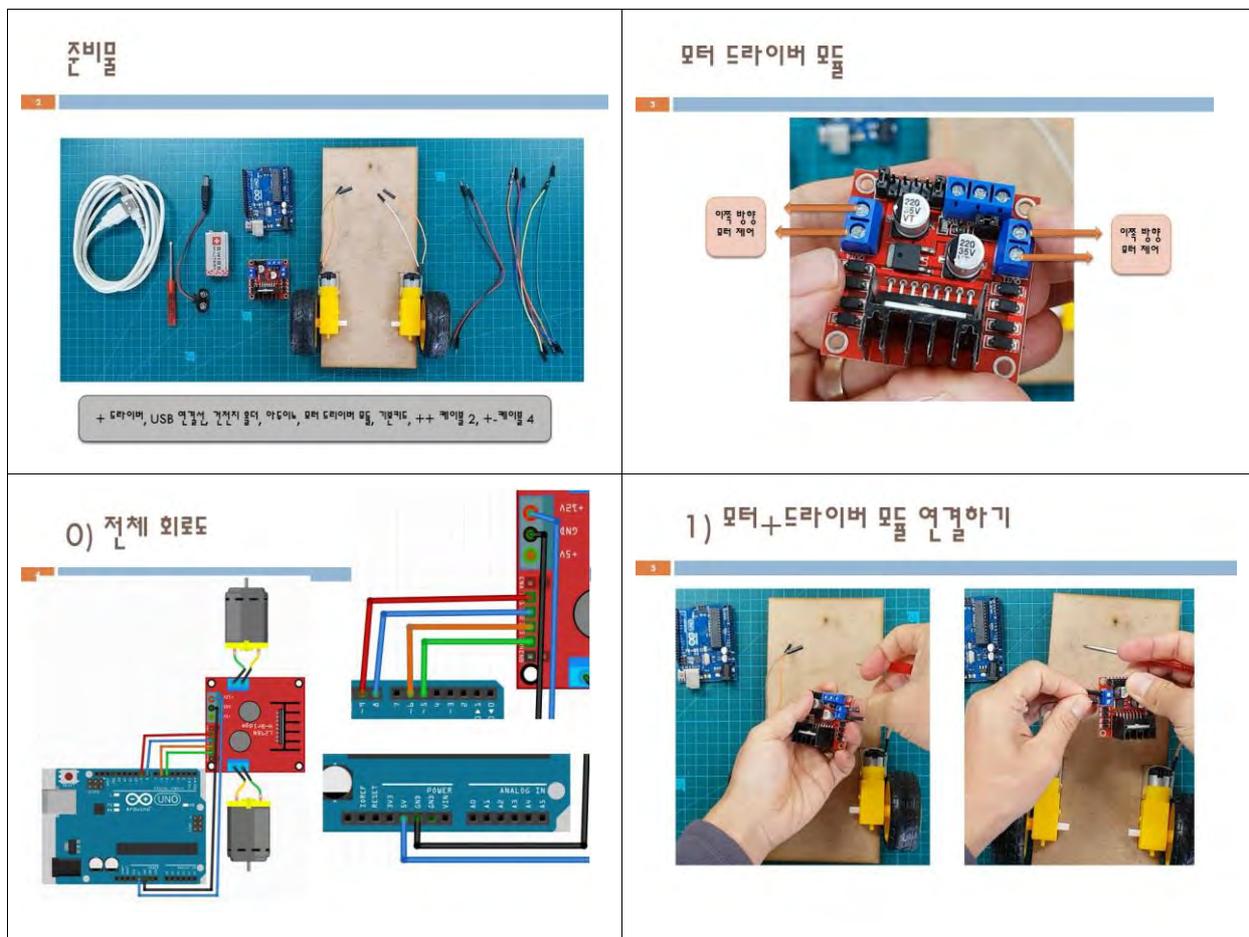


Figure 4. PPT slideshow created for class application

<pre>#define MA1 5 #define MA2 6  void setup() {   pinMode(MA1, OUTPUT);   pinMode(MA2, OUTPUT);    digitalWrite(MA1, 1);   digitalWrite(MA2, 0);   delay(1000);    digitalWrite(MA1, 0);   digitalWrite(MA2, 0); }  void loop() { }</pre> <p>핀번호 5, 6번 제어</p> <p>// 평상시 digitalWrite(MA1, 1); digitalWrite(MA2, 0);</p> <p>// 역방향 digitalWrite(MA1, 0); digitalWrite(MA2, 1);</p> <p>// 정지 digitalWrite(MA1, 0); digitalWrite(MA2, 0);</p>	<pre>#define MA1 5 #define MA2 6 #define MB1 8 #define MB2 9  void setup() {   pinMode(MA1, OUTPUT);   pinMode(MA2, OUTPUT);   pinMode(MB1, OUTPUT);   pinMode(MB2, OUTPUT);    digitalWrite(MA1, 1);   digitalWrite(MA2, 0);   digitalWrite(MB1, 1);   digitalWrite(MB2, 0);   delay(1000); }  void loop() { }</pre> <p>핀번호 5, 6, 8, 9번 제어</p>
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Figure 5. Simplified source code: code was simplified to a level that students could easily understand

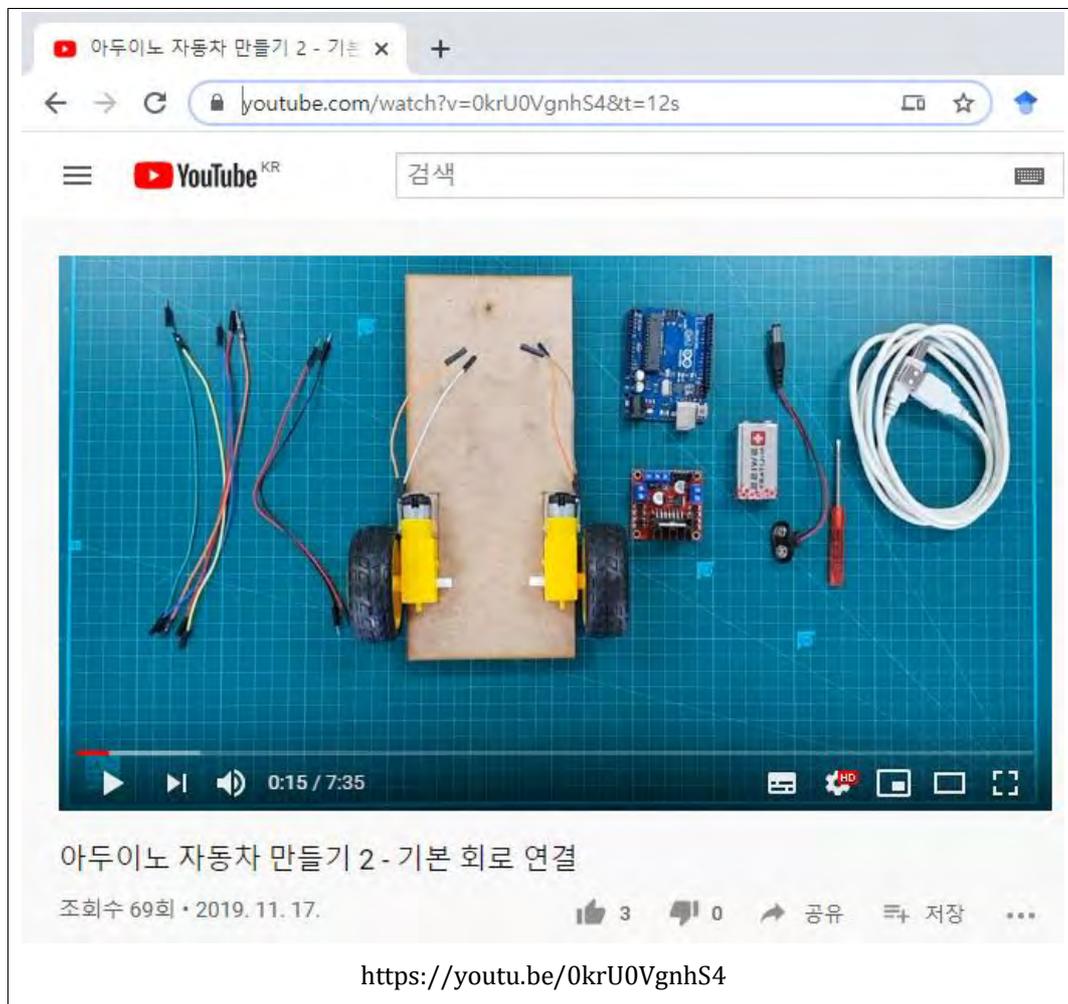


Figure 6. Production process guide video on YouTube (presented to students for pre-learning, or directly in class)

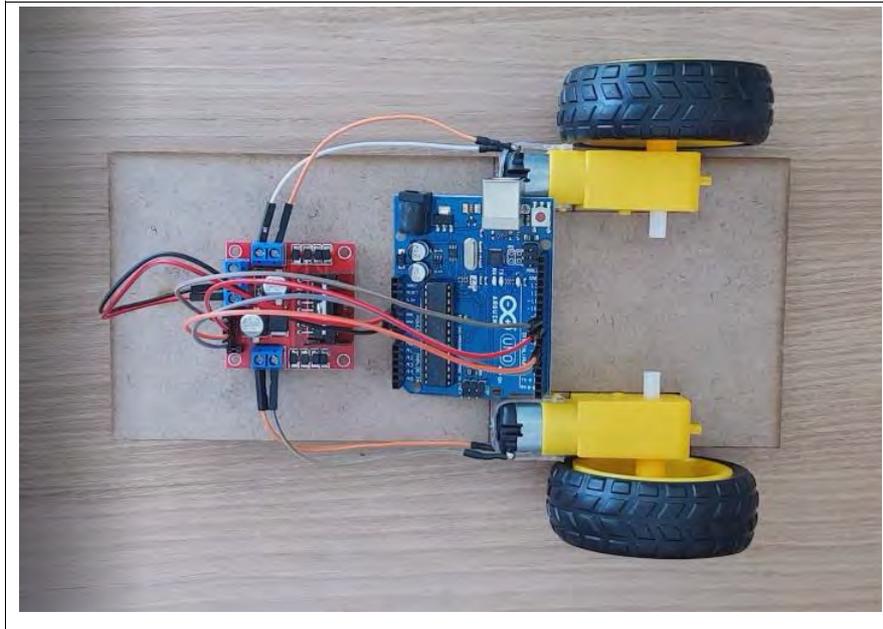


Figure 7. Model with completed circuit configuration for controlling the automobile in various forms by programming the source code

- Stage 5: Implementing Lesson Plans

The class was conducted among 44 students in the first year of middle school who were participating in the visitor experience program of the author's university department. The class took place on November 22, 2019 and was conducted by a total of eight preservice teachers working with groups of six students each. Prior to the class, the author showed a demonstration of the class in advance for preservice teachers to conduct the class. In addition, the author delivered notes from the class at a separate time. The preservice teachers conducted the class using the teaching materials produced by the author.



Figure 8. Class progress by preservice teachers

A brief survey was conducted to evaluate the participants. The questionnaire consisted of a total of seven questions, six of which had responses on 5-point Likert scales and one of which was a free-description question. The six Likert-type questions were three items evaluating the program and three evaluating low-cost microcontroller-related experience activities. Table 3 presents the response results. The responses showed an average rating of 4.66 and a standard deviation of 0.457, and the students had a very positive perception of the program.

Table 3. Survey results of participating students (n = 44)

	Question	M	SD
1	The program proceeded smoothly.	4.64	0.532
2	The content of the program was appropriate.	4.73	0.499
3	I am generally satisfied with my program participation.	4.68	0.518
4	I was able to attend a lecture related to low cost microcontrollers.	4.61	0.655
5	I was able to experience low-cost microcontroller-related equipment.	4.70	0.509
6	I was able to use a low-cost microcontroller.	4.61	0.655
<b>Total</b>		4.66	0.457

In addition, in the free-description questions, the opinions and suggestions for participation in the program were freely described. Most students responded positively.

*# Student 3: Teacher 000 and teacher 000 told us what the Arduino and driver modules were as we were making the Arduino car and kindly showed us how to put the wires on the Arduino and the driver module lines.*

*# Student 4: The teachers did very well and were so nice and fun.*

*# Student 5: It was fun coding with Arduino.*

*# Student 19: It was interesting to assemble and code the parts and make the cars roll.*

*# Student 23: I wasn't interested in Arduino, but it was a very satisfying and fun time, and the teachers worked so hard.*

*# Student 26: It was great that the teachers kindly answered the questions. And it was fun to write code that made the car move.*

However, some students wrote that they were sorry that the driver module did not work properly.

*# Student 5: Our team could not complete with the Arduino car because the motor driver module was broken, but it was fun. Coding the Arduino itself was fun.*

*# Student 10: It was fun and interesting, but I was sorry that the parts were bad.*

Last, interviews were conducted with the prospective teachers who ran the program, and the following comments were made.

*# Preservice Teacher 1, 2: The students were very interested but were embarrassed that the L298N part didn't work normally.*

*# Preservice Teacher 5: After showing the circuit using the video presented by the professor, the students were asked to construct the circuit. There were students who were encountering Arduino for the first time, but they did a very good job in connecting the circuit after watching the professor's video.*

*# Preservice Teacher 6: The students were amazed that the car could move with simple coding using Aduino.*

*# Preservice Teacher 8: When I become a teacher, I definitely want to use this program in my class.*

- *Stage 6: Improvement*

The author received feedback from the preservice teachers who had conducted the class, concerning problems or improvements that presented themselves during the class. As an example of a problem in the class, motor driver module parts were inoperative. The motor driver module used by the author was L298N, and in Figure 9.a the part with "L298N" written on the back of the part worked normally, but the part shown in 9.b did not work. The motor driver module without the inscription was an additional part purchased for the class, and it failed to confirm that the part would work based on looking the same. Later, it was confirmed that driver modules without the inscription require a separate power supply in order to operate. Later, with consultation from experts in this field, the author identified the L9110 motor driver module as having the same function as L298N while being less expensive, simpler, and smaller. The author was able to conduct subsequent classes by using the L9110 motor driver module.

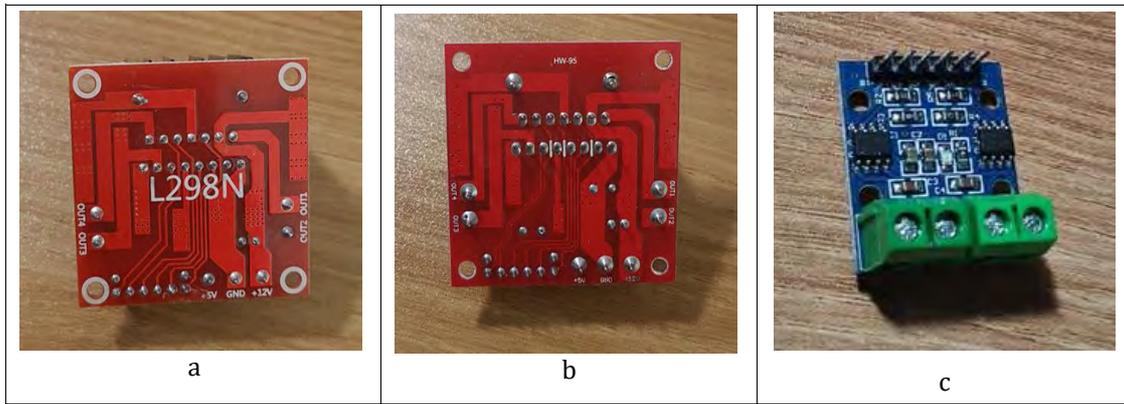


Figure 9.a. L298N motor driver module in normal operation

Figure 9.b. L298N motor driver module lacking power supply and “L298N” unmarking on the back

Figure 9.c. L9110 motor driver module for future classes

### Discussion

The low-cost microcontroller-based teaching and learning model developed in this study developed through consideration of the process of connection and testing of low-cost microcontroller and other components before class. This is different from the existing maker education or software education-related teaching and learning models, which are mainly focused on activities to be carried out in class. In order to apply a low-cost microcontroller in class, there must be a research process before the class regarding whether the function to be realized in the class can be implemented. In addition, it is necessary to create and modify source code required for implementing the functions to be used in class with low-cost microcontrollers.

Secondly, in the model of this study, the author suggested that the process of connecting low-cost microcontrollers with various other electronic components be presented as a video material when demonstrated. Demonstrations of such videos are considered essential in classes that use low-cost microcontrollers. This supports Kim et al. (2015) and Lee and Koo (2018), who suggested the use of demonstrations in maker education and software education. This is because low-cost microcontrollers can cause serious faults with short circuits unless students’ discretion is guided in detail for the correct circuit connections to be constructed. In addition, the size of low-cost microcontrollers and other components is very small, so there is a limit to how the connections can be shown to students directly in demonstration. Therefore, if teachers provide videos of circuit composition directly in class, it can be helpful for the smooth progress of class. On the other hand, teachers can check the materials they will use in class while filming these videos, and they can experience the whole process in advance. And if the video is posted to sites like YouTube and students are guided to watch it before class, they can connect the circuitry in less time during real-world classes, which can lead to more efficient use of class time (McGaillard, 2016).

Third, it is necessary to present the configuration and programming sources of kits and circuits as simply as possible when conducting classes by applying low-cost microcontrollers. Low-cost microcontroller kits on the market today are composed of a number of components that must work properly. These various parts must be assembled in several stages and may not work if any stage is skipped. Therefore, if classes are conducted using these kits, students will have trouble focusing on the assembly manuals provided by a manufacturer (Nam, 2018). In addition, programming sources that will drive the low-cost microcontroller provided by the manufacturer of the Internet or kit are often very complex, or presented at a level of complexity that students cannot understand. Therefore, when low-cost microcontrollers are applied in class, these complexities need to be simplified. In other words, it is necessary to identify the key structure of a kit consisting of cut frames, bolts, nuts, etc.—and then to restructure it into kits that students can easily configure. In addition, by deleting or annotating unnecessary content, programming sources need to be reconstructed to make it easier for students to understand.

Fourth, it is important for teachers to be willing to accept and learn new technology. This means that teachers should be prepared to learn a number of things related to low-cost microcontrollers (Martin, 2015; Van Holm, 2015). There are various types of low-cost microcontrollers, each with a slight difference in the language or method of running the program. For example, Arduino uses C language in a Windows-based compiler called Sketch, but Raspberry Pi uses the Python language based on Linux. In addition, various sensors that extend the functions of these low-cost microcontrollers are being released by various companies. Boards that have already been released are upgraded at regular intervals, so parts may not be compatible or programming sources have to change. Therefore, a teacher who wants to use low-cost microcontrollers in class needs to have an open mind for learning new things or confirming that familiar things still work. In other words, it is necessary to update your class material from time to time, instead of insisting on using a new board or materials you may have created before the advent of a new sensor.

Finally, a positive response was confirmed with the use of the model developed in this study. The average satisfaction level of middle school students who participated in the program was 4.66 out of 5, and most of the students gave a positive report to the free-description question. In addition, the prospective teachers who conducted this class also positively evaluated it, saying that the program was an appropriate example of the application of Arduino to technical curriculum activities. However, because a simple questionnaire was used in this study, no specific effects of the use of the teaching-learning model could be presented. In future research, programs should be developed based on the model of this study, and follow-up studies should be carried out to verify the effectiveness of this teaching model with pre-post examinations.

### Conclusion

In this study, a low-cost microcontroller-based teaching and learning model was proposed in six stages. After developing and applying this research model, the conclusions reached are as follows.

First, a number of prerequisites affect the progression of low-cost microcontroller-based classes. The preparation of the keywords includes a typical analysis process, including curriculum and textbook analysis. In addition to these traditional analyses, however, the author believe that research and development processes are needed in order to determine whether the materials discussed herein could be implemented as working microcontrollers. In other words, analysis of existing low-cost microcontroller kits, source code, reconfiguration options, and photos or videos showing the circuit connection process—all of these are required.

Second, the model developed in this study can be applied to various activities in different subject areas. This is because connecting sensors to low-cost microcontrollers can implement a variety of different functions. This is a limited example of a class case using a low-cost microcontroller. If teachers introduce low-cost microcontrollers in their classes, they can use them as teaching materials that implement certain functions, or as experimental equipment to replace expensive Microcomputer Based Laboratory (MBL) kits. It can also be used in programming education where source code is used, and also in providing a spectacular effect for artwork. These low-cost microcontrollers can therefore be applied for various purposes required by classes in various subjects including science, technology, art, and computer.

The study was meaningful in that it provided a teaching and learning model that was applied in a class, based on low-cost microcontrollers such as Arduino, Raspberry Pi and MicroBit. The model developed in this study will be a guideline for teachers who want to introduce low-cost microcontrollers in their classes. Subsequent studies need to validate the effects of this study, by developing low-cost microcontroller-based programs using the models applied herein or by applying them at actual school sites.

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