A Study of High School Mathematics Teaching Method: Maker-Education Combined With Mathematical Experiments

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This study aims to allow students in math class enjoy a sense of participation, rather than the traditional lecture way. Teachers help students to use the ruler and the protractor to solve practical problems through the method of mathematical experiments combined with mathematical software and knowledge. It includes the use of mathematical drawing application (APP) on a mobile phone, computer mathematical drawing software, and three-dimensiona (3D) printer while the curriculum of mathematics teaching in senior high school is designed with maker-education concept. This study conducts research of technology-oriented high school teachers in Southern Taiwan, who have formed a maker-education curriculum development team, including teachers of mathematics and information science. This study with the mathematical polar coordinate graph unit, employs the “problem-oriented learning” and “cooperative learning” teaching strategy. Mathematics teachers and computer science teachers will corporate for the teaching activity. Teaching aids include ruler and the protractor, mobile phone APP, mathematical drawing software, GeoGebra mathematical drawing software, and 3D printer. In the teaching process, there will be pre- and post- test about attitude scale toward mathematics in order to understand the students’ learning attitude change. It is hoped that through hands-on practice with the mathematical function graph 3D printing, students can feel the interaction with mathematics and life science. Teachers will record teaching experience and inter-disciplinary integration is discussed. It is expected that this teaching mode can be used to promote the teaching methods diversification and maker-education as cross-domain integration.

Keywords: three-dimensiona (3D) printer, maker-education, mathematical experiments

Introduction

Nowadays, high school students tend to use pen and paper to draw graphs in learning mathematics function, which seems very monotonous, complex, and time-consuming. Besides, it can only depict the shape of the function. All these have cost the students’ learning motivation. If the coefficients or parameter range is changed which is hard to understand, students are easily to get frustrated and lose interest (Liang & Chen, 2009).

There are limits in terms of tools that students can use. For instance, the traditional semicircular protractor has only 180 degrees. Besides, when taking examinations, students are not allowed to use rulers with angle...
measuring function, while teachers rarely have the opportunity to let students use a ruler or a triangular or using 360° protractor to measure angles. Generally speaking, students are required not to use mobile phones in class, thus teachers seldom apply mobile phone application (APP) for mathematical graphing teaching. As use of computer requires the change of classroom and downloading software is time-consuming, teachers rarely give students the opportunity to use the computer to draw graphs. The graphs drawn by general mathematical software cannot directly be printed by three-dimensional (3D) printer. Therefore, students are under the impression that function graphs are either on the blackboard or on paper without specific sense of connection.

This study on teaching design focuses on polar coordinate function graphing as the key point, since the high school mathematics has Cartesian coordinates and polar coordinates conversion. However, students only know about the Cartesian coordinate function graphing, not knowing the polar coordinate function graphing, which varies greatly, such as cardioid, the rose curve, limacon, and so on. The early mathematical experiment employs very little the mathematical software. When reviewing the Cartesian coordinate function graphing, researchers allow students to draw by using APP on mobile phone that have been developed, such as Mathway and mathematics. At present, there are many pieces of mobile phone mathematical software available free of charge. GeoGebra is used for teaching computer graphing, so that students could draw the graph of a function.

Considering the fact that even if a mobile phone or a computer is used to draw graph on the screen, it is only one graph and picture on a screen, which does not exert great impact on students’ perception. Therefore, with the assistance of information technology (IT) teachers, the pictures will be printed out and students are encouraged to change it for decoration or other applications. Combined with mathematical software and knowledge to solve practical problems, the teaching and learning process will be more effective and interesting.

To sum up, this study designs the following ways for hands-on teaching class:
1. Have students use a ruler, triangle, compasses, and 360° protractor in class for practice;
2. Have students download the graphing APP program on Mathway by phone to verify the function graph;
3. Use GeoGebra software to graph the polar coordinate function;
4. Use 3D printer for the rose curve function graph.

In this study, in addition to the use of ruler and 360° protractor, the mathematical software for drawing is combined with maker-education in teaching design. In this way, students are cultivated for hands-on ability (Yeh & Lo, 2015). It is expected that this study can lead to the design and planning of high school mathematics curriculum teaching that put emphasis on students’ hand-on ability, combination with other fields, and multiple innovative teaching methods, which help students improve the mathematical learning interest.

**Literature Review**

**Maker-Education**

Maker-education movement began in 2012 in the United States (U.S.) initiated by Dale Dougherty who issued the magazine *Make* and started expo called “Maker Fare” in San Francisco and other big cities. Translated as “chuàng kè” (literally means “those who create”), makers emphasize the do it yourself (DIY) spirit to solve their needs or problems by making things themselves (Dougherty, 2012).

Maker-education puts emphasis on students’ hands-on skills, such as how to make a finished product, how to use cardboard box, tape, and some electronic parts with software, such as Arduino, Makey, and Raspberry Pi, to produce paper products, wood products, or electronic appliances. During such process, students can obtain practical learning experience (Lin, 2011). In terms of the maker-education development trend in Taiwan, the
general movement started from 2009 when Open Lab, Taipei was opened in Treasure Hill International Art Village. In 2012, Taipei Hacke space received sponsorship and settled in Taiyuan Road of Taipei City, followed by other 19-hacker spaces settling in Taiwan with their own characteristics (Lin, 2015). It all demonstrates maker-education in Taiwan has attracted attention from all walks of life.

The reasons to introduce maker-education into mathematics teaching are as follows. Ausubel (1968) had proposed meaningful learning, John Dewey (1938) stood for “learning through doing,” meaning that hands-on activities can promote students’ participation and motivation in mathematical learning, cultivate their problem-solving confidence, improve learning efficiency, and enhance the math homework achievement (Yi, 2004; Chien, 2003). After introducing maker-education into mathematics classroom, combining science and technology to solve the problem with mathematics by hands-on practice, learners not only need “eyes,” but also “hands” and “mind.”

**3D Printer**

The 3D printing originated in the U.S. in 1970, and then, was introduced to other European countries (Liu, 2013). It is a kind of rapid prototyping (RP) technology (Lin, 2013). By means of computer design, it prints products directly through multi-layer stack, thus, it is also known as additive manufacturing (AM) (Kruth, Leu, & Nakagawa, 1998). With the development of computer technology, more and more mature graphing software are developed, and laser technologies change rapidly, making the design and development capabilities of users more progressive (Chinese Society of Mechanical Engineers, 2013).

The 3D printers have risen in Taiwan, and with more and more display of software and hardware products, it has entered the application level, such as clothes print out (Lin, 2015).

There are some teachers in Taiwan who have been using 3D printer for teaching, in which way, they could specify the difficult mathematical concept and copy some important mathematical inventions. Using 3D printer for teaching also creates a lot of surprises in the classroom.

**Mathematical Experiment**

With the assistance of mathematical software, mathematical experiment aims to solve practical problems by combining mathematical knowledge. Different from the traditional learning style, it emphasizes students’ hands-on mathematical learning method. The experiment will gradually play an important role in Mathematics (Li, Chen, Wu, & Zhang, 2003). In mathematical experiments, due to the application of information technology and mathematical software, more and more extensive content is introduced into mathematical thinking and teaching methods. Students can get rid of the heavy tedious mathematical calculations and numerical calculation. It promotes the combination of mathematics and other disciplines, so that students have time to do more creative work.

Nowadays, mobile APP is easy to download. Re-graphing after changing the function conditions through mobile phones can reduce a lot of graphing time and it is easy to see the difference between the graphs and make comparison of graphs before and after such change.

**Method**

**Research Design**

This study takes one class of the third grade in a technology-oriented high school in South Taiwan as an example with 10 teaching hours, one math teacher and one IT teacher. The action research is conducted by
MAKER-EDUCATION COMBINED WITH MATHEMATICAL EXPERIMENTS

guiding “problem-based learning” and “cooperative learning” of students. Through collaborative teaching process and 3D printing equipment to assist teaching, students can print out products through 3D printing and verify the mathematical learning content, so as to feel interaction among mathematics, life, and technology. It is expected that through the effectiveness verification of this teaching mode, this study can be used as a cross-domain integration to promote combination of mathematical teaching and maker-education.

This study adopts the “problem-based learning” and “cooperative learning” teaching strategies for the high school students to learn the polar coordinate function graphing. It also integrates 3D printing technology and maker-education into the curriculum.

Problem-based learning. It refers to the teaching method that during teaching process, teachers focus on the practical problems, while students are encouraged to conduct group discussion, in order to cultivate students’ active learning, critical thinking, and problem-solving ability (Chi & Chang, 2001). The advantages of problem-based learning can be summarized as the following:

1. To arouse students’ learning motivation;
2. To cultivate high-level thinking abilities;
3. To strengthen students’ metacognitive ability;
4. To solve real world problems (Wu & Lin, 2005; Cheng, 2006).

In view of these advantages, this study will have students print out polar coordinate function graph from 3D printer. In this way, they will get a sense of achievement and participation, be guided to more discussion, and be stimulated for critical thinking and creation. Moreover, this study will guide students all the way from the definition of mathematical problems, collecting information, analyzing information, making assumptions, and comparing different solving strategies. Such process will help to train students to constantly reflect on learning ability and help with the actual application in future situations.

Cooperative learning. It is a student-centered teaching method that gives the learning initiative back to students, who can be divided into several groups where team members can complete the learning objectives by joint participation and share risk for success or failure (Wills, 1992). Cooperative learning has been widely used in the field of teaching. After many experimental results, it has been verified that students’ learning achievement is excellent (Siegel, 2005). Lo, Tsai, and Tseng (2011) pointed out that cooperative learning has the following features: (a) heterogeneous group; (b) positive inter-dependence; (c) face-to-face interaction; (d) individual responsibility for performance; (e) social skills; and (f) the process of group development.

Therefore, this study will divide students into different groups to share mathematical learning and problem-solving experience, so that students can reach their goal of study with more diversified learning tips. In addition, through maker-education task arrangement, such as 3D printing, students will have the opportunity to discuss with each other and help each other and finish the task by encouraging each other.

Teaching Design

The current high school mathematics has content about Cartesian coordinates transformed into polar coordinate. Though each pole coordinate can be traced to a specific point on the plane, there is no particular polar coordinate function graph content in the textbook. Students may be confused in this regard. For instance, is the graph formed by function points similar to that of the function \( y = f(x) \)? Or does it have a special graph? Polar coordinate function graphs, such as cardioid, limacon, and rose curve, are very beautiful and changing the coefficient or parameters of the function can make the graph size change or the graph present a new style.
This study does not affect the original consideration of school curriculum and teaching schedule. It only takes six weeks (three days a week) after examination to conduct problem-based learning teaching. Students will be divided into three to four groups and learn through group cooperative learning method. Through team knowledge construction and personal reflection, students can enrich their learning experience and are inspired to explore new ideas and vision (Lo, Tsai, & Tseng, 2011). The teaching process and course content are as the following:

**Course notes and pre-test.** In the first lesson, the purpose of this course was explained to students, giving a clear understanding of the teaching objectives of the course and a pre-test of the mathematics learning interest scale was conducted.

**Rectangular coordinates and polar coordinate units.** Firstly, the Cartesian coordinates and trigonometric functions of a generalized angle were reviewed, which would connect students’ prior knowledge. Then, the polar concept and polar function graph were taught. Finally, teachers proceeded with the problem-based learning and asked students to do group discussion before drawing the graph.

1. Review Cartesian coordinates and polar coordinates
   (1) Review the Cartesian coordinates and polar coordinates, and let students use the ruler of $30^\circ$, $60^\circ$, and $90^\circ$ triangle side length to calculate the length ratio which is $1: \sqrt{3}: 2$, which can verify the relationship between the actual length and the Pythagorean formula;
   (2) Use a $360^\circ$ circular protractor (see Appendix 2) to mark the polar coordinates.
2. Use the mathematical software Mathway for Cartesian coordinate function graph unit teaching
   (1) Require students to download the mobile phone APP Mathway, and then, draw a straight-line function graph;
   (2) Ask students to use Mathway to draw quadratic function graphs.
3. Use mathematical software GeoGebra for polar coordinate function graph unit teaching
   (1) Draw the function graph of $r = 3 \sin \theta$;
   (2) Draw the function graph of $r = 3 \sin 2\theta$;
   (3) Draw the function graph of $r = 3 \sin 3\theta$;
   (4) Draw the function graph of $r = 3 \sin 4\theta$.
4. Use 3D printer to print the GeoGebra math curve
   (1) Use GeoGebra software to draw mathematical curves, output curves as scalable vector graphics (SVG) file;
   (2) Use the Inkscape software to modify the SVG file, output the SVG file to the Tinkcad, and set the height according to requirement;
   (3) Output 3D drawing as standard template library (STL) file and open the 3D printer for software printing.

**Integrating maker-education into curriculum.** The course focuses on integrating maker-education into the course teaching. First of all, IT teachers will assist to use the 3D software and 3D printer to print out the rose curve, which will be demonstrated to students for the purpose of their self-learning and application. During the course, the connotation of maker education, including its concept, ideas, and innovations, will be transformed through DIY into the actual articles. The maker-education can stimulate students’ learning motivation, take the study of polar coordinate function graph seriously, and teach students learn how to present creative works with 3D printing technology.

**Summary and post-test.** The post-test of “mathematical learning interest scale” is conducted and summarized by teachers. It emphasizes the importance of learning and doing and unlimited future of students. In addition, students are invited to share experience about problem-based learning and cooperative learning for learning experience exchange.
Results

The data collection and analysis in this study include qualitative part and quantitative part. The quantitative part contains students’ mathematical learning attitude scale collected before and after the teaching practice, while the qualitative part contains students’ learning experience, teaching experience from mathematics teachers, and cooperation experience from IT teachers.

Quantitative Part

Mathematics learning attitude refers to a person’s constant behavioral orientation for mathematical learning. It can also refer to the positive or negative psychological reactions or behavioral tendencies arising from learning activities or the environment. This study adopts the “mathematical learning attitude scale” originally proposed by Chin (2015). The score is seen as an individual indicator for mathematics learning attitude. The 5-point Likert scale is employed (5 = “Strongly agree,” 4 = “Agree,” 3 = “Neutral,” 2 = “Disagree,” and 1 = “Strongly disagree”) (see Appendix I).

From Table 1, we can see the following six results and analyses:

1. The mean of pre-test scores ($M = 73.76$) is significantly lower than that of the post-test ($M = 76.24$). The $t$-value of the two means is -2.267 with the significant level reaching 0.05, meaning the total score of post-test is significantly higher than the pre-test scores. The Eta squared equals 0.204;

   Analysis: The result shows that the students have high acceptance for pluralistic and hands-on class.

2. The means of pre-test scores ($M = 14.29$) is the same as that of the post-test ($M = 14.29$). The $t$-value of the two means is 0.000, meaning no significant difference. It shows that the total score of post-test bears no difference with the post-test score;

   Analysis: In order to avoid students’ being too score-oriented, there is no paper test during the teaching process, which is in accordance with the result that shows no difference between the two tests.

3. The mean of pre-test scores ($M = 15.10$) is slightly lower than that of the post-test ($M = 15.43$). The $t$-value of the two means is -1.046 which did not reach the significant level. It shows the total score of post-test bears no significant difference with the pre-test scores. The Eta squared equals 0.052;

4. The mean of pre-test scores for attitude ($M = 14.71$) is slightly lower than that of the post-test ($M = 14.81$). The $t$-value of the two means is -0.169, which did not reach the significant level. It shows the total score of post-test bears no significant difference with the pre-test scores. The Eta squared equals 0.001;

   Analysis: The duration may not be long enough to show significant changes.

5. The mean of pre-test scores for achievement ($M = 14.62$) is significantly lower than that of the post-test ($M = 16.00$). The $t$-value of the two means is -4.045 which has reached the significant level of 0.001. It shows the total score of post-test is significantly higher than the pre-test scores. The Eta squared equals 0.450;

   Analysis: Students draw pictures in class, and have a sense of participation and achievement, so this difference is significant.

6. The mean of pre-test scores for class participation ($M = 15.00$) is slightly lower than that of the post-test ($M = 15.71$). The $t$-value of the two means is -2.107 which has reached the significant level of 0.05. It shows the total score of post-test is significantly higher than the pre-test scores. The Eta squared equals 0.182;

   Analysis: Students have the initiative to operate and the sense of participation increases, so the difference is significant.
Table 1  
*T-test Statistics of Dependent Samples in Pre- and Post- Test*

<table>
<thead>
<tr>
<th>Pair variable</th>
<th>Pre-/Post-test</th>
<th>M</th>
<th>N</th>
<th>SD</th>
<th>t-value</th>
<th>(\eta^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>Pre-test</td>
<td>73.76</td>
<td>21</td>
<td>7.76</td>
<td>-2.267*</td>
<td>0.204</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>76.24</td>
<td>21</td>
<td>9.66</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability</td>
<td>Pre-test</td>
<td>14.29</td>
<td>21</td>
<td>2.10</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>14.29</td>
<td>21</td>
<td>2.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attitude</td>
<td>Pre-test</td>
<td>15.10</td>
<td>21</td>
<td>2.21</td>
<td>-1.046</td>
<td>0.052</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>15.43</td>
<td>21</td>
<td>2.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Values</td>
<td>Pre-test</td>
<td>14.71</td>
<td>21</td>
<td>1.95</td>
<td>-0.169</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>14.81</td>
<td>21</td>
<td>2.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Achievements</td>
<td>Pre-test</td>
<td>14.62</td>
<td>21</td>
<td>1.77</td>
<td>-4.045***</td>
<td>0.450</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>16.00</td>
<td>21</td>
<td>2.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class participation</td>
<td>Pre-test</td>
<td>15.00</td>
<td>21</td>
<td>2.00</td>
<td>-2.107*</td>
<td>0.182</td>
</tr>
<tr>
<td></td>
<td>Post-test</td>
<td>15.71</td>
<td>21</td>
<td>2.19</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Notes.* *p* < 0.05; ***p* < 0.001.

**Qualitative Part**

**Students experience.** After class positive words of description of learning experience in mathematics class of the students are: lifestyle, vivid, interesting, love mathematics, meaningful, fun, happy, do not have to recite, not abstract, not difficult, many changes, easy to learn and diversified.

**Teaching experience of math teachers.** Mathematics teachers express teaching experience in mathematics class: teaching smoothly, strengthen students learning motivation, computer operation in which students are full of interest, and no more textbooks simple graphs

When students measured the length of a triangle with a ruler, they indicated that no teacher had ever let them do so before and they had a deep impression on the trigonometric function. In the teaching about quadratic function, students were asked that if it is possible that the graph will be non-linear graphs. Students said because there was not a point that conform to the function. It shows that students were fully convinced that quadratic function graph is linear. Students saw the function graphs presented through mobile phones and was quite interested.

**Teaching experience from IT teachers.** It is not difficult to teach students to draw with mathematical software and make it into 3D model. To those who have never come into contact with 3D printing, the process may be unfamiliar. During the process, drawing software (in this case, Inkscape) is used to modify curves drawn by mathematical software system. Only some basic tools are needed. Vector graph files will be modified again to be converted into the 3D model with the use of 3D software (in this case, Tinkercad). The above modification and transcoding software is available free of charge and easy to operate, so the students do not have the financial burden. As for the 3D printing of the 3D model, if taking the 3D printer installation and 3D printing software parameter setting out of consideration, the operation for printing is not difficult.

The process of transforming the mathematical results into realistic product is not difficult and the software used in the process is easy to obtain. In addition, it does not require proficiency in the software functions.

**Conclusions**

This study integrates the maker-education into high school mathematics teaching with specific curriculum teaching design to guide students to learn polar coordinate function concept. It uses mathematical software to
draw the polar coordinate function graphs, such as cardioid, limacon, and rose curve. In addition, this research uses 3D printing technology to print graphs and enables students to experience the spirit of maker-education. After the implementation, the following conclusions are reached.

**Integrated Curriculum Design and Planning**

This study suggests that the integration of maker-education into high school mathematics teaching must first consider whether the teaching objectives and characteristics have the feasibility of integration (Liu, 2016). For example, what kind of corresponding activities in senior high school education can be developed for the implementation of maker-education and can be combined with the high school mathematics teaching? After discussions with the teachers, it is considered that there is high feasibility for high polar coordinate function graph unit in mathematics at senior high school, therefore, integrated curriculum should be designed and planned.

**Implementing the Teaching Strategy that Taking Students as the Main Part**

This study suggests that during the integration of maker-education into high school mathematics teaching, teachers are not the main body, but rather a guide for the students and a master who adjusts the course schedule and time. In the process of learning, students should be regarded as the main body. Teaching design should cultivate students’ ability of thinking (Lou, Dzan, Lee, & Chung, 2014). In this way, students can enjoy more initiative and freedom and obtain the knowledge of mathematics and a growing maker experience.

**Teachers Are Encouraged to Develop Inter-Disciplinary Expertise**

The reason that this course can be realized is because the group discussion before the research. The group is made up of teachers with expertise in various fields of the school, for example, mathematics teachers and IT teachers. Through brain-storming to develop inspired innovative teaching method, students can learn mathematics. At the same time, they can learn experience the application and interaction between mathematics and life, science and technology, so as to stimulate students’ learning motivation. Therefore, schools should encourage teachers to carry out inter-disciplinary cooperation and cultivate related interdisciplinary knowledge, in order to stimulate more innovative thinking and improve the teaching effectiveness (Yeh & Lo, 2015).

**Maker-Education Has Far-Reaching Influence**

When a student makes mathematical results as a finished product, he/she is a “maker.” Maker refers to a group or an inventor who makes mind, ideas, concepts, or ideas become realistic products by the means of hands-on process. In recent years, the rapid development of new technology, such as laser cutting machine, computerized numerical control (CNC) machine and 3D printer allows significantly reduction in costs for prototype design, development, and manufacturing. It also shortens product-testing, modification, monitoring process, and the customization can be realized, which has ushered the manufacturing industry into a new era (Kraft, 2014).

The Ministry of Education began to promote the high school creative 5-year plan in 2015, to encourage schools to purchase 3D printing machines and other equipment (Lin, 2016). However, the majority only used the printing technology in metal carving or doll items while mathematics teaching seldom uses such technology. The author put forward the suggestion the application of 3D printing be put into the mathematics teaching. The 3D printing equipment can be used to assist teaching, so that students can verify mathematical learning content through 3D printing products and feel the interaction between mathematics and life, science and technology. In this way, the mathematics learning might be more effective and interesting.
References
## Appendix I: Mathematics Learning Attitude Scale

Mathematics learning attitude scale description: The answer is mainly to study the impact of this course on your attitude. Please choose from the five levels: “Strongly agree,” “Agree,” “Neutral,” “Disagree,” and “Strongly disagree” according to your actual situation. Please answer in order and do not miss any item. Thank you.

<table>
<thead>
<tr>
<th>Description of learning attitudes in mathematics</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A: Ability</strong></td>
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<tr>
<td>1. I think my basic computing ability is good.</td>
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<td>2. I think I have a good idea about mathematics.</td>
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<td>3. I am confident that I can solve math problems by myself.</td>
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<td>4. I think math is difficult for me.</td>
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<td><strong>B: Attitude</strong></td>
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<tr>
<td>1. When I fail to understand some mathematical ideas, I will try to figure them out.</td>
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<td>2. When I get the wrong answer I will try to understand the reason for the mistake.</td>
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<td>3. When I do my math homework, I ask someone directly instead of thinking about it by myself.</td>
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<td>4. I will take the initiative to do math calculation homework or others.</td>
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<td><strong>C: Values</strong></td>
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<tr>
<td>1. I think math is very important, because it can be used in everyday life.</td>
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<td>2. I think math is very important, because it can stimulate my thought.</td>
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<tr>
<td>3. I think learning math is to learn the way to solve problems and it is very important.</td>
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<tr>
<td>4. I think math learning is for exams.</td>
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<tr>
<td><strong>D: Achievements</strong></td>
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<tr>
<td>1. In learning mathematics, I think the most rewarding time is when solving a problem and one gets more and more confident.</td>
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<tr>
<td>2. When I am studying math, I think the most satisfying thing is when I solve a math problem.</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>3. When I am studying math, I feel most fulfilled when my ideas are accepted by the teacher.</td>
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<td>4. When I am studying math, I feel most fulfilled when my ideas are accepted by my classmates.</td>
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<td><strong>E: Math class</strong></td>
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<tr>
<td>1. I would like to take part in math class, because it is interesting and challenging.</td>
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<td>2. I would like to take part in math class, because the teacher’s teaching is changing from time to time.</td>
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<tr>
<td>3. I would like to take part in the math class, because the teacher values me.</td>
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<td>4. I would like to participate in math class, because students can discuss with each other.</td>
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</tbody>
</table>
Appendix II: Teaching Tools

1. Mathway APP—math problem solver


2. 360° protractor

Source: https://global.rakuten.com/zh-tw/store/the-bunbougu-manyou/item/uchida-1-822-0000/.

3. GeoGebra

GeoGebra Math Calculators with Graphing, Geometry, 3D, Spreadsheet, CAS, and more!

Source: https://www.geogebra.org/?lang=zh_TW.
4. **3D Printer** (To avoid broken graphs, inner circle is added in the center)

*Figure a. 3D printer printing*

*Figure b. 3-, 4-, and 5-leaved rose curve.*