Designing Visually Interactive Learning Modules to Promote Students' Critical Thinking in Mathematics

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Abstract— **This Innovative Practice Full Paper presents our study of promoting critical thinking and achievement in mathematics with the use of technology via easily accessible resources. We believe that creating easy-to-use learning modules that are accessible for students everywhere is a great way to help students comprehend abstract logic process in problem solving. More specifically, we developed a series of learning modules that interactively visualize and illustrate the steps of Geometry proofs by using GeoGebra, a dynamic learning platform for mathematics [5, 10]. Survey study shows that our interactive learning modules are beneficial in promoting students' learning interests and ability of critical thinking.**

Keywords—STEM, Critical Thinking, Education Technology, Geometry, Mathematics, Interactive Learning, Visualization

I. INTRODUCTION

There are times in everyone's life where they have wanted to raise their hands to ask for assistance. This happens a lot when something becomes too difficult for people to manage. Imagine, when you did not have that helping hand. Did you give up? Did you keep trying? Or did you seek other resources? According to the National Center for Children in Poverty, "…45 percent live in low-income families and approximately one in every five (22 percent) live in poor families" [2]. There are about 72 million children in the United States that live in a low social economic status (LSES) background [1]. There are several researches about how living in a low-social economic background has an impact on a student's academic success [19, 20]. Focusing on the area of academic success in mathematics, a research showed that "high levels of families in LSES situations have a negative relation to the mathematics achievement" [8]. This study stated that there was a lack of resources/support for LSES students that was so essential for students to succeed. Some of the essential resources include involvement from the parent, motivation, and concrete resources such as books, internet and technology [8]. Not only do students in LSES homes have a lack of resources, but so do the schools they attend.

According to the U.S. Department of Education, "all young people should be prepared to think deeply and to think well so that they have the chance to become the innovators, educators, researchers, and leaders who can solve the most pressing challenges facing our nation and our world, both today and tomorrow" [17]. However, about one third of Americans say they are not good at math, although over ninety percent of Americans admitted that math is important to be successful [4]. The anxiety that Americans have about math is problematic. Why do people find math difficult? People find math difficult because math is hard to relate to, it is too abstract, it is too tedious, and any negative stigmatism about math pasted down by past generations.

Given that critical thinking in math is essential to success in STEM disciplines, the ultimate goal of our study is to develop widely accessible computing based learning modules to promote problem solving skills in math. One of the most important characteristics of our learning modules is that they should be able to divide a complex problem into multiple smaller problems and to demonstrate an abstract math process in intuitive and easy-to-follow steps. In this paper, we will report our development of interactive learning modules on high school Geometry.

Another important goal that we are pursuing is that all our learning modules should be widely accessible. First of all, all learning modules will be able for access through Internet. However, given that there are still certain percentages of homes that don't have Internet access [13], we are also in the process of installing our learning modules on donated used tablets and mobile devices and donating those devices to public libraries so that students can check them out for access.

The rest of the paper will be organized in the following ways. In section 2, we describe our design of interactive learning modules on high-school Geometry in details. In section 3, we report our survey study that demonstrates the effectiveness of our learning modules. Finally, we conclude our paper and briefly mention some future work in section 4, Ease of Use.

II. RELATED WORK

The National Council of Teachers of Mathematics believe that, "All students should have the opportunity and the support necessary to learn significant mathematics with depth and understanding [24]." NCTM states that being able to apply and understanding mathematics is an important factor in the work force. If we want students to be able to apply and understand mathematics than to give them a free resource to discover, visualize and understand mathematics. When students start to take ownership of their learning the more successful they will be in that content. According to research in the NCTM article, students become more confident when they solve a difficult problem on their own [24]. Students would more likely feel accomplished and successful when they take ownership of their own learning. The importance of students being able to manipulate and come up with their own conclusions is the

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foundation to critical thinking and problem solving. We believe that students being able to have assistive interactive resources at home would benefit students with their critical thinking and problem solving skills.

Technology in the classroom today has been a growing topic for several years. There are several countries like Lithuania, Austria, Germany, Sweden and several other countries that are trying to integrate GeoGebra into the classroom [14, 16]. Several research studies believe that students needs could be met by integrating interactive learning into the classroom [25, 26, 27]. By using technology to discover and learning mathematics, students would be able to see how to solve different problems in new ways [25]. Mathematics is abstract which makes it difficult to visualize and understand. However by using technology to help visualize the concepts it would be able to close the gap of abstract thinking. This way students would be able to discover and learn concepts they are able to see. Being able to visualize difficult topics could cause students to discover, analyze, evaluate and question the solution for themselves. We believe that this will allow students to practice critical thinking and problem solving. Technology also gives student the opportunity to discover and problem solve at their own pace. Just as a reminder, technology should not be a replacement for educators, they should only be used as an assistant to help facilitate learning.

GeoGebra is a dynamic mathematics software that is free to download on any device or use through an internet browser [7]. This dynamic software helps teachers create, program, and model several abstract concepts such as proofs. The benefit of using GeoGebra is that it is free, assessible, innovative, open source and user friendly. After GeoGebra has been downloaded onto a device it does not require the use of the internet. The disadvantages of using the software is creating lesson are time consuming and there will be a learning period for both teachers and students.

III. Interactive Learning Modules

The core task of this project is to design interactive learning modules that visually presents critic concepts and the proof processes of high school Geometry, such that abstract math concepts and processes can be perceived on a step by step manner. We use the software GeoGebra [5, 10] to build our learning modules. The ultimate goal of this task is to cover all knowledge points that are included in the State Geometry Standards. Our design is highly modulized such that a learning module may include component modules for constructing concepts or processes and this learning module may be a building block for a bigger learning module. Figure 1 (a) shows an example module that we built to demonstrate proof that triangle DEM and triangle ABM are similar.

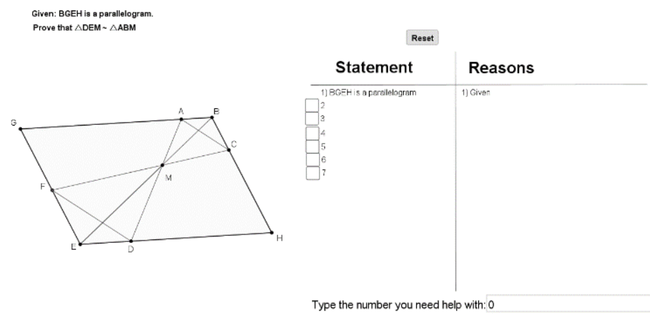
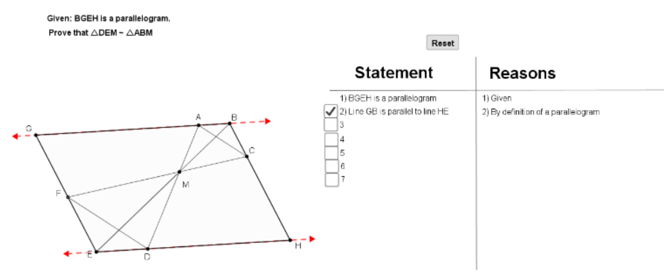
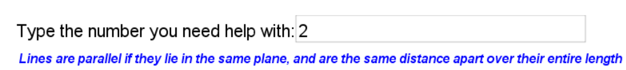


Figure 1. Triangle Similar Module 1

When working on this module, students will see a two-column proof process that demonstrates proof statements and their reasons step-by-step as shown in Figure 1(b). Students can explore this learning module in two ways: 1) Using the check boxes to show the statement and reason for the next line, as shown in Figure 2 (a); and 2) Getting help on any step by inputting the number of that step as shown in Figure 2



a) Check the next step



b) Choose a step to get help

Figure 2. Interactively learn each step of the proof process

Figure 3 shows what it looks like as the student progresses through the proof. If the student wants to start over and try to do the problem again themselves, they can reset the module clicking the 'Reset' button. The great thing about the reset option is that students could retry the problem themselves until they understand or see the whole picture. After the students have worked out what was given and what could be inferred based on those givens, this would be where new concepts come in and understanding the definitions of shapes, theorems, and postulates. Figure 4, shows one way to solve for the proof.

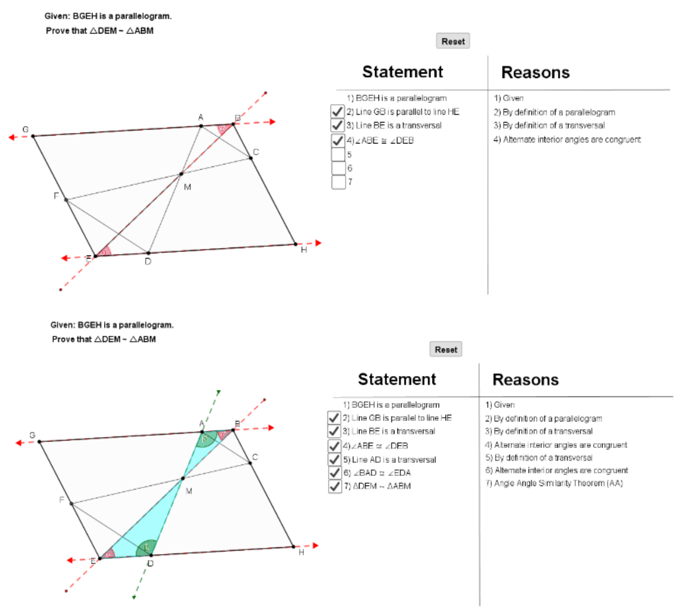


Figure 3. Progress Through the Proof

Because of the modulized design, a student who needs to review certain definitions/concepts used in the current learning module can refer to a component module to learn that specific concept. For example, if the student had a problem with understanding what a parallelogram is (the second step of the current module), he or she could open the corresponding component module on parallelogram (as shown in Figure 4) and explore this particular concept.

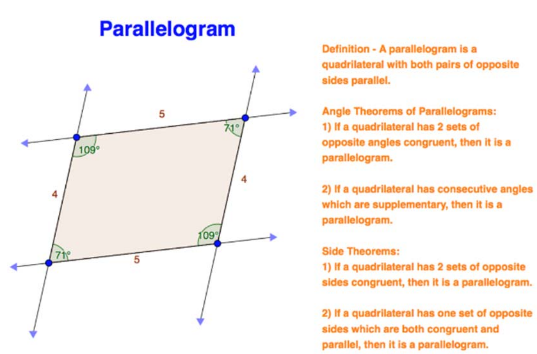


Figure 4. Component Module on Parallelogram

This current learning module that demonstrates the proof that triangle ABC and triangle DEF are similar can be further used as a building block for an extension problem. For instance, Figure 5 demonstrates an extension module where the conclusion of the current learning module (i.e., ΔDEM~ΔABM) is used as the second step to prove that ΔABC~ΔDEF given BGEH is a parallelogram. Our modulized design also helps to train students using divide and conquer strategy to solve complex problems.

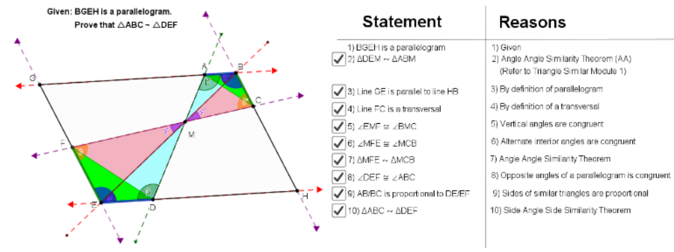
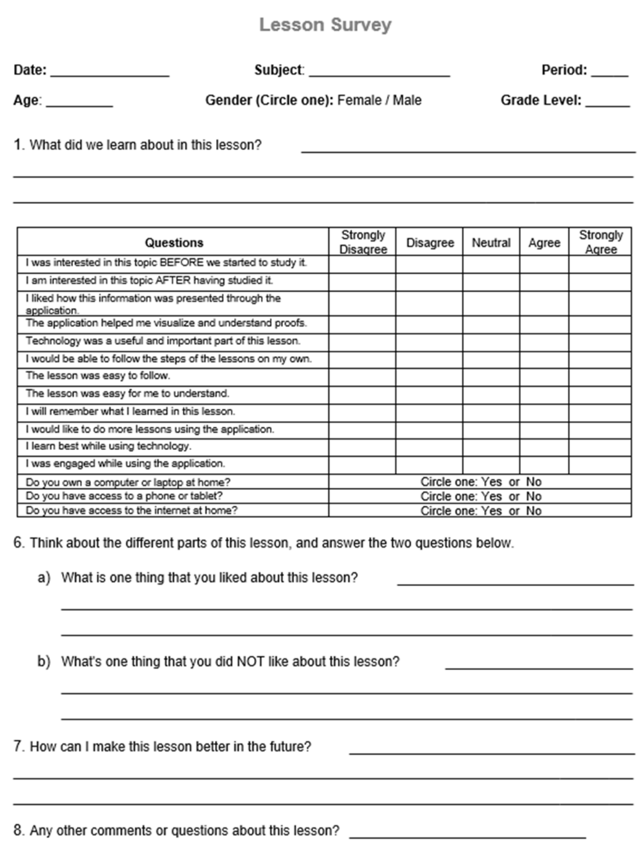


Figure 5. Triangle Similar Module 1 as One Step in a Bigger Problem

IV. Survey Study

The populations of our survey study are Georgia public school students in tenth-grade Geometry. The learning module of the extension problem that is described in section 2, as well as all its component modules were given to 80 students who are currently enrolled at a public high school in Georgia. These 80 students were separated by class level: Honors Geometry and Geometry. The goal of the survey study was to see how our modules would help the students in understanding the logic steps of Geometry proof without an instructor. The following survey was given to students to critique.



Lesson Survey

Date: ______________ **Subject:** ________________ **Period:** _____

Age: ________ **Gender (Circle one):** Female / Male **Grade Level:** ______

1. What did we learn about in this lesson? ____________________

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I was interested in this topic BEFORE we started to study it.					
I am interested in this topic AFTER having studied it.					
I liked how this information was presented through the application.					
The application helped me visualize and understand proofs.					
Technology was a useful and important part of this lesson.					
I would be able to follow the steps of the lessons on my own.					
The lesson was easy to follow.					
The lesson was easy for me to understand.					
I will remember what I learned in this lesson.					
I would like to do more lessons using the application.					
I learn best while using technology.					
I was engaged while using the application.					
Do you own a computer or laptop at home?	Circle one: Yes or No				
Do you have access to a phone or tablet?	Circle one: Yes or No				
Do you have access to the internet at home?	Circle one: Yes or No				

6. Think about the different parts of this lesson, and answer the two questions below.

a) What is one thing that you liked about this lesson? ____________________

b) What's one thing that you did NOT like about this lesson? ____________________

7. How can I make this lesson better in the future? ____________________

8. Any other comments or questions about this lesson? ____________________

Figure 6. Student Survey Questions

The survey data (shown in table 1) collected from students who used our learning modules shows that the modules were beneficial to a noticeable extent. First of all, the learning modules helped to promote students' interests in the subject.

The data showed a shift in percentage when it came to the question of interestingness after and before the lesson. Most of the answers shifted from one rating higher than the previous under the level of interest in the topic. More specifically, the data shifted from 21 out of the 80 students strongly disagreeing to only 10 strongly disagreeing; shifted from 26 out of the 80 disagreeing to only 15 disagreeing; and shifted from 4 out of 80 agreeing to 15 agreeing.

Second, the learning modules helped to promote critical thinking in an intuitive way. Data shows that the majority 72% of the students liked how the information was presented through the applications; 79% of the students thought that the application helped them visualize and understand the proofs; and 67% of the students thought that technology was a useful and important part of this lesson.

Furthermore, students can easily follow the learning modules without extra instructions. 65% of students agreed or strongly agreed that "I was able to follow the steps of the lesson on my own", and 68% thought the modules were easy to follow. Figure 6 further presents the percentages of what the students answered from a five-point scale from strongly disagree to strongly agree.

Table 1. Aggregated Survey Data

QUESTIONS	STRONGLY DISAGREE–	DISAGREE–	NEUTRAL–	AGREE–	STRONGLY AGREE–	TOTAL number of students
Percent	27%	33%	31%	5%	4%	
I was interested in this topic BEFORE we studied it	21	26	24	4	3	78
Percent	13%	19%	45%	19%	4%	
I am interested in this topic AFTER we studied it	10	15	35	15	3	78
Percent	1%	8%	18%	49%	23%	
I liked how this information was presented through the application	1	6	14	38	18	77
Percent	3%	4%	14%	53%	26%	
The application helped me visualize and understand proofs	2	3	11	40	20	76
Percent	3%	7%	24%	39%	28%	
Technology was a useful and important part of this lesson	2	5	18	30	21	76
Percent	1%	8%	25%	51%	14%	
I was able to follow the steps of the lesson on my own	1	6	19	39	11	76
Percent	3%	12%	18%	52%	16%	
The lesson was easy to follow	2	9	14	40	12	77
Percent	1%	7%	25%	43%	24%	
The lesson was easy for me to understand	1	5	19	33	18	76
Percent	0%	9%	37%	41%	12%	
I will remember what I learned in this lesson	0	7	28	31	9	75
Percent	7%	16%	28%	39%	11%	
I will remember what I learned using the application	5	12	21	29	8	75
Percent	7%	16%	29%	40%	8%	
I learn best while using technology	5	12	22	30	6	75
Percent	4%	13%	31%	44%	8%	
I was engaged while using the application	3	9	22	31	6	71

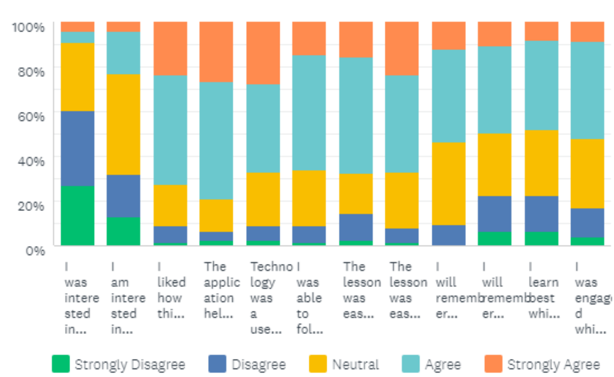


Figure 6. Bar Chart of Survey Results

V. Conclusion and Future Work

We developed a series of interactive learning modules to promote logic thinking in high-school Geometry study by following the state standards. Our survey study shows that the learning modules are beneficial in promoting students' learning interests and enhancing students' comprehension of critical concepts and proof processes. Our future work includes completing our development of all learning modules and broadening our survey study by involving more schools with higher diversity and social economic backgrounds. Besides making our learning modules publicly available via Internet, we also plan to install our learning modules on donated used tablets and mobile devices and donate them to public libraries and schools so that students who have the need can easily access the technology.

References

[1] S. Addy, W. Engelhardt, & C. Skinner, "Basic Facts About Low-income Children: Children Aged 12 through 17 Years, 2014", National Center for Children in Poverty, February 2016

[2] Jiang, Y., Ekono, M., & Skinner, C. (2016). Basic Facts about Low-Income Children:

[3] Children under 18 Years, 2014. New York: National Center for Children in Poverty,

[4] Mailman School of Public Health, Columbia University. "Public Library Use – ALA Library Fact Sheet Number 6", American Library Association, October 2015

http://www.ala.org/tools/libfactsheets/alalibraryfactsheet06

[5] "Socioeconomic status", American Psychological Association, 2016, http://www.apa.org/topics/socioeconomic-status/

[6] "In a New Survey, Americans say, 'We're Not Good at Math'", www.mathnasim.com, January 2015

http://www.mathnasium.com/http-changetheequation-org-press-new-survey-americans-say-e2-80-9cwe-e2-80-99re-not-good-math-e2-80-9d

[7] GeoGebra – Dynamic Mathematics, https://www.geogebra.org/

[8] GPS Mathematics https://www.georgiastandards.org/Standards/Pages/BrowseStandards/MathStandards9-12.aspx

[9] J. Gerlach, "STEM: Defying a Simple Definition", NSTA Reports, 2012 http://www.nsta.org/publications/news/story.aspx?id=59305

[10] M. Hernandez, "The Relationship between Mathematics Achievement and Socio-Economic Status", eJournal of Education Policy, 2014

[11] S. L. Hofferth & J. F. Sandberg, "How American children spend their time", Journal of Marriage and Family 63: 295-308, May 2001

[12] M. Hohenwarter & J. Preiner, "Dynamic Mathematics with GeoGebra", The Journal of Online Mathematics and Its Applications, Vol 7, March 2007

[13] M. Hutchings, "Introduction to mathematical arguments", https://math.berkeley.edu/~hutching/teach/proofs.pdf.

[14] S. Lange, "Strategies to Promote Critical Thinking in the Elementary Classroom", 2014

http://www.p21.org/news-events/p21blog/1435-strategies-to-promote-critical-thinking-in-the-elementary-classroom

[15] A. Perrin & M. Duggan, "Americans' Internet Access: 2000-2015", Pew Research Center, June 2015

[16] E. J. Pettigrew, "A Study of the Impact of Socioeconomic Status on Student Achievement in a Rural East Tennessee School System", Electronic Theses and Dissertations. Paper 1844. 2009

http://dc.etsu.edu/etd/1844

[17] "Developing Critical Thinking in Students" https://k12teacherstaffdevelopment.com/tlb/developing-critical-thinking-in-students

[18] "Understanding Interactive Learning" http://www.scholastic.com/parents/resources/article/your-child-technology/understanding-interactive-learning

[19] "Science, Technology, Engineering and Math: Education for Global Leadership", 2015

http://www.ed.gov/stem

[20] K. Weber, "Research Sampler 8: Students' difficulties with proof", Mathematical Association of America, 2016

[21] http://www.maa.org/programs/faculty-and-departments/curriculum-department-guidelines-recommendations/teaching-and-learning/research-sampler-8-students-difficulties-with-proof

[22] T. Risley & B. Hart, Meaningful Differences in the Everyday Experiences of Young American Children, Paul H. Brookes Publishing Co., 1995, ISBN 1-55766-197-9

[23] C. D. Jerald, "Dispelling the Myth Revisited: Preliminary Findings from a Nationwide Analysis of 'High-Flying' Schools", The Education Trust, 2001

[24] National Council of Teachers of Mathemtics, "Executive Summary: Principles and Standards for School Mathematics", June 2018

[25] J. Hohenwarter & M. Hohenwarter, "Introducing Dynamic Mathematics Software to Secondary School Teachers: The Case of GeoGebra", Jl. of Computers in Mathematics and Science Teaching, pg 135 – 146, 2008.

[26] D. Majerek, "Application of GeoGebra for Teaching Mathematics", Advances in Science and Technology: Research Journal, Vol 8, December 2014.

[27] K. Kumar & C-Y. Chang, "Incorporating GeoGebra into Geometry learning – A lesson from India", Eurasis Journal of Mathematics, Science & Technology Education. 2015.