VISUALIZATION TOOLS USE IN SECONDARY MATHEMATICS CLASSROOM EDUCATION

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ABSTRACT

Xiaoqian (Sophie) Niu: Visualization Tools Use in Secondary Mathematics Classroom Education
(Under the direction of David Gotz)

Previously literature has investigated the visualization tools used in primary education in natural sciences, and this research focuses on visualization tools that could be used in college level mathematics classroom to facilitate students' learning and teachers' teaching experience. In the end, the research derived future visualization tool design implications from students' and teachers' interviews and four class observations.

Thanks to my advisor David Gotz and my research method course instructor Mohammad Jarrahi,
I would not be able to do this without your guidance and support.
Also thanks to my friends, thank you all for cheering me all the way to the end.

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

According to National Center for Education Statistics (2016), there has been more bachelor's graduating with mathematics and statistics degrees. There is a tendency to assume that a lot of students enjoyed what they can learn in mathematics courses which lead them to pursue a career in the field. Stepping in the mathematics classes, people don't see much excitement about learning mathematics as anticipated. Walking in the math buildings, one seldom sees excitement and enjoyment shown by others' facial expressions. And if one says that learning mathematics is fun, he can easily receive a lot of "you are crazy" look from other students. Students have identified a few reasons for disliking mathematics courses. First of all, the mathematics concepts are abstract and hard to understand. Secondly, there is always a lot of handwriting note-taking in class, and sometimes the professors don't have good handwriting or quickly jumping from topic to topic which makes the learning experience even worse. What's more, when they sit in a mathematics class, they usually don't have much engagement with the content and find the courses boring to listen to. In other word, students who are learning mathematics, have a hard time enjoying the learning process.

Learning in class is affected by the instructor's teaching tool selection. Here at UNC, most of the classrooms are equipped with projectors and document cameras, and some even have smartboards. While other science teaching has engaged students with YouTube videos and other technology-aid learnings, mathematics teachers have kept their teaching style old-fashioned and consistent throughout my elementary school to college - writing with chalk on blackboards and not using any current digital technologies. On Quora, the popular question-and-answer site, people asked “Why do most math professors prefer giving lectures using blackboards rather than whiteboards or projectors? Do you prefer to do math on a whiteboard or a chalkboard? Why? (Quora, 2012; Quora, 2014)” Professors say that teaching with board and chalk is the way that they learned from their teachers. Comparing to projecting PowerPoint, writing with chalk on the board provides, they can show the process of argument development to students. In fact, Chris Buddle, an assistant professor at McGill University, argued that teaching with blackboard and chalk kept students focused and actively engaged as they would more likely to take notes on the materials that the instructor put on the board than on the projector (Buddle, 2012).

Students are not satisfied with the current mathematics learning experience, and professors are using the “outdated technology,” blackboard and chalk, to teach. Previous works have shown that integrating visualization technology can improve students’ learning experience in the classroom, yet not a lot of studies have included teachers’ feedback for the technology evaluations.

Thus, the research is proposed to further investigate how technologies, especially visualization tools, should be designed to be integrated into secondary mathematics education in classroom settings. Visualization tools are defined as physical subjects and digital technologies that are designed or could be used for the purpose of presenting information with various degrees of graphic or words use. Some examples of physical visualization tools are blackboards, whiteboards, textbooks, touchscreen computers, smart boards, tablets. Some examples of digital visualization tools are PowerPoint slides, mathematical program packages. As a basic science subject, mathematics is fundamental to the development of sciences and should not be isolated from digital technology as the world goes on to be more and more digitalized. The research wants to answer the question, “When we are improving teaching visualization tools that could be used in secondary mathematical classroom education, what are the crucial functional requirements that the tools should have in the context?” To answer this question, the researcher has proposed the following research questions to investigate the phenomenon:

RQ1. What are the visualization tools that math instructors and students use in class?

RQ2. What are characteristics of the mathematics classroom education’s content and context that influences the selection of visualization tools?

RQ3. What are teachers’ and students’ behaviors and preferences that affect visualization tools’ use?

By answering these questions, this research provided design implications for digital technologies that could be incorporated into mathematical education, and shed light on how digital technology, if properly designed, can improve the secondary mathematics learning and teaching in classrooms.

CHAPTER 2 LITERATURE REVIEW

The research's objective is to investigate how visualization technologies could be integrated into the secondary mathematics classroom education. In order to better design future teaching or learning technological tools, this research is dedicated to explore the reasons why the current technology, especially blackboard and chalk, is the technology that mathematicians pick, while various educational technologies, ranging from hardware such as smart board, tablets, touchscreen computers to software such as online graphical calculators, mathematical calculation and visualization programs, handwriting recognition tools, are available to them to facilitate teaching.

Visualization technologies or visualization digital tools are technology or digital tools that enable people to visualize certain concepts with graphs or interactive animations. With limited words, people sometimes make sense of information better with visualization tools.

Visualization can be divided into categories by the number of interactions, the commonly-seen displaying visualization, and interactive visualization. Displaying visualization presents the data or abstract concepts in a graphic way and rarely involves users' interaction with the visualization, while interactive visualization involves users' interaction in the visualization interface. Users can manipulate the visualization based on their understanding of the interface, with more autonomy for exploration; users could generate more insights about the task than merely see the display (Conati, Carenini, Hoque, Steichen, & Toker, 2014).

Section 2.1 Visualization Technology Use in Daily Life

Research has shown that visualization technologies have improved people's life quality. With the rapid development of digital technology, the society has started to incorporate visualization aids into every aspect of people' life, ranging from facilitating work, enhancing leisure pursuit in music and managing personal life (Huang et al., 2015; Kandel, Paepcke, Hellerstein, & Heer, 2012; Nguyen & Le, 2016; Schedl & Markus, 2017). For example, Kandel et al. (2012) interviewed business data analysts to see how the visual analytic tools can improve to enhance their working speed through the more meaningful presentation of data through interviews with 35 analysts from different sectors. In addition to aiding workflows, Huang et al. (2015) promote visualization tools into personal information management field as a way to connect data collected from daily life and make sense of the data. What's more, researchers have designed visualization tool, Hyper Word Clouds, to improve the exploratory music search in large music repositories (Nguyen & Le, 2016; Schedl & Markus, 2017).

Seeing the full integration of visualization tools into people's daily life, researchers have developed learning technology and educational technology as the aftermath of technology development. Since education is such an essential part of life, educational technology, the study of "properly creating, using and managing technological processes and resources" (Robinson, Molenda, & Rezabek, 1963), spurred in various directions in different disciplines. Education has expanded from fixed classroom learning to long-distance learning and now mobile learning. With more and more venues for learning to take place, when one thinks of improving the learning quality, one should try to maintain a balance between old technology and new technology so that the maximum benefit of various learning environment could be gained (Muttappallymyalil et al., 2016).

Section 2.2 Visualization Technology in Educational Settings

Traditional education setting is in a classroom with a teacher lecturing mostly in the front of the classroom. With knowledge of people's learning behaviors, active learning is promoted for better learning outcome. For better active learning, technology integration into the classrooms would be able to provide the students with more widely available knowledge online and more possibilities of collaborations with others to gain knowledge.

Previous research has shown the impact of integrating interactive visualization for educational purposes. One example of interactive visualization would be video-gaming. Video-gaming requires a lot of user-interface interactions and video-game players quickly learn and addict to the well-designed interactive games. Seeing the great attachment that players have to the games, researchers have incorporated gaming into learning to enhance the learning quality. A study has shown that properly designed math games can be beneficial to students' math learning (Vandercruysse, Elen, & Oostendorp, 2015). In addition to that, if reflections after the games are provided, students could learn more about the proper reasoning to understand math concepts.

By complementing learning with interactive visualization, such as augmented reality, students are more motivated and engaged in learning (Akçayır & Akçayır, 2017). Education in scientific subjects, such as physics, astronomy, biology, and anatomy, are especially active in incorporating modern technologies to facilitate students' understanding of the subject matter (Chi, 2005; Ferrer-Torregrosa, Torralba, Jimenez, García, & Barcia, 2015).

Active learning calls for students to take the lead in the learning process, which means that teachers who were trained for lecturing style and had the mindset of an instructor need to change their previous values. These studies primarily identified students as the major use of learning technologies, which may neglect the other important stakeholder in the learning system: the teachers.

Section 2.3 Visualization Technologies in Secondary Mathematics Education

As a foundational subject in science education, mathematics, however, has been downplayed in research that developing comprehensive visualization technologies for students' learning and teaching. However, pure displaying visualization technologies are more prevalent than interactive visualizations. Comparatively, more geometrical software is available for use, which mostly emphasized on the visual display of the geometry rather than engaging students' learning through interactions (Bertot, Guilhot, & Pottier, 2004; Mara Cotic, Zuljan, & Simcic, 2005; Zengin, Furkan, & Kutluca, 2012).

In general, more guidelines have provided to K-12 teachers' math course planning and the ideal amount of knowledge that students should gain (Michigan State University, 2014). However, there are rarely large associations or government involvement in standardizing secondary mathematics education or measuring the students' learning quality in higher education institutions. From a pragmatic view, higher education institutions should not only provide the adequate information to students upon the field knowledge, but also prepare students to use the technology that will be useful in a workplace within the subject of study since technologies are so integrated into workplaces for efficiency and easiness (David & Abreu, 2014). With the social trends of utilizing information and communication technology to collaborate in work and calls for active learning in educational settings, students are set to use technology in their academic learning.

Hence, with limited research on visualization technologies used in secondary mathematics teaching and learning experience, this research aims to fill in the literature gap by investigating how visualization technology can improve the secondary mathematics experience in classroom settings.

Section 2.4 Teachers' Roles in Visualization Technology Integration

Since a lot of the visualization technology evaluations and implementations are based on students' feedbacks and focused on learning perspective, students are engaged in the development of learning technology. However, what's more concerning lies in the neglected perspective of the frequently leading role in the classroom — the teacher. Despite the tools designed for mathematics education, rarely do any mathematics teachers use technology teaching aids.

Researchers have investigated on characteristics of teachers that could have caused this lack of technology integration into teaching. Virtual technologies including VR and AR are good ways to increase students' engagement in class, yet teachers' beliefs and readiness of technology greatly impact on technological integration into teaching (Howard, Chan, & Caputi, 2015). Specifically, study shows that teachers' episode memory impacts their beliefs, which subsequently limits technological integration into teaching (Er & Kim, 2017). To better integrate technology into teaching, teachers' episode memories need to be reassessed and evoke their change in beliefs. Also, Martín-Gutiérrez (2017) identifies that the teachers who resistant to integrate visualization technology innovations into teaching may think that adopt new technologies requiring a great amount of time and energy (Martín-Gutiérrez, 2017).

Nevertheless, Technological integration requires teachers to open up flexibility for students to learn so that students are more confident in their ability. A teacher's beliefs of their positioning in a classroom need to be changed from an expert in the field, who provides the students with the knowledge, to a facilitator that guides students' actions to find the knowledge, and that he also believes that students could find, or be their source of knowledge (Kim, Kyu, Lee, Spector, & Demeester, 2013). This change in beliefs has taken place in teachers' education since Obiefuna & Offorma (2014) shows that pre-service teachers are more optimistic about mobile use in classrooms. Because of the prevalence of the technology, teachers start to adjust their perception of technology use in class so that the technology, such as mobile phone, could become an access point to great visualization tools instead of a distraction from learning the materials.

Section 2.5 Theoretical Framework

Most of the research done has based their research on either teachers' or students' perspectives, which lead to the imbalanced evaluation feedback for technology implementation. As a result, visualization technology could hardly be applied in the general classroom setting. To provide literature that will promote actual use of visualization technology tools in the classroom settings, this exploration analysis would like to take on Nardi & O'Day's (2000) information ecology framework to have a holistic view of the interactions between human and technology in the classroom setting.

In the information ecology concept, we need to consider the environmental factors as well as personal factors as interdependent. Elements in the system will change based on other elements' changes. With constant changes, there are still some keystones species in the ecology that remain in the system. In this research, the students and teachers are the primary species that are not absent from the system. Millennials, who have been emerged in digital media along with their growth into adulthood, are capable of learning through the internet for both learning and living. Thinking of the issues of digital use in classrooms, researchers have taken an ecology view of the context to better understand the interactions among different factors in play, consequently seeing a more holistic view of the current situation (Johri, Teo, Lo, Dufour, & Schram, 2014). In another word, considering an ecology as a system, then students and teachers are the two critical stakeholders for the product, visualization technology tools that researchers need to gather feedback from. Guiding with the framework, below is a visualization of the classroom ecology that this research will investigate on. The research questions are designed to investigate both environmental factors (RQ2) and personal factors (RQ1) following this theoretical framework.

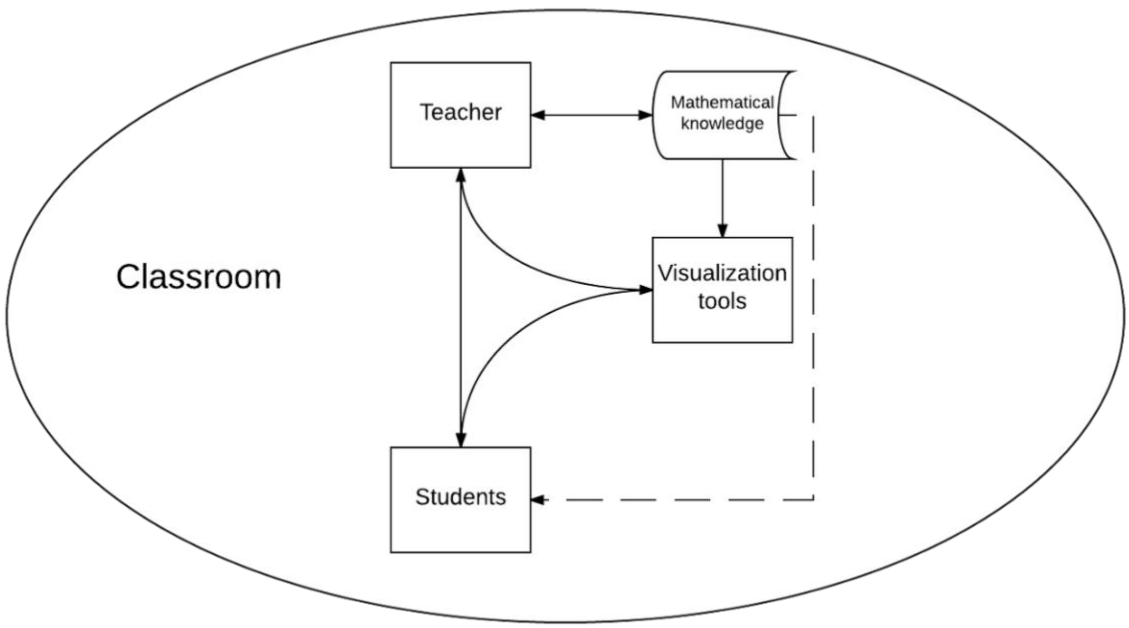

Figure 1 Researcher Identified Classroom Ecology

In all, there are two gaps in the prior works that this research has designed to fill in. For one, limited research has done on visualization technology in the context of secondary mathematics education, and the studies mostly analyzed the current tools' functionalities without further concluding on the crucial functions that visualization tools should have. Also, few studies have collected data from both stakeholders of the system, i.e., the students' and teachers' viewpoints. This research seeks for both teachers and students' perspectives to open up a possibility to integrate visualization technology tools into secondary mathematical education that would be beneficial to both parties.

CHAPTER 3 METHODOLOGY

As Creswell (2009) suggests, "Qualitative research is exploratory and is useful when the researcher does not know the important variables to examine." With limited earlier research done on the technology tools used for secondary mathematical learning and teaching in classroom settings, this research is by nature exploratory research. Thus, this research will incorporate in-depth interviews to gain insights from both teachers and students, and also include four class observations sessions to evaluate the current interactions happening in the classrooms.

Section 3.1 Data Collection

As a major qualitative data collection method, interviews allow researchers to gain deep insights from interviewees about the subject matter which quantitative research methods such as questionnaires or experiments can hardly gather. By asking follow-up questions, researchers can direct the interview to collect more information from interviewees about specific topics. Seeking to understand both teachers' and students' perspectives on the technology tools used in mathematics classrooms, the researcher interviewed mathematics professors and math major undergraduate students.

Even though the research could expand the sample representativeness by conducting virtual interviews with students and professors across the United States through Skype or Google Hangouts, the researcher would then lose a lot of non-verbal information with the interviewees including their body languages and their emotions, which is important for understanding interviewees' attitudes. Hence the research conducted face-to-face interviews. As a result, the research was only carried out in universities and colleges located in the North Carolina Research Triangle Park (RTP) area.

The interviews were conducted in common places that interviewees would be in for their daily life. Specifically, the interviews with mathematics professors took place in the professors' offices. And the interviews with the students were carried out in reserved library study rooms on campus. By interviewing in a somewhat natural setting for the interviewees, interviewees can be less anxious, which could be caused by being in unfamiliar locations.

However, since interviews are really subjective and interviewees may have bias when describing their current classroom education, the researcher conducted classroom observations to gain a more objective perspective about the current classroom education. Based on the interviews with teachers, the researcher asked teachers who had either strong teaching philosophy or innovative teaching tools for class observation. The researcher observed three classes, including Calculus of Functions of a Single Variable 1 class in UNC, Statistical Models class in WFU and an Introduction to Applied Mathematics in NCSU. The calculus class had around 110 students in a large auditorium setting hall. The instructor taught with iPad and Apple Pen. The statistical models class had about 40 students in a five-row lecture room and the instructor taught with projected slides and wrote on the whiteboard with markers on the side. And the applied mathematics class had around 18 students in a four-row classroom and the instructor taught with blackboard and chalk and then projected and talked through a relevant PowerPoint slide for another course.

The researcher conducted the interviews based on initial interview protocols for teachers (Appendix 1) and students (Appendix 2), and she observed the class noting down the frequencies of interactions in the class and so on following her observation guideline (Appendix 3). The teacher interview protocol has three sections, investigating the teaching motivation and goal, use of technological teaching tools, and teaching environment. Student interview protocol followed a similar fashion and break down into three sections, math learning background, math learning experiences and future envisioning for math learning aids. Rather than an inclusive of all the questions that the researcher asked and scenarios that researchers took notes on, the protocols and guideline showed the main questions and things that the researcher noted as useful to answer the research questions. In order to better analyze the interviews, the researcher used her phone to voice to record all the interviews.

Section 3.2 Interviewee Recruitment

The researcher first selected universities and colleges nearby to conduct teacher interviews. Then the researcher selected teacher interviewees based on mathematics department faculty websites in each university and college. Due to the limited information provided on the websites, the researcher consulted with her friends who are studying in the institutions and had taken a few math classes for interviewee recommendations as they would know more about the professors in their institution. The researcher sent emails to the selected teacher interviewees and scheduled one-hour interviews with the interviewees.

Since there is no public contact information online about undergraduates, who are math majors in any institutions, the researcher sent out student interviewee recruiting email through the department mailing list. The researcher chose to focus on the math major students as they are the group of students who take most math classes and are important stakeholders in the mathematics classroom ecology. To better incentivize students, the researcher compensated $10 cash for the thirty-minutes recorded interview to each student participant.

In total, the researcher interviewed 11 students, composed of six seniors, one junior, two sophomores and two first-year students, from University of North Carolina at Chapel Hill(UNC). And she also interviewed 13 teachers, including five professors, three associate professors, three assistant professors, one lecturer and one graduate student, from UNC, Duke University, North Carolina State University(NCSU), Wake Forest University(WFU) and High Point University. These were six male students, five female students, ten male teachers and three female teachers.

CHAPTER 4 ANALYSIS

The two data sources that the study bases on are the interview recordings and class observation notes. In the end, the researcher had over nineteen hours of recordings. For the sake of time, she used Temi, an online automatic transcription website to transcribe the voice recordings in bulk quantity. Then she revised the inaccurate transcription based on the voice recordings. After revision, she generated repeating themes and counted number of teachers who mentioned the themes. In the following section, the researcher will further present her interpretation of the data by answering the research questions:

RQ1. What are the visualization tools that math instructors and students use in class?

RQ2. What are characteristics of the mathematics classroom education's content and context that influences the selection of visualization tools?

RQ3. What are teachers' and students' behaviors and preferences that affect visualization tools' use?

Section 4.1 Visualization Tools Used in Math Classes

Visualization Teaching Tools

As stated by the teacher interviewees, most of the classrooms are equipped with blackboards or whiteboards, classroom computers that connect to projectors and portable screen. Sometimes the classrooms also have document cameras in the front of the classroom that could be used with projectors. The computers are connected to the internet and also external tools such as personal computer or tablets can connect to the classroom computer. With various tools available in the classroom, the teacher often first select blackboard as their teaching visualization tool. Based on the interview recordings, the study compares and contrasts the advantages and disadvantages of blackboard with other alternative tools.

visualizaiton tool	writing utensil	overhead projector	traditional use	learning curve	surface	Marker width	Length of content durability	use of colors	side product
blackboard	chalk	no	yes	low	rough	perfect	short	hard	chalk dust
whiteboard	marker	no	no	low	smooth	thick	short	easy	chemical smell
Doc Cam & paper	pen	yes	no	medium	perfect	perfect	long	medium	paper notes
Tablet & PDF editor	stylus	yes	no	high	smoother	adjustible	long	easy	digital notes
Touchscreen laptop & pdf editor	stylus	yes	no	high	smoother	adjustible	long	easy	digital notes
Smartboard	stylus or finger	yes	no	high	smooth	adjustible	short	hard	digital notes

Table 1. Comparisons among visualization teaching tools

Writing on the blackboard with chalk has been the teaching convention in mathematics classroom education for several reasons. First of all, this is how people taught in a classroom setting in the history and the instructors mostly learnt mathematics in a classroom by seeing their teacher writing with chalk on the slate blackboard, blackboards made of thin layer of black or dark grey slate stone. Hence, when the instructors start to teach, they follow their teachers' selection. Yet this tendency of following the tradition could be changing. Quite a few of the teacher interviewees said that they started to utilize other visualization tools, especially the digital visualization tools such like transparencies, document cameras since the nineties. And out of the thirteen teacher interviewees, there are two professors who use touchscreen laptops, tablets with stylus to teach and a few who are interested in trying to teach with tablets and stylus. Hence, their students are exposed to multiple visualization tools for teaching and the tradition will be adapted.

In addition to the historical reason, writing on the board can start right away and there is no need for learning how to use it. Comparing to the other electronic tools, blackboards and chalks are really intuitive to use as they are similar to pen and paper that people use to jot down things, except that people may write a bit differently on a vertical blackboard surface with a chalk than writing on the flat paper with a pen. Yet, in order to use other tools that involves projecting screen, the teacher needs to learn how to appropriately project things on the screen. For example, if they want to write on paper with a pen and project it using document camera, they need to know how to adjust the camera lens. If they want to show slides from their own computer, they need to have the compatible adapters that connect the computers. If they want to use tablets and a stylus to write electronically, they need to know how to set up the simultaneous wireless connection between the tablet and the class computer system before class. In other word, using blackboard and chalk doesn't require any learning curves for the teachers to use like other digital visualization tools do.

Writing on the whiteboards with markers doesn't require learning curves as well, yet a teacher interviewee who largely prefer to use blackboard claimed that there are fewer people allergic to the chalk dust than the pungent chemical smell of whiteboard markers. And a teacher interviewee who prefer whiteboard to blackboard, said that "I find that there's something very aesthetically unpleasing about tactile writing with chalk on the board, like it just gets in my nails and I really don't like it. Especially, the colored chalk is disgusting. It could really get into your soul." Even though he doesn't think the dust does much harm to him, he would rather use markers that doesn't create difficulties for him to maintain clean and tidy.

Besides the impact of side products, teachers also noted the different writing experience on different surfaces with different handholding utensils. The difference mostly is caused by the different level of frictions. The blackboard surface is generally rougher than the whiteboard surface and electronic surfaces such as a computer touchscreen and a table. Thus, writing on the blackboard has the 'inherent slowness' that paces lectures with an appropriate speed for students' learning.

What's more, teachers preferred the chalk mark width and fluency to other handholding utensils' mark width. The whiteboard markers usually have really thick writing marks that distort teachers' handwriting. And stylus usually can adjust the displaying mark width, yet stylus require fluent and accurate surface recognition for electronics, which isn't universally good across touchscreens and tablets.

Nonetheless, teachers also argue that there are downsides for using blackboard. For one, the writings on the blackboard will only exist for the short period in class, and students won't be able to see it after it is erased. If writing on paper and project it on to the overhead screen, teachers are able to later scan the notes and share the notes with students electronically. Or if the teacher writes on the electronics, he or she can immediately share it with students after class. Saving the writings electronically not only helps students to review and study, but it also helps teachers to read over when they teach the same class in the future and reduce the preparation time for the class. Teacher interviewees said that if they had the notes that they created in earlier semesters, they could usually finish preparing the typical one-hour long class in less than forty minutes, some as short as fifteen minutes.

In addition, among the interviewees, nine out of thirteen teachers agreed that because of the dark surface color, chalks on blackboard don't show colors as well as markers on the white board, not to mention the great colors shown on other high resolution digital screens. There are limited numbers of color chalks that are distinct enough for people to recognize as different colors. Hence teachers need to be careful about the number of different colors they want to use when they want to put different emphasis on concepts.

Though PowerPoint slides are the first visualization teaching tool that interviewees thought of other than blackboards and chalk, they generally disliked slides in math classes for that teachers could pace through the materials too fast. One teacher I interviewed said that she used PowerPoint slides at the beginning of a course, then in the middle of the semester, students complained that she went over the materials too quickly using the slides, and they could not have enough time to make sense of the material in class as they would have without the slides. After hearing the comment, she gave up on using slides and taught by writing notes on the blackboard using chalks and students did not complain about her teaching pace any more.

More importantly, they would not be able to see how the teacher developed the argument or the thought process to tackle a problem, which students would be able to learn how to understand and dissect a similar problem using the new concepts or logic.

Visualization Learning Tools

While teachers have a lot of visualization tools, such like Wolfram demonstration projects[1], Linear Algebra Toolkits[2], Geogebra library [3]and so on, to use for demonstrating concepts, students use relatively fewer learning tools in math classes – paper and pens. Just like one teacher interviewee said, "Our students are trained to take very good notes in class", most of the students would first take notes on things that the teacher writes on the board and then later review the notes when doing homework to further understand the material. In essence, students utilize their notes as a visualization to understand the material. While it is common for college students to take notes with laptops in class, relatively few students would do so in math classes.

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[1] http://demonstrations.wolfram.com/topics.html This is a collection of science, math, technology demonstration programs that individuals created and uploaded for others to use.

[2] http://www.math.odu.edu/~bogacki/cgi-bin/lat.cgi This is a collection of online linear algebra calculation toolkits that students or teachers could use to learn the concepts.

[3] https://www.geogebra.org/materials/ This is a collection of Geogebra online calculator based programs open for public to use for learning mathematics.

Below the research listed out advantages and disadvantages of visualization learning tools based on the students and teachers' interview transcripts.

tool	utensil	input speed	organization	correction	input method	other accessory
paper	pen	fast	hard	hard	handwrite	color, highlighter
paper	pencil	fast	medium	easy	handwrite	N/A
laptop	keyboard	slow	easy	easy	type	color, highlight, bold font
tablet	stylus	fast	easy	easy	handwrite	color, highlight, bold font

Table 2. Comparison among visualization learning tools

There are several ways that student interviewees have tried to take notes with computers. For one, students can type notes into computers. One student had tried to use laptops or phones to take notes, but he could not type as fast as he wrote and it was hard to put a plot in a word document, so he just used pen to take notes in a notebook. The other student used laptop to type up notes on Latex. However, it was really slow as well and she didn't do that anymore.

Both students mentioned that it was really slow to type notes, and the major reason is that mathematics notes usually involves Greek letters and it is really hard to line up equations from line to line in a short time. Mathematicians use Latex to type their research paper, but there's a really deep learning curve to learn Latex and students may not be able to type notes in the limited time that they have for the class.

When asked for whether one would like to take notes using stylus and tablet, students have different standings. One student said that, "I have not used tablet and stylus to take notes, but I feel like it is quicker to write on the computer and if I do it on paper, it'll take a little longer to write on paper because I think I have to push harder. But you barely had to hold the pen up to the computer, and I feel like, doing that, takes a little longer and I am going to spend more time on the material." The students emphasized that she would think through the material when she was taking notes, and the longer time that she could take to digest the notes, the better she would be able to learn. While a few other students said that they would "happy to try it out" because writing with a stylus on a tablet is similar to writing with a pen on paper notebooks.

Besides the speed of jotting down the notes would impact on their learning, students also use colors to organize their notes visually to facilitate their learning. Three of the interviewees mentioned that they would use different colored pens to separate definitions, corollaries, theorems and examples, or to separate different concepts. One student would use a pen to take down words that the teacher wrote, and then use a pencil to draw sketches for concepts and problems because pencil marks can be erased quickly and easily so that when he needs to review the notes, he would have an organized and clean sketch to help him visualize the problem setting or the concept.

Even though students and teachers both mention that they would acquire a textbook for the class, textbooks are not the primary visualization tool in class. Rather, students would use textbooks as a backup learning resource only when they could not understand the notes that they took in class or could not think of a way to solve the homework problem.

In all, blackboards, whiteboards, document cameras, slides, touchscreens with stylus were all visualization tools that teachers could use to teach in class, but each tool has their drawbacks and advantages. Blackboards are used as the mainstream teaching visualization tool, but teachers are trying out alternatives to compensate for the short endurance of blackboard notes, lack of color recognition, and generation of chalk dust. Students mostly write down organized notes with pens to help them understand and color-code the materials for the sake of faster speed comparing to type notes with computers.

Section 4.2 Environmental Factors That Influence the Use of Visualization Tools

As visualization tools can be seen as one new species in the classroom ecology, we want to investigate some environmental factors that influences the its interaction with other two key species, teachers and students.

Characteristics of Mathematics

First of all, the study would like to investigate how the subject matter, mathematics, influences on the visualization tools' design.

I. Misconception About Mathematics

For the general public, there is a misconception that "Math is typically presented as old, static and done a long time ago." In order to clarify the misconception, teachers need to introduce things that are unknown and introduce that there's still a lot to learn even by the most expert people. teachers could introduce these concepts by sparking students' interest in mathematics through attractive visualization tools.

There are a lot of online animated visualizations of specific concepts, such as GIFs of Fourier Series[4], different colored-dots falling to different event bars to show different conditional probabilities[5]. After seeing these in the interviews, professors were amazed to see the visualization demonstration of the specific concepts. And they said that they would try to show the visuals to students in class as the visualizations are innovative and fun to play with, teachers could try to bring those visualization into class demonstration to keep students engaged.

[4] https://math.stackexchange.com/questions/733754/visually-stunning-math-concepts-which-are-easy-to-explain The researcher showed these GIFs to interviewees and asked for their opinions.

[5] https://students.brown.edu/seeing-theory/compound-probability/index.html#section3 The researcher showed this to teacher interviewees to demonstrate the interactive visualization concept used in statistical learning.

Yet professors consider that these specific animated visualizations would not be the main part of the learning, as

> *"we are trying to see the forest of all mathematical ideas, and these visualizations, when built, are only for students to see the trees of very specific concepts."*
>
> *"It is always going to be narrow because I mean, you know, making a visualization tool, you gotta be very specific about what you're visualizing."*
>
> *"They are too specific and could only be seen as a side dish to the course, but the main dish should still be the teacher talking through concepts, students thinking through and connecting ideas."*

In other words, innovative visualization tools would be helpful to maintain students' engaging in the class and would be helpful for students to understand one or two specific theories or concepts, but they are not the level of abstraction that students need to have for all their mathematical knowledge.

Another way that would boost students' interest in mathematics is by building up their confidence in tackling math problems. As three professors mentioned that they would seldom have students to do exercise problems in class, and if they saw one student who got it correctly, they would have the student present his or her work to the class. One professor who uses an iPad to teach said that, "one nice thing about the iPad is that in my smaller classes like the first-year seminar, I can take the iPad and use as a camera and I can show, either by taking a picture or showing live of students' work by showing it in the projector. They can write on the iPad as well." In this way, students can engage with the material and feel that they are able to solve the problems, which encourage their studies in the subject. Hence, visualization tools like tablets with camera functions could assist to increase students' engagement in the class, which will in turn increase their understanding of the material and build their confidence in learning the material.

II. Procedural Development Presentation in Class

“I like teacher to write on the board because then I can see how the teacher’s thinking process like.”

“What I write on the board is like an example of how they could develop their arguments. I don’t want them only know the answer, but also know how to get to the answer.”

From both students and teachers, they all talked about showing procedural development for either proving a theory or approaching an applied real-life problem. And thus, teachers should be mindful of not giving away too much information at a time. Visualization tools like blackboards and whiteboards will constrain teachers from doing that because they can only write so much at a time, however for visualization tools like PowerPoint slides, the teacher needs to leave space for steps to be developed at the stage. What’s more, one teacher said that, “Giving away too much information would just spoil the fun.” As, students learning mathematics are learning the skill to solve new problems using meticulous logical arguments gained from existing concepts. Thus, visualization tools need to provide space for teachers to ad-hoc show their thinking process or logic flow so that students can develop their problem-solving strategies from teachers’ demonstration.

III. Students Learn Better By Struggling in Doing

“over the years I realized that the more a professor does in front of students, the less they learn. they need to do problems themselves, we cannot do things for them. It doesn't matter how nice you demonstrate on the board is. It's just like playing a musical instrument or learning a foreign language. If you don't speak it, you don't learn. It doesn't matter how well you can actually look at a French speaking person speaking the perfect language. You have to practice.”

Throughout the interviews, over half of the teachers agree that students can only learn well if they do the problems on their own and they need to experience the struggle in solving the problems to actually learn how to use the theories. But students are not necessarily doing it on their own, as one professor made an analogy to theory of scaffolding in childhood.

"scaffolding in early childhood. It's the same as with undergraduate and frankly is like, you know, you can't read for them, you can't write for them, but you start off by tracing the letters and having them trace them or you know, you do things like they read one page and I read one page or you correct them and let them stumble."

And the way that the professor said how he taught following this theory, is that he tried to do minimal amount of how to do certain things or how to understand certain concepts, and then had the students to do something and then generated questions. In this way, students would learn through some self-exploration, which is necessary when they are solving new problems that they have never seen before.

Another reason why teachers would create more time for students to doing something is class is that, students are not always very good at admitting to themselves or knowing right away that they don't understand something. And by doing a problem, they would be able to see their actually level of understanding. As students also reported that they only knew how well they learned when they did the homework problems. And they learned the most from doing the problems, as another professor said, "By doing problems or creating proofs, students would be able to see where they stumble and ask the right question to understand the process of tackling problem."

In essence, teacher should create little momentum by providing the bare minimum for use of the concepts, and then students need to spend time on struggling and finding ways to use the new concepts to tackle a problem. By only showing limited the amount of information, neither teacher nor visualization tools should take away the thinking and struggling process from students.

After all, mathematics carries with a misconception, and teachers need to disprove it, which could be done by engaging students to learn better in the class. Students need to learn how to develop the thinking process, thus teachers need to show the procedural of argument developing rather than only providing one answer. By doing the problems and struggling on their own in class, students can explore and discover ways to develop their own arguments, which means that they actually understand how to use the concepts with higher self-confidence.

Characteristics of In-Person Classes

Besides some characteristics of mathematics education that influence the objectives of visualization tools, some characteristics of in-person classes also are environmental factors on the visualization tools, such as class size and in class time length.

For one, the class size influences how teachers interact with students, and visualization tools could help to facilitate. The larger the class gets, the hard it is for teacher to assess students' learning progress. And teachers may easily pace too fast and students are lost in the lecture and not able to learn the material. Some introduction classes would have more than 100 students in a class, where teacher can never interact with each individual student. With mass online question answering systems such as poll everywhere, teachers can see students' answers to the questions through the chart distribution or world cloud. In this way, the online system help teacher to visualize quickly visualize students' understanding level and decide on the next teaching step. In other words, for larger mathematics classes, teachers could pace the lecture better with some visualization of overall students' learning progress.

Another constraint for in-person class is that the class time is limited. As there are lots of materials and ways to demonstrate the ideas, teachers need to carefully select the teaching method and use the class time wisely. Particularly, teachers would like to have little to none time transitioning between visualization tools so that the class is more dedicated to learn the actual material rather than to learn how to work with the visualization tools. For example, if a teacher is using blackboard to teach and wants to show a graph in computer, he would either put up the graph at the beginning or the end of the class to avoid wasting time heating up the projectors or connecting different visualization tools to projectors. However, that may not be the best time to show the graphs for student to understand the concepts. Hence, visualization tools should try to incorporate multiple types of visualization, including sketches, graphics, animations in one place to save time for file transferring or alternation among tools so that the class time is better used.

To conclude, facing the time constraint, visualization tools should have a great capacity for various types of visualizations so that teachers can demonstrate the concepts with the most effective visualization for students while not wasting time on setting up the visualization tools. and for teaching in large classes, additional visualization tools for quick assessment of students' learning progress would be helpful for teachers to pace their teaching progress.

Section 4.3 Personal Factors That Impact Designs of Visualization Tools

In addition to environmental factors such as mathematics education characteristics and classroom characteristics, personal factors such as acceptance to typing or level of interaction would also influence how visualization tools should be designed.

<u>Typing is less achievable than handwriting</u>

While people nowadays type more than write, mathematics teachers still think that handwriting is better than typing for the class demonstration. Hence, new visualization tools in the context should be developed with good handwriting recognition technology so that teachers can easily write on the tools.

> *"Typing not only do I think it brings no value in this context, I think it's counterproductive because a student will look at this [class notes that I wrote] and see handwriting, handwriting, handwriting. And when students write up the homework, they are going to be handwriting, handwriting, handwriting and they'll see stuff that is achievable and thinking that they could do that. In a sense, I'm giving them a demonstration of what it is I'm expecting them to do. You look at these beautiful computers generated and see the shading and multiple colors on these figures and it's like, wow, it's like a photograph! I can't do that with my pencil. But I want students to look at that and be like, "Oh the teacher did it by hand, I can do that, too."*

The above example shows that the teacher would like to make the materials appear achievable for students by writing the notes. Even though this could be one reason, the vast majority of mathematics teachers would prefer handwriting because it is easier to do and taking less time to accomplish, especially when there are a lot of special mathematical characters that are not easy to type in the commonly used Word document.

<u>Crucial Human Interaction</u>

> *"I lecture at you, you take diligent notes, I give you homework problems, you go do problems without cheating or looking them up and you generate questions and you then come to office hours and ask. I think this is a paradigm a lot of professors will want it to be true, yet it is only true for very, very, very diligent students.*
>
> *Since professor's time is a precious resource, professor is thinking that the best use of their time is to lecture, but I think the best use of their time is making the dialogue with students about what's actually going on and the best way to provoke that is to have it happen in class."*

Comparing to online courses, in-person class education provides the invaluable chance for students to interact with the teacher to learn. Hence, visualization tools in the context should be developed to facilitate the interaction between teachers and students.

Teachers are able to assess students' understanding by asking conceptual questions and answering questions that students have, so the learning process is tailored to students' need. It works as teachers will need to answer fewer questions after class, and students don't need to spend long time on understanding a concept after class before they could use the concepts to do problems. However, students reported that they would hesitate in asking questions in class and would mostly try to understand the materials by going over the material again after class. To minimize the duration of unnecessary self-learning, visualization tools should break the barriers between people by building in functions to encourage or facilitate students to ask questions in class, especially in larger classes.

As discussed earlier, students are able to learn better by involving into the argument developing process or doing the problems in class. Teacher interviewees who create time for students to do problems in class usually walk around the class to help out individual students or peak at students' work over their shoulders to see where they get stuck. And in one class that I observed, the teacher wrote out the steps or side comments on the iPad as she walked around and helped out. And if she were using blackboards or document cameras, she would need to go to the front of the class and do so, which is not so convenient and flexible as portable tablets.

In addition, teachers preferred board writing than document cameras because "it feels static, less engaging, to sit at a place and write than standing in front of the board and write. Also, students are less focused when you are sitting down and writing." As teachers feel that teaching is more effective when they are standing than sitting, visualization tools should be able to allow teacher to write on the interface while standing.

Students don’t learn all material in class

Even though students try to pay attention to the teacher’s teaching, and to understand as much material as they can in class, it is actually not quite possible for students to learn all material in the class. Just like the student mentioned earlier on, when it takes longer time to write down the notes, she can spend more time on understanding the concepts. It takes time for the learning to happen, and even if the students can learn the materials right away, studies have shown the students will forget a lot of the materials if they don’t review it in a timely manner. As suggested by students, a recording of the class that documented teacher’s explanation along the notes will be helpful for students to review the materials without selecting valid sources online to understand the materials. In fact, the professor who teaches with a touchscreen and stylus actually record his screen and voice for every class, and he would upload it online after class so that students can watch part of the recording to understand the materials on their own pace.

In addition, as students admitted that they don’t always have long attention span and would zoom out for a short period of time during the lectures. Hence, students would like to have longer time to see previous steps that the teacher went over in class. As a result, visualization tools should be able to have enough space for large amount of information to be presented at a time so that the teacher doesn’t need to erase the previous information in order to find space and write further argument development. Alternatively, visualization tools should have functions to resize, tag previous written information so that it could be retrieved for comparing and contrasting similar concepts.

CHAPTER 5 CONCLUSION

Section 5.1 Implications and Contributions

In the study, we first compared current visualization tools used by teachers and students in secondary mathematics classroom education, then by analyzing the environmental and personal factors in the classroom ecology, we derived some functional requirements for future visualization tools:

Easy to set up for use in class

Easy element edits such as moving, copying, highlighting, erasing, resizing and tagging

Various color selection for color coding information

Easy transfer among people

Portable to use while standing

Generate records of in class activities for future use

Integrate different kinds of visualization in one place

Open to innovative visualization that can allow exploration

Section 5.2 Limitations and Future of Work

Even though the research is able to discover these useful design implications and requirement for visual tools, there are still places that need future work to validate and improve on. One limitation of this study is that interview participants were only recruited in North Carolina which may include regional biases. Future studies could duplicate the study design and recruit teachers and students from across the United States to compensate for the possible regional biases in this study.

Another limitation that is influenced by sample selection is that the interviewees mostly from research universities. Comparing to other types of secondary institutions, such as community colleges, liberal arts colleges, research universities are more focused on academia researching than professional developing. Thus, the study's result may not be true to other types of secondary institutions. To better understand the overall secondary mathematics classroom education in the United States, similar study design could be carried out in community colleges and compare and contrast the results with this study to gain a more holistic view across different types of secondary institutions.

Furthermore, even though the researcher emailed a few graduate students, generally the graduate students did not respond to participate in the study. Graduate students tend to be new to the teaching realm and they may have different preferences on visual tools from professors who have been teaching for over five years. Hence future studies that focus on the graduate students would be valuable for developing the future visualization tools as they will be the main users.

In addition, this study is a cross-sectional study that relied on short interviews which are largely dependent on the interviewees' subjective perspectives and limited to the specific time frame in a school semester. Hence, the study result may be validated by a longitudinal case study with one teacher in the future.

APPENDIX 1: TEACHER INTERVIEW PROTOCOL

Teaching motivation & goal

What's the ideal proportion for teaching, researching and servicing? Why?

What's your actual division of each part that is required by the department?

What's your teaching philosophy?

Have your earlier (teaching) experience influencing your teaching? How?

What are the typical courses you teach?

How long have you been teaching?

what's a typical flow of your class?

What do you expect students to do in class?

How do you evaluate students' performance? why do you choose these methods?

what do you expect students to gain from the class?

Use of tech teaching tool (presentation method)

What do you use for preparing the class? how long do you need to prepare for a class?

What materials and tools do you use for teaching the class?

Have you tried to use other tools to teach? What worked? What not? What are some implementation needed that you would continue on using those?

How would or should viz help to assist teaching/ improve student (conceptual) learning in class?

How's technology affecting the way you are preparing for the class?

How do you feel about using tablet, touchscreen laptop, white board, blackboard, smartboard, doc cam, slides to teach?

How do you balance conceptual learning and real-life problem solving?

How do you pick textbook for the class that you are going to teach?

Have you used any visualization tools to demonstrate or illustrate concepts? If so, where did you find it?

How do you feel about group work or collaboration among students?

What do you think of students' using tech/computer in class?

Teaching environment

Have you noticed changes in students or use of tech influencing your teaching?

If you are giving an advice to new phd student for teaching, what (type of) technology tools you may suggest? Why?

Has the classroom influence how you teach? If so, how teaching tools help mediate the influences?

What's an ideal classroom environment for you (class size, equipment)?

What are something that you wish to have in class?

If the department is able to provide free support on training or additional financing, what would you like to have? Why?

APPENDIX 2: STUDENT INTERVIEW PROTOCOL

Math learning background

What are some math classes that you have taken?

What made you decide to major in math?

Math learning experiences

Say you want to learn the content to 100%, how much do you learn before class, in class and after class?

What are some materials that you use to study a math class?

Recall your fav/ worst math class that you have had, what makes it enjoyable? Did teacher do anything different in the class?

Do you like group work with other students in math classes? why or why not?

How do you take your notes?

What do you usually take notes on?

Do you go to office hours? Why or why not? How frequent?

Do you use resources other than class notes, textbook? If so, what are they?

How do you use your textbook, if you have one? Do you have preference in printed or digital textbook?

What do you value the most in a math class?

Future envision for math learning aids

What are something that you wish to have that you think would help your learning?

If there's an opportunity to provide you with other learning tools for free, what would you like to have? What can you achieve by using these tools that current tools cannot?

APPENDIX 3: CLASS OBSERVATION GUIDELINES

In class, the researcher noted down:

Number of students' questions:

Class size

Tools student used

Number of group discussions/ talk around

Length of writing on the board by teacher

How the instructor used the demo tool

the class structures

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