Learning Mathematics with Graphing Calculator: A Study of Students' Experiences

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Abstract

Assumptions: Today, when technology has taken its place in almost all classrooms in schools and colleges across the country, there is a need to know how technology "influences the mathematics that is taught and enhances students' learning" (NCTM, 2000, p. 24).
Rationale: This presentation describes qualitative study which purpose was to understand the process of mathematics learning by high school graduates, recent Developmental mathematics students, in a technology rich environment.
Objectives: The study accesses students' beliefs about the use of graphing calculator (GC) TI-83 and describes students' experiences in learning mathematics with GC.
Theoretical framework: The reason for the major impact of electronic technology (ET) on the reform in mathematics education is its effect on the cognitive processes—nature of mathematical thinking and understanding (Heid, 1997). From this perspective, a concept of "cognitive technologies" is used to investigate the impact of technology on mathematics education. Among cognitive tools used in mathematics education are GC. They give students easy access to computational and graphical results (Heid, 1997). Studying the role of GC as a cognitive tool might concentrate on the ways in which students perceive GC as promoting conceptual understanding.
Techniques: Multi-case study of mathematics learning of high school graduates, recent Developmental Mathematics students at CCBC-Essex, presents one aspect—the role of GC as a cognitive tool.
Results: The presented qualitative study includes an analysis of students' experiences in learning mathematics with GC, as well as students' perceptions related to technology use for specific mathematics topics.
Conclusions: The implementing of GC as cognitive tools for mathematics learning is consistent with an emphasis of contemporary school mathematics and Developmental mathematics on the problem solving and modeling.
Summary:
This presentation describes qualitative study which purpose was to understand the process of mathematics learning by high school graduates, recent Developmental Mathematics students, in a technology rich environment. The study accesses students' beliefs about the use of graphing calculator (GC) TI-83 and describes students' experiences in learning mathematics with GC.

Conceptual Framework

Focus of the Research and its Purpose

Today, technology has taken its place in almost all classrooms in schools and colleges across the country. In the Principles and Standards for School Mathematics, NCTM noted that "technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning" (NCTM, 2000). A position statement of the National Council of Teachers of Mathematics (NCTM) on the use of calculators strongly urged that calculator usage be promoted by school districts, teachers at every level, authors, and educators (NCTM, 1998). In view of NCTM's position on use of electronic technology (ET), there is a need to know how ET "influences the mathematics that is taught and enhances students' learning" (NCTM, 2000).

The purpose of this study is to understand the process of mathematics learning in a technology rich environment by high school students. This study accesses the feelings of the students toward the use of a graphing calculator (GC) TI-83 and describes their experiences in learning mathematics with a calculator.

Significance of the Research--it's Framing in the Larger Theoretical, Policy, Social or Practical Context

The use of ET as a cognitive tool. With an availability of ET since the late 1980s, mathematics education has undergone a great change. Technology has been an important part of this change (Heid, 1997). According to Heid, the reason for the major impact of technology on the reform in mathematics education is its effect on the cognitive processes—nature of mathematical thinking and understanding. From this perspective, a concept of “cognitive technologies” is used to investigate the impact of GC on mathematics education. “Cognitive technologies” are defined as media that help “transcend the limitations of the mind…in thinking, learning, and problem-solving activities” (Pea, 1987, p. 9).

In mathematics education, reform occurs in algebra and calculus. In algebra reform, the concept of function was emphasized. The computer tools are used to move students from procedural knowledge to conceptual understanding of functions (Heid, 1997). In calculus reform, along with reduction of computations and concentration on the concepts, the emphasis was made also on visualizing of the problem. As a result, the reform has produced the shift in pedagogical philosophy from behavioral to constructivist, from introverted learning to cooperative, with emphasis on conceptual understanding (Kulik, 2003). The reform has found its reflection in the NCTM’s Principles and Standards for School Mathematics (NCTM, 2000). This document deemphasizes computational skills and encourages use of calculators and computers. NCTM recommends the use of GC to complete routine computations in order to concentrate on conceptual understanding (NCTM, 2000). GC is also important from the constructivist view because it provides different models of multiple representations that help students to build conceptual connections.

Cognitive technologies differ in the purposes they are used for and in the structure and features of their interfaces (Heid 1997). Among cognitive tools used in mathematics education are graphing calculators (GC). They give students easy access to computational and graphical results. Graphing and symbolic calculators are defined as computers because they are programmable and perform many of the same functions as a computer.

Initial guiding questions

Some recommendations were given for research to move beyond effectiveness studies and address more fundamental questions about the actual processes of teaching, learning and thinking with GC, and how GC functions as a cognitive tool for learning (Ruthven, 1996; Berger, 1998). Thus, there is a need for research to move beyond reporting differences in outcomes with or without using calculators to explaining why these differences occur. In the view of this need, studying of the role of GC as a cognitive tool might concentrate on the ways in which students perceive GC as promoting conceptual understanding.

The described study includes an analysis of student experiences in learning mathematics with GC, as well as student perceptions related to technology use for specific mathematics topics. This study looks for answers to the following research questions:

- How do the students experience implementing of GC in mathematics classrooms?
- What are students' views of how GC enhanced conceptual understanding?
- What non-cognitive outcomes are achieved in mathematics learning with GC?

Forecast of the Literature to be Reviewed

Early research on calculator effectiveness. The early suggestion that mathematics should shift away from paper-and-pencil calculation to the use of digital calculators was supported in the research literature since the 1980s. Hembree and Dessart (1986) conducted a landmark study on the effects of calculators being used in school mathematics. This meta-analysis integrated the findings of 79 studies on the effects of calculators on student achievement and attitude in pre-college mathematics. Two factors had affected the performance of students in classes taught with and without calculators: (1) the allowance or not of the calculator during the outcome tests, and (2) types of the tests—on computations (basic operational skill) or on conceptual understanding (problem-solving). Hembree and Dessart (1986) found that calculator use during instruction does not hold back computational skills and conceptual understanding; furthermore, it increases outcome results on non-calculator tests, both computational and conceptual. Although this effect was negligible, it supported the assumption of the positive effect of calculator use on the cognitive processes. The opportunity to concentrate on concept learning opened the door for wide use of calculators and computer technologies in mathematics classrooms.

Today, calculators are widely used in the teaching of mathematics. In recent meta-analysis of findings from 54 research studies, Ellington (2003) concluded that when calculators are used in instruction and assessment, the operational skills, computational skills, skills necessary to understand mathematical concepts, and problem-solving skills are improved.

Graphing calculators. Algebraic graphing tools transform data from either tabular or equation format into graphic representation. In mathematics classrooms at all levels, programmable GC are becoming common. The use of GC was specifically recommended by the NCTM in Curriculum and Evaluation Standards (NCTM, 1989). NCTM (1989) suggested that GC should be used to facilitate student understanding by a multiple representation approach to functions (tables, graphs, symbolic expressions, and real-world modeling).

GC can also improve problem solving (Dick, 1992). According to Dick, the following are some examples of how graphing technology assists with problem solving:

- Graphing technology frees up time for instruction by reducing attention to algebraic manipulation.
- It supplies more tools for problem solving especially useful for students with weaker algebraic skill.
- Students perceive problem solving differently when they are free from numerical and algebraic computations to concentrate on problem set up and analyzing solutions (Dick, 1992).

Methodology

Rationale for the Use of Qualitative Methodology in the Investigation of the Issue

A methodology is a model entailing the theoretical principles and frameworks that provide the guidelines for conducting research (Bogdan & Biklen, 2003). Recommendations were given to move research beyond effectiveness studies so as to address more fundamental questions about the actual processes of teaching, learning, and thinking with graphing calculators (GC), and how GC functions as a tool for learning—as a cognitive tool (Ruthven, 1996; Berger, 1998). Taking these recommendations into consideration, researchers need to move from quantitative to qualitative methodology. A move to qualitative methodology is based on a paradigm shift in philosophy.

A paradigm is a set of propositions that explains how the world is perceived (Bogdan & Biklen, 2003). Positivist tradition in education holds that the world is only knowable through controlled experimental inquiry. Prevailing in today's philosophy, post-positivist thinking has claimed that what goes on in the classroom is too complex to understand and predict using experimental methods. Interpretive research is recognized as one of the most effective ways to consider and study complexity. Recently, in educational research, paradigm shift has occurred from positivism toward constructivism. This paradigm shift guides the researcher’s choice of qualitative methodology.

Characteristics of qualitative methods. Qualitative research attempts to study naturally occurring phenomena in all their complexity (Bogdan & Biklen, 2003). Qualitative methodology adopts a subjective perception of reality, employs a value-bound, naturalistic type of inquiry, and is inductive. Its central principles are openness, the process-nature of the research and the object, reflexivity of the object and analysis, and explication and flexibility (Bogdan & Biklen, 2003). In qualitative research, the researcher sees reality as subjective and problematic, is active and close to the participants, and explains human action in non-deterministic terms.

How characteristics are appropriate to the specifics of the investigation. A criterion for the choice of methodology is purposefulness. The purpose of this study is investigating the role of GC as a cognitive tool. Learning processes in a technology rich environment have deep psychological roots. I think that a qualitative study is most appropriate for the research questions because they appear to be rather complex and not easily revealed through statistical figures. Adequate description of the learning processes requires researcher’s dialogue with participants and, if time permitted, researcher’s observation of participants in the context of the environment. Within qualitative methodology, I selected multi-case study design because it seemed to suit my inquiry best. I wanted to include several representative cases. If a study includes more than one case, it can use multi-case design. According to Bogdan and Biklen (2003), multi-case design is substantive in nature.

Identification and justification of the particular genre for qualitative research

The paper presents one aspect of a case study of high school students—the role of GC as a cognitive tool. The presented study is qualitative in nature. It can be best implemented using multi-case design. A case study is an in-depth investigation of an individual, group, or institution to determine the variables, and relationship among the variables, influencing the current behavior or status of the subject of the study (Bogdan & Biklen, 2003).

In order to implement the proposed design, the researcher should select a method, a tool or an instrument employed to collect and to analyze data. The method selected is in-depth interviewing with a number of open-ended questions. The respondents were interviewed two times for approximately 30 minutes. A semi-structured interview schedule has been developed and was used to obtain students' views on the role of GC in learning of mathematics. The interviews were audio taped and transcribed in preparation for later analysis. First round analysis of the preliminary interviews has lead to follow-up in-depth interviews.

The questions in the student interview were grouped into five sections: (1) students' attitude towards mathematics; extent of students' use of GC; (2) effect of GC on students' skills, their enjoyment and understanding of mathematics; (3) features of GC used in lessons and their relative importance; (4) the teacher's use of GC; (5) general summary of the role of GC.

Data from interviews with students were analyzed from the following perspectives: (1) the opportunities offered during the lessons for the use of GC as a cognitive tool to promote conceptual understanding versus procedural competence; (2) the opportunities for the use of GC for students' investigation; (3) students' views of how GC enhanced conceptual understanding; (4) the difficulties that students encountered in practice with GC. The results were expected to provide insights into ways in which students perceive the role of GC as promoting conceptual understanding.

Data Collection

Respondents' Selection

Weiss (1994) gives several methods of sample selection specifically for researchers using interviewing as a means for data collection. One of the techniques involves *samples that attempt to maximize range.* This strategy seeks to find as many different kinds of experiences as possible within a given population. Instead of selecting respondents randomly, the researcher try to find people who can give different points of view from one another and try to avoid duplication of the same stories. He/she may also choose cases that meet some criterion.

Since the presented study is one of small scale, in choosing the respondents, I felt important that a range of views be sought, and some criteria present. The main criteria were that the respondents have had experiences working with GC in mathematics lessons, were familiar with the functions of GC, and were reasonably knowledgeable regarding the uses of GC.

Two girls, high school graduates, who have agreed to participate in the study, were selected for individual interviews focusing on their perceptions of the effects of GC use. The researcher's next task was to actually collect the data by conducting interviews with the respondents.

Nature of Interviewing

Interviewing is one of the techniques utilized in qualitative research. Weiss (1994) defines interviewing as a conversation with a purpose to gather information. One of the cases when this technique is appropriate and useful is when a depth of understanding is required (Rubin & Rubin, 1995). Weiss (1994) believes that the qualitative approach of interviewing gives researchers, and eventually readers, a more complete picture of the perspective of the subjects of the study. He sees interviewing as especially important means for data collection: "…interviewing gives us a window on the past. We can also, by interviewing, learn about settings that would otherwise be closed to us…" (p. 1).

Interviews can be structured, unstructured, or semi-structured. Rubin and Rubin (1995) refer to this as the family of qualitative interviews. In a semi-structured approach, a number of predetermined questions and/or topics are presented to the subjects. It is important to process the types of questions the researcher wants to ask and the types of responses the researcher might receive. This approach guides the researcher in developing the questions to be asked and in determining the type of interviewing format to implement (Weiss, 1994). Interviewing format implemented in the study was semi-structured.

Questions for the study were open-ended that gave the possibility to discuss the topic. In interviewing, it is important to remember that the respondent has been chosen because he/she has some insight to offer, so the questions chosen should allow him/her to speak about their experiences (Weiss, 1994). According to Weiss, it is equally important to never interrupt an interview and not to press the respondent to answer the question more fully. As a novice researcher, I did not always follow these recommendations. However, I had directed the conversation to the topics covered by the question guide. (The list of guiding open-ended questions for the semi-structured interview is given in Appendix A).

Occasionally, it was also necessary to use probing questions for respondents to give more details. I did ask follow-up questions, when I needed clarification on a point that was made. Probing questions were often successful in helping respondents to further develop their answers. Probing questions allowed the researcher to explore emerging themes and to confirm hypotheses (Merriam, 1998).

In the beginning of the interview, I engaged in small talk with the interviewee in order to allow her to be comfortable. After I discussed the purpose of the study, I asked whether she is ready the tape recorder to be turned on. In the end of the interview, I thanked her for sharing with me her experiences and turned the tape recorder off.

The role of the researcher as an instrument. In a qualitative study, the researcher is the primary instrument for gathering and analyzing data. He/she responds to the situation by making the best use of opportunities for collecting and producing meaningful information. However, mistakes could be made, opportunities could be missed, and personal biases could interfere. The role of the researcher as the instrument is limited because the instrument is a human being. Therefore, the researcher could influence the validity and reliability of the research study.

The researcher must also do “bracketing” or his/ her biases brought to qualitative research. Because the primary instrument is a human being, all observations and analyses are interpreted from his/her philosophy, values and perspective. It is important to remember that one of the philosophical assumptions underlying qualitative research is that reality is not objective. Rather, there are multiple interpretations of reality. The researcher brings a construction of reality to the situation, with other people's constructions or interpretations of the subject being studied. The final product is another interpretation by the researcher of others' views filtered through his/ her own.

Data

The data of the study are the interviews with two purposefully selected participants. To establish validity for the interviews, each interview was audio recorded and later transcribed. The transcriptions were shown to the participants to validate their statements (Merriam, 1998). In the transcripts, the participants were assigned letters to protect their identity; thus, a letter in the text or in brackets refers to a unique individual. Samples of the interview transcriptions are given in Appendices 3 and 4.

The data from the two case studies are analyzed, synthesized and claims are presented. The analysis of relevant portions of the data from these sources, synthesis, and findings are described in the next sections.

Data Analysis

Analysis. The qualitative analysis was used to organize the data from the interviews. Data sets were analyzed and reported following Creswell's (1998) procedures:

1. Organization of data. The interviews were recorded and transcribed, to check for accuracy. The text was then loaded into tables.
2. Categorization of data. The data were clustered into meaningful groups (coded).

3. Interpretation of the data. Statements that fell into like codes were examined for specific meanings in relationship to the purpose of the study.
4. Identification of patterns. The data and their interpretations were examined for themes and patterns that characterized the study and allowed the researcher to draw conclusions.

Overall, eighteen codes were created from the representation of participants' responses.

Synthesis. A total of seven themes or categories emerged from the analysis of the transcripts: (a) enjoyment of mathematics; (b) mathematical skills; (c) conceptual understanding; (d) purposes for which the GC was used; (e) usefulness of GC in mathematics learning; (f) the effect on thinking; (g) and learning to use GC.

The list of the themes with initial codes is given in Appendix B. The section below draws on most of these themes.

Findings

The following conclusions were drawn based on the data presented.

(1) Students' perceptions of the effect of GC use on their enjoyment of mathematics (codes **LT**--Takes Less Time; **ME**--Makes Easier).

Participants indicated that they enjoyed mathematics more when the GC was used. Two main reasons emerged from their responses: (1) using GC makes easier doing mathematics by removing lengthy calculations and other demanding mathematical tasks, and (2) using the calculator takes less time.

Result shows that girls believed that using GC makes easier doing mathematics. For example, J. stated:

> I think it [using graphic calculators] makes it [learning mathematics] a lot easier, specifically the graphing…To me, it [learning mathematics] would find it more difficult without using a calculator. Because I have been using it for so long that I got used to it…was excited about it, and about trying new things. I felt comfortable with it, like I said as soon as I started to use it, I understood it. (J., IntJ, p. 1)

C. stated that: “I think graphing is much easier with a calculator because you just plug it in and you get it.” (C., IntC, p. 2)

Participants also mentioned the time factor. For example, C. stated that:

> It’s [doing more problems using a GC] a lot faster, like if you have a page of things, as opposed to doing it by hand, you can get a lot more done, quicker… A lot of kids choose to use it [GC] because it’s a time saver. It doesn’t require that much as hand-written does. (C., IntC, p. 2)

J. stated that: “…it takes less time to write it all out, going through each process, where just typing it in is faster.” (J., IntJ, p.1)

(2) Students’ perceptions of the effect of GC use on mathematical skills (codes **US**--Unused Skills, **NS**--Neutral on Skills).

Participants were asked their views on the effect of GC on mathematical skills. J. did not believe that the use of GC had affected mathematical skills negatively, as can be seen from J.’s comment below: “I leaned more toward the calculator, but I use both ways.” (J., IntJ, p. 2)

On the other hand, C. believed that with the constant use of GC, some mathematical skills were unused and then forgotten. According to C.:

> You mean by using a calculator you lose you basic skills? Yes, that’s harder for me to remember, like multiplying, cause you’re so used to plugging it in, and doing multiple things, you can lose the basic skills of what you have learned in the past. (C,IntC, p.2)

(3) Students’ perceptions of the effect of GC use on their understanding of mathematical concepts (codes **VT**--Visualization Tool; **EC--**Exploring Concepts).

In addition to being asked about the effect of the calculator on mathematical skills, subjects were also asked their views on the effect on their understanding of mathematical concepts. Participants recognized the two ways in which they identified GC use as enhancing their understanding of mathematical concepts: (1) as a visualization tool (2) and for exploring concepts.

C. considered the calculator helpful in her understanding of concepts because of her access to graphical aspects: “I think [skills learned in using a GC were] graphing, finding intercepts, X, Y, um, like the boundaries… Somewhat I learn about functions when using GC.” (C., IntC, p. 2)

J. mentioned an example of how her use of GC helped her explore statistics.

> There were problems for different concepts… Whenever they [teachers] would introduce a new concept, they would have an overhead projector…Like finding the mean, median, and mode. Like you would enter the list of numbers and then she would show you each step to find the mean, median, and mode, it’s hard to explain. (J., IntJ, p.2)

J’s last comment shows that she also found it easier to visualize things with the calculator’s graphic displays. C. also gave an indication that her use of GC makes her more likely to try different methods and approaches. C. stated: “Like um, by using it [GC] makes me what to do new things with it? Yeah, it depends on what I’m doing to.” (C., IntC, p. 3)

(4) Uses of GC as reported by the students (codes **AR**--All Round tool; **PS**--Problem Solving tool; **TD**--Teacher Demo tool; **HO**--Homework/Other).

Participants recognized the four purposes for which the GC was used as the following: (1) all round tool; (2) problem solving tool; (3) teacher demo tool; (4) homework/other. They commented on the use of the calculator as an “all round” tool—

for example, to draw graphs, carry out simple calculations, finding the mean, median, and mode by entering the list of numbers.

Girls also mentioned use of GC in solving problems, where the distinction was made between complex (problem solving) and less complex (all round) purposes. J. gave an example of complex—problem—solving use of GC:

> …in calculus … we were given a list in the beginning of the year of applied problems to real life and he [teacher] just kind of let us go our way in the beginning and see what we knew with the calculator to test our abilities. (J., IntJ, p. 2)

C. gave an example of less complex—all round—use of GC:

> In my math class we had to do things like go shopping to be able to multiply and add and we had a certain budget to work from and we had to see how much we had left in the end and just working with it to compute different things. (C., IntC, p. 2)

Participants were also asked how their teacher used the GC. Girls mentioned that the teacher used the calculator, with an overhead projector, primarily for demonstration. For example, J. stated that:

> Whenever they [teachers] would introduce a new concept, they would have an overhead projector where you could see the numbers on the calculator, and everyone could see every step and everyone could follow, and then she'd make rounds through the room and make sure everyone is at the same spot. And then, that's how she would introduce it. (J., IntJ, p.)

(5) Students' views on the usefulness of GC in mathematics learning (codes **HI**--by Hand is Important; **HF**--learn by Hand First; **UF**--UseFul in learning; **NU**--NonUseful in learning).

A theme emerging from some of the responses of the participants concerning the usefulness of GC was the need to do mathematics without calculators. These comments were probed further in the interviews as they relate directly to current calculator issues regarding dependency and deskilling.

C. commented that: “It’s useful, but it’s not, say they [students] don’t have it, they need to know how to do it both ways, on how to do it on paper and how to do it on a calculator.” (C., IntC, p. 1)

(6) Students’ views on the effect of GC on thinking (codes **AT**--Affects Thinking (neg); **ET**--Enhances Thinking (pos)).

It is clear from C’s opinion that, as a consequence of calculator use, students were not able to think enough. It appears that, although she enjoyed doing mathematics with the calculator and found it very useful, she associate understanding with doing tasks manually.

> …I choose to do it by hand. It helps me to understand what I’m doing better rather than plugging into a computer basically and getting an answer. I like to see step by step of how I get what I get, if something goes wrong, I can see where I went wrong…Some of the kids just want the easier way out, of just being able to have things done quicker, instead of having a step by step process, and some teachers want to show how you do each step, and other kids just want to plug it right in and not have to show the steps, just show the answer itself. (C., IntC, p. 3)

J. appeared to take a positive position, answering positively on the question whether her ability to learn mathematics was enhanced with the calculator.

Validity and Reliability

To ensure the trustworthiness of the findings of the research, the validity and reliability should be discussed. Qualitative researchers are concerned about the reliability and validity of their research. Reliability refers to the extent to which research findings can be replicated.

Validity is concerned with the extent to which the research findings correspond to reality (Merriam, 2001). The strategies used to check the validity of qualitative research can also serve the double purpose of checking its reliability (Merriam, 2001).

Merriam (2001) listed several basic strategies to enhance the internal validity of a qualitative research study. One strategy is triangulation, using multiple means by which data is collected. Examples include using co-researchers and multiple sources for data collection. Another strategy is to check with the group that was interviewed and ask if the interpretation is correct; this process is recursive. One more strategy clarifies the researcher's bias. This involves clarifying the researcher's assumptions, world-view, and theoretical orientation at the beginning of the study. To validate the findings, the interview transcriptions were shown to the participants.

Summary

The analysis of participants' interviews shows that the use of GC in mathematics class was perceived to affect students' enjoyment of mathematics, mathematical skills, and conceptual understanding. The following is the summary of what was found out about the issue with connection to research questions.

(1) How do the students experience implementing of GC in mathematics classrooms?

Participants saw the GC as an all-around tool that can be used in most mathematical topics. They went further, saying that they also used the GC as a tool for problem solving.

(2) What are students' views of how GC enhanced conceptual understanding?

In terms of conceptual understanding, participants indicated two ways (visualization, exploration) in which GC use had helped them understand some concepts.

C. was concerned about students' calculator dependency and consequent deskilling. She said that always using the calculators in tasks negatively affected students' mathematical skills (e.g. mental computational). On the other hand, J. claimed that her ability to learn mathematics was enhanced with the calculator. Participants felt it valuable to "do things by hand" more often, which they presumed would make them think more and so learn better.

(3) What non-cognitive outcomes are achieved in mathematics learning with GC? Participants claimed they enjoyed mathematics more, primarily because GC reduced the time consuming nature of certain mathematical tasks (e.g. drawing graphs).

Conclusions

While participants identified ways in which GC enhanced their conceptual understanding, they were also concerned about deskilling effects of calculator use. This raises the issue of the role of exercising basic mathematical skills in achieving the goals of school mathematics. On the one hand, in light of technologies that preclude the need for certain mathematical skills, it would seem irrational for modern mathematics to invest heavily in the development and practice of such skills. An alternative focus is the interpretation and "making sense" of potential mathematical situations, rather than students exercising basic skills in accomplishing monotonous tasks. The implementing of GC as cognitive tools is consistent with an emphasis of contemporary school mathematics on the problem solving and modeling.

Reflections

Overall, experiences from this study gave rich insight into qualitative research. After this study, I am ready for the paradigm shift in my philosophy. With this experience, I understand better the assumptions underlying qualitative research that reality is holistic, multidimensional, and ever changing. I did learn that it is not a single, fixed, objective phenomenon waiting to be discovered, observed, and measured as in quantitative research.

Appendix A

Guiding questions for the interview

1. What do you think about the computing power of graphic calculator (GC)? Does it make it easier to explore mathematical ideas?
2. What experiences did you have in using GC in mathematics learning?
3. What experience do you recall in using GC for real-life problem in math classes?
4. How often can you use GC outside the classroom or in real life?
5. Do your teachers use GC on a regular basis in every class?
6. What do you think about students' attitudes toward using GC; did you recognize who wanted to use it and who didn't? Can you compare the attitudes of these students?
7. What difficulties do students encounter when using GC?

What types of problems were included in your math tests: the testing of concepts and the usefulness of the calculator, or were you tested on your ability to use GC?

Appendix B

List of themes with initial codes

(1) Students' perceptions of the effect of GC use on their enjoyment of mathematics

Code	Meaning
LT	Takes Less Time
ME	Makes Easier

(2) Students' perceptions of the effect of GC use on mathematical skills

Code	Meaning
US	Unused Skills
NS	Neutral on Skills

(3) Students' perceptions of the effect of GC use on their understanding of mathematical concepts

Code	Meaning
VT	Visualization Tool
EC	Exploring Concepts

(4) Uses of GC as reported by the students

Code	Meaning
AR	All Round tool
PS	Problem Solving tool
TD	Teacher Demo tool
HO	Homework / Other

(5) *Students' views on the usefulness of GC in mathematics learning*

HI	by Hand is Important
HF	learn by Hand First
UF	UseFul in learning
NU	NonUseful in learning

(6) Students' views on the effect of GC on thinking

Code	Meaning
AT	Affects Thinking (neg)
ET	Enhances Thinking (pos)

(7) *Students' experiences of learning to use GC*

Code	Meaning
EF	Exciting Feelings
CF	Confusing Feelings

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