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The experiential modification of a computer software package for graphing algebraic functions

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Graphing software and graphics calculators are widely used in most of the world's larger economies to facilitate students' development of conceptual understanding of mathematical function analysis. This has proved to be an extremely effective vehicle in making complex mathematics more accessible to the majority of learners. In contrast, its use in South Africa has been limited. Possible reasons may be the cost of graphics calculators, limited availability of supporting study material, and teachers who lack the necessary skills and confidence. At the School of Teacher Training, University of Pretoria, the Master Grapher for Windows was introduced by way of a pilot study in an effort to adapt the training of mathematics teachers-in-training to meet the specific needs of these students. The experiences of five students were monitored. The aim is to enhance and facilitate trainee-teachers' understanding of mathematics, but also to equip them to develop learner-centred, group-based learning experiences in future teaching situations. Action research was implemented to develop the course.

Introduction

The concept of function is a fundamental unifying idea in mathematics. A function is represented by a written statement, an algebraic formula, a table of input-output values, or a graph. Students need to work with these representations in order to gain experience and develop an intuitive understanding of functions (Boughlaghem, Wilson, Beachem & Sher, 2002).

Research has shown that the connections students make between formulas, graphs, and tables are weak or non-existent. Students often view algebraic and graphing data as being independent of each other (Even, Lappan & Fitzgerald, 1988; Hennessy, Fung & Scanlon, 2001). Worse still, students fail to grasp the connection between graphing and the real world. The knowledge and skills they may acquire by means of systematically working through the textbook, chapter by chapter, remain unassimilated.

To address this problem (if only in part), strong pleas for the use of computer- and calculator-based graphing in the teaching and learning of mathematics began to appear in professional publications in the late 1980s. Today this practice is common in schools and universities around the world (Clutter, 1999; Mok, Johnson, Cheung & Lee, 2000). This is not yet the case in South African schools. Reasons include the cost of graphics calculators, limited availability of supporting study material and teachers who lack the necessary skills and confidence.

Researchers believe that technology has the potential for transforming traditional, teacher-centred classrooms into student-centred, collaborative classrooms and have reported that when technology is integrated into teacher education programmes, the instructional practices of teachers change (Rice, Wilson & Bagley, 2001). The implementation of mathematics practicals, where student teachers engage in mathematics aided by technology, is therefore a high priority.

The need for the study

In January 2001 the former Onderwyskollege Pretoria (College of Education Pretoria) was legally incorporated into the University of Pretoria and became part of the Faculty of Education under the name School of Teacher Training. As part of the incorporation agreement, the Faculty of Education relocated to the former College campus in October 2001, which then became known as the Groenkloof campus of the University of Pretoria. Two of the advantages of this incorporation were

- the establishment of a modern, well-equipped computer centre at the former college campus, and
- permission to use the Master Grapher for Windows program with its supporting study material, developed by Greybe, Steyn and Kerr (1998) at the main campus, University of Pretoria, for mathematics students pursuing a scientific career. This program has been used with great success in the Gold Fields Computer Centre for several years (Steyn, 1998).

Student teachers from the Faculty of Education following academic mathematics courses at the University of Pretoria have the following options:

- The regular mathematics courses on the main campus;
- a specialised course at the Groenkloof campus aimed at training teachers in mathematics for Grades 8–12;
- a specialised course at the Groenkloof campus aimed at training teachers in mathematics for Grades 4–7.

Most of the students taking mathematics at the Groenkloof campus do not qualify, because of their unsatisfactory school results, for admission to the regular mathematics courses at the main campus, nor do they wish to do so. Since these students' focus is on a teaching career, mathematics practicals were introduced for students taking the above specialised courses at the Groenkloof campus, making use of the Master Grapher for Windows from the beginning of 2002. A tutor trained at the Gold Fields Centre at the main campus presented this course.

Purpose of the study

In spite of the fact that the excellent quality and applicability of the program have been verified by experience and research (Steyn, 1998), we became aware that a significant percentage of the students appeared disillusioned with the mathematics practicals. Given the possible influence of their experience in the mathematics practicals on the way they could think about and approach their own teaching in mathematics, the necessity of adapting the practical course to a more acceptable format to suit the needs of our particular students became clear. Guzman (2000) maintains that while numbers can uncover a trend, the use of qualitative observations may help to explain why certain trends exist and suggest strategies to circumvent or change these trends. Acting upon the truth of this statement, a decision was made to undertake a qualitative action research study that would explore the students' experiences, focusing on their attitudes.

Aims of the study

The primary aim of this study was to conduct a pilot study aimed at enhancing the understanding of the algebraic and graphical concepts of function by a sample of mathematics trainee teachers at the University of Pretoria's School of Teacher Training. Secondary aims included preliminary investigating guidelines for adapting our mathematics practical course to a format more suited to the needs of our trainee mathematics teachers.

Research questions

In our attempt to investigate the question formulated above, the fol-

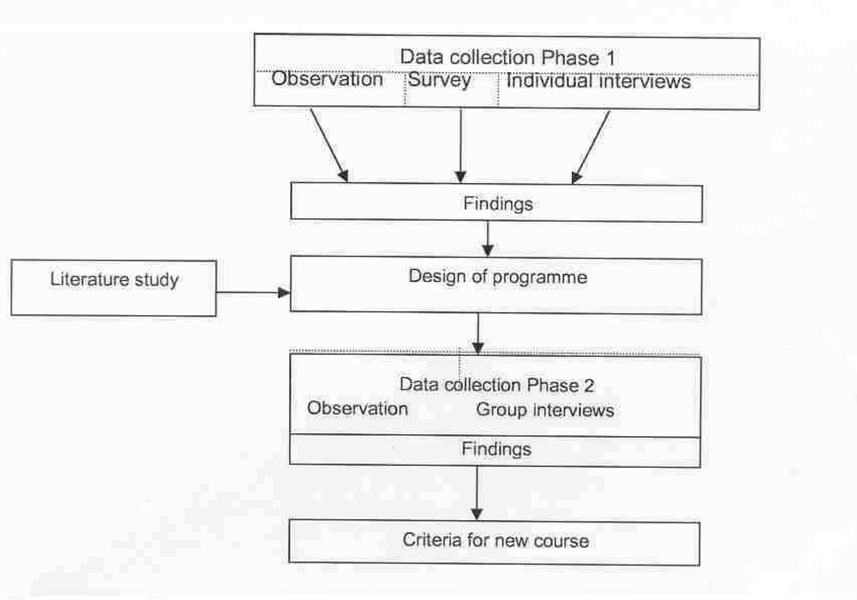

Figure 1 Research strategy

lowing secondary questions were considered:

- What are the reported and observed experiences of five pre-selected student teachers-in-training when using the pre-packaged Master Grapher for Windows course in their practical mathematics programme?
- What are the reported and observed experiences of the same five students in a follow-up study when they are using a suitably modified and adapted version of the Master Grapher for Windows course in their on-going practical mathematics programme?

Background study

Frequent pleas are made for a more creative, enjoyable, playful approach to the learning and teaching of mathematics (Flannery & Flannery, 2000; Hoyles, 2001; Sinclair, 2001). It is important that the environment must be psychologically stimulating in order to capture learners' interest (Polaki & Nenty, 2001) and to provide an incentive for concentrating sufficiently (Devlin, 2000). Our focus group perceived that the handling of the mathematics practicals was "*dry*" and even "*dusty*". Studies indicated the potential of elevating mathematical thinking in a technology-enriched environment by providing good motivation and opportunities to work in an open-ended way (Mok *et al*., 2000). The need for programs to be accessible, portable, and inexpensive is pointed out (Boughlaghem *et al*., 2002). A private copy of Master Grapher was inaccessible to our focus group, despite their need and desire for such a copy. Access to technology does not in itself promise any miracles. Several provisos were mentioned: the users of technology must appreciate what they wish to accomplish and how the technology may help them; the technology must be carefully integrated into the curriculum and not simply added on to it, and the focus must be on mathematical knowledge and not on the hardware or software (Hoyles, 2001). At the same time, without the technical skills to manage the program efficiently, frustration and discouragement are generated. The necessity for a satisfactory degree of technological competence before embarking on creative work is self-evident (Orion & Thompson, 1999). The applicability of technology as a tool in teaching students how to learn is shown by Churach and Fisher (2001). Each member of our focus group expressed their appreciation for being able to see how complex graphing could be done electronically by themselves.

Research design

Mouton (1996:175) asserted that the objective of a research design is to plan, structure and execute the relevant project in such a way that the validity of the findings is maximised.

The process followed during the current project can be represented as in Figure 1. The strategy will now be explained in detail.

Action research

The approach adopted in this project was action research, described by Cohen, Manion and Morrison (2000). In essence, this is a procedure that is aimed at dealing with a concrete problem in an immediate situation. A qualitative approach is used in this article as a methodological framework for generating and analysing post-conference data. Qualitative approaches locate the researcher firmly within the research process and acknowledge the role of researcher subjectivity. Fundamentally such approaches seek to gain a deep understanding of a phenomenon from an insider perspective and propose to describe and understand rather than explain and predict human behaviour (Babbie, Mouton, Payze, Vorster, Boshoff & Prozesky, 2001). The key to such approaches is gaining an understanding of individual perspectives and experiences and in understanding the phenomena in natural settings (Fraenkel & Wallen, 1993; Maykut, & Morehouse, 1994). This implies an all-embracing approach that includes sensitivity to context and process, an inductive approach to analysis, flexibility in research design and a commitment to understanding rather than proving or promoting (Green, 1998).

In the production of new knowledge, universities have generally operated within a Mode 1 epistemology of learning, i.e. learning that is factual, systematic, explicit, objective, codified, fragmenting into more specialisations, reductionist, orderly, empirical, establishment minded, context independent, theory bound, authoritarian, impersonal, universal, and transcultural. More recently though, universities have moved to Mode 2 epistemological approaches in which learning is conceived and assumed to be holistic, context driven, mission oriented, multi-authored, heterogeneous, divergent, reflexive, personalised, insecure, entrepreneurial, and workable (Hills & Tedford, 2003).

Subjects and sampling techniques

The context of this study was the experience of the 121 pre-calculus student teachers (three groups) in their first year of study who were enrolled for the specialized mathematics courses at the Groenkloof campus of the University of Pretoria, and who, during their mathematics practicals, made use of the Master Grapher for Windows program and its accompanying workbook and answer sheets. Judgemental sampling was used to select five students specifically chosen to represent the diversity of the group of students in the study. These students were selected after 28 weeks, at which stage their normal mathematics practical sessions had been completed. The selection criteria were as follows:

- Modicum of teaching experience. Two male first-year mathematics students had been teaching extra mathematics lessons privately, whereas three female mathematics students had had at least 12 weeks of teaching practice experience.
- Mother tongue. Two Afrikaans-speaking, one English-speaking and two African language-speaking students were included.

Data collection and analysis: Phase 1

The students were observed during various practical sessions, using the Master Grapher for Windows and accompanying workbook and answer sheets. Students were provided with a survey sheet (Appendix A) to gain information on the extent of their experiences with computers in general and graphing facilities in particular. There were also questions on the extent to which they found the practicals enjoyable, creative and useful for the development of their own skills and understanding of functions, as well as for application in their future teaching careers. Subsequently semi-structured, individual, in-depth interviews (Appendix B) were carried out with the focus group to determine their attitudes to the practicals while using the Master Grapher for Windows course.

The data were then analysed to show that the attitudes or experiences of some students were associated with or linked to their involvement in the experimental practical mathematics course. Important ideas which emerged from Phase 1 were subsequently triangulated with the findings of a literature study and used to determine criteria for success in designing an intervention programme (in the current study, the term "themes" was used, although we realise that it would probably be more correct to refer to "important idea", especially since only five students were available for in-depth study).

Data collection and analysis: Phase 2

To assess students' attitudes towards the programme, it was presented to two groups, comprising students with whom in-depth interviews had been conducted earlier on. Observation of these students engaged in the programme was then again followed up by semi-structured, in-depth group interviews (Appendix C). Conversations were video- and audio-taped and data were analysed on the basis of Morse and Field's approach (comprehending, synthesising, theorising, and recontextualising) (Morse, 1994; Morse & Field, 1996).

Table 1 records the criteria considered in the validation process and how they were applied in both data collection and data analysis.

Ensuring trustworthiness

Trustworthiness (Guba in De Vos, Strydom, Fouché. Poggenpoel, Schurink & Schurink, 1998) of the results was facilitated in the following way. Much time was spent with participants during the course of lectures, which facilitated rapport and helped students feel at ease. Qualitative researchers with many years' experience in interviewing conducted the interviews in an attempt to eliminate bias. The lecturers were both highly trained and vastly experienced, not only in teaching mathematics at tertiary level, but also in the implementation of anti-bias programmes. Trustworthiness was further enhanced by peer examination (researchers reviewed each other's work at all stages), independent coding and comparison of information at different stages of the research. The relationship of trust between the lecturers and the students and the fact that students were motivated to contribute to the adaptation of the programme to their needs further facilitated trustworthiness.

Table 1 Data collection and data analysis strategies: criteria implemented in the validation process, phase 2

Strategy	Description
Data collection*	
Participant language: *verbatim* accounts	Obtained literal statements from participants e.g. *verbatim* accounts of conversations and interviews, as well as quotations from documents
Low-inference descriptors	Recorded concrete, precise and detailed descriptions of the participants and the situations in field notes
Member checks	Rephrased and probed to obtain more complete and nuanced meanings during interviews
Participant review	Participants reviewed the researchers' synthesis of all interviews
Data analysis**	
Participant validation	The participants were asked to validate the data analysis process. The participants were also asked whether they could confirm the results of the data analysis throughout the process
Avoiding subjective interpretation	The researchers acted as objectively as possible while analysing the research data
Avoiding poor coding of qualitative data	The research data were carefully coded by the researchers and verified by an external coder
Avoiding making unsupported references	Generalisations were not made beyond the capability of the data to support such statements. The external coder assisted in this process
Avoiding selective use of data	Data were not used selectively to falsely verify findings. The external coder assisted in this process
Avoiding researcher bias	The researchers guarded against their own expectations, misperceptions and need to find answers that would support their preconceived notions about the research. The external coder assisted in this process

* (Adapted from McMillan & Schumacher, 2001)

** (Adapted from Cohen, Manion & Morrison, 2000)

Limitations of the study

This was a limited, local, naturalistic study with limited inferential value. Time constraints on the part of the researchers and timetable restrictions on the part of the students could be considered as limitations of the study. Furthermore other researchers may interpret the findings differently.

Ethical aspects

Permission was requested and obtained in writing from the university as well as from the students in order to conduct the research and publish the findings. Assurance was given that no individual would be identified.

Determining the attitudes of the students to the mathematics practicals with The Master Grapher for Windows course: Phase 1

Semi-structured, individual, in-depth interviews yielded interesting data. Findings indicated that the students were positive about the mathematics practicals, but experienced a number of significant frustrations, which are described in the following themes that emerged from the data analysis. Need for background knowledge; venue; creativity; time pressure; cost; usefulness; group work and real-world context. These themes will be discussed and supporting findings from the other two instruments (observation of students during practical sessions and a survey sheet) will be mentioned where applicable. Comments on the critical incidents are interwoven in the text.

Need for background knowledge

During the individual interviews, one of the common attitudes towards the practicals mentioned was a feeling of being lost. Some comments were:

> "*The lecturer must give us more clues ...*"
> "*I needed more background knowledge ...*"
> "*One must not be expected to do practical work on a concept not covered in lectures, because that is too confusing*"

Our observations indicated that the students wanted considerably more individual assistance to deal with the demands of the course. This "ability *versus* demand gap" could be addressed by scaffolding, a process of guiding the learner from what is presently known to what needs to be known. Scaffolding allows students to perform tasks that would normally be slightly beyond their ability without the assistance and guidance of the lecturer.

(In Phase 1 no scaffolding was supplied for the students undertaking Part 1: Linear graphs.)

Venue

There are two large computer venues at the Groenkloof campus. These venues are available for lecturing purposes as well as for personal work of the students. The mathematics practicals are restricted to these venues, as the Master Grapher for Windows program may only run on these computers. This has the unfortunate consequence that other students use the venue while the practicals are in progress, causing frustration to all parties. The students indicated that they would have preferred to do the practical work in groups in their own time. As the survey showed that 61% of the students had access to a computer at home, this would have been possible if the program could have been made available to the students. This would have had the added benefit that students would own material they could use later in their teaching careers. The difficulty in own-time work on the program is the logistical problems that arise when working in groups. Timetables often cannot be co-ordinated; individual levels of self-discipline vary enormously, making "knuckling down to do the job together" conflictual.

Creativity

It was clear from the individual interviews that the students wanted a more creative program but when prompted could not provide any idea of how to bring this about.

> "*We only worked step by step through the lesson in the textbook. I was frustrated, struggled... It was all so according to a recipe.*"
> "*We only followed the textbook. I did not like the rigid structure.*"

Lack of experience in their own education up to this point of a "hands-on" approach to mathematics learning has clearly limited their cognitive acuity in terms of the possibilities of doing mathematics creatively. Nevertheless they remained instinctively aware of the need for creativity.

Time pressure

It was observed that many students experienced frustration at not being able to complete the worksheets in the allocated time. They also complained about insufficient time for reflection and feedback.

> "*There must be enough feedback as soon as possible. You can repeat the same mistakes over and over.*"

Cost

Most of the students complained about the cost of the books they needed for the practicals.

Usefulness

The students expressed the need for the practical work, not only to enhance their own understanding but also to serve later as a teaching aid. They wanted more information on the methodology of teaching graphs at different levels with the aid of a function grapher.

> "*I will use such a program once I start teaching and I must say that I did not know that computers could be used like this in mathematics. I would just like some more ideas.*"

Group work

The students felt that they could benefit from the synergy of working in groups but had to work on their own as well. A common concern that arose in this context was the risk of one student doing all the work while others were only cursorily involved. Interpersonal conflict in dealing with this phenomenon was frequent.

Real-world context

Students complained that the course did not address their need for guidance on how to make mathematics more interesting and related to everyday life in their future teaching.

> "*It was boring to only follow steps.*"

At the same time they were unable to suggest suitable modifications to the course that would meet this need.

Design of the programme (Phase 2)

Themes, which emerged from the Phase 1 data analysis, served as a basis for the establishment of criteria in the design of a new mathematics practical which more appropriately addressed the needs of these particular students. These themes were aligned with those that emerged from a literature review, they were ranked in order of importance, and used as criteria to design the programme. Researchers identified a striking degree of correspondence between themes that emerged in the current study and those described in the literature. However, "need for background knowledge" was extended to include "scaffolding" and "venue" was elaborated in order to ensure that the crucial aspect of "availability" was included. After these adaptations had been made, the original themes were used as measures by which the intervention programme (which lasted two weeks, one hour per day) would be evaluated. In other words these criteria were implemented to design the intervention programme discussed in the current article. Prioritising the criteria facilitated design effectiveness and efficiency. Table 2 indicates how prioritisation of criteria was established. Each of the lecturers involved with the research evaluated every horizontal criterion against each of the vertical criteria using percentages. Thus, for example, when Need for background knowledge was weighed in importance against Venue, Need for background knowledge drew 80% (first column, second row) as against the 20% for Venue (first row, second column).

According to the totals summated column by column, the following order of priority emerged:

- Need for background knowledge (scaffolding)
- Real-world context
- Creativity
- Usefulness
- Cost
- Time pressure
- Group work
- Venue (availability)

The criteria for success in the design of the intervention programme were measured against the design principles for a Constructivist learning environment as synthesised and summarised in a Constructivist Checklist on her website by Elizabeth Murphy (Murphy, 1996). They were in line with the characteristics of Constructivist learning and teaching. With these criteria and the relative importance of each in mind, an intervention programme was designed and applied during Phase 2 of the data collection.

Intervention programme: Phase 2

During this phase attention was given to students' complaints (referred to earlier). In order to see whether or not students' attitudes towards

Table 2 Establishing prioritisation of criteria for evaluation of the intervention

	Need for background knowledge	Venue	Creativity	Time pressure	Cost	Usefulness	Group work	Real-world context
Need for background knowledge		20	40	40	30	30	30	40
Venue	80		70	80	90	80	20	90
Creativity	60	30		40	20	40	40	50
Time pressure	60	20	60		40	60	50	70
Cost	70	10	80	60		30	30	70
Usefulness	70	20	60	40	70		20	50
Group work	70	80	60	50	70	80		60
Real-world context	60	10	50	30	30	50	40	
Total	470	190	420	340	350	370	230	430

the course could be changed, they were provided with a number of assignments. Intervention two was divided into two parts. No control group was selected, since the emphasis during this stage was not so much on comparing groups in an experimental programme, but rather on gathering and analysing qualitative data and generating research hypotheses. In a certain sense, though, we suppose that the rest of the group of 121 students could be regarded as a control group. Nonetheless, we readily acknowledge that this matter could be viewed as a limitation of the study, since this research design does not control adequately for the Hawthorne effect.

Part 1. Linear graphs

Students were first divided into two groups (comprising two and three persons, respectively). Students were firstly requested to design a project to find out, with the help of the grapher, what effect the coefficient of x (m) and c in the equation $y = mx + c$ have on the graph of a linear function and, secondly, to design a Grade 8 lesson aimed at helping learners to experiment with graphic representations of linear functions and combine these with algebraic representations. Students were given one week (five one-hour sessions) for this assignment.

Part 2. Further assignments

Session 1

Subsequently students were given three further assignments and allocated one hour for each of these assignments. The first question read as follows:

> "The image (Figure 2) was created by joining numbers making the sum of 9. Create the same image on your computer screen by making use of linear graphs."

The second question read:

> "The same principle can be used to make other patterns, for example: Join numbers making a sum of 13."

The third question read:

> "Observe the image (Figure 3). Create the same image on your computer screen by using linear graphs."

As was expected, this proved to be a difficult assignment. The main reason for this question was to facilitate a realisation that modern technology is a) necessary and b) available to deal with similar problems.

Session 2. Greeting card assignment

During the first part of this session, scaffolding was built into the worksheet. Students were told:

> "Design a valentine card by making use of the graphs of $y = |x|$ and $y = |\sin x|$ and their transformations in such a way that it forms a heart in the first quadrant." (Figure 4)

Students were allowed one hour in which to complete both this assignment and the following one.

During the second part of session 2 the following question was posed.

> "Now design other greeting cards using your own ideas" (based on the idea from Maria Fernandez, 2001).

Changes in the attitudes of students after the implementation of the programme of intervention (Phase 2)

Observation of the two groups engaged in the intervention programme yielded interesting information. We observed how the individual members of each group reacted and participated in the lesson. The findings are listed below, using the same themes as before. Comments on critical incidents are interwoven in the text. (All conversations were video- and audio-taped for independent verification, which was done by a senior colleague in the Faculty, a person with many years' of experience in teaching mathematics.)

The effect of providing more sufficient background knowledge (Scaffolding)

Scaffolding was built into the programme in the sense that clues were given in such a way as to ensure that learners still regarded the experiment as a challenge without becoming discouraged by the enormity of the assignment. Learners could still work on their own and share the joy of being in control. The students were observed to be confident, did not require assistance from us, were deeply involved with problem solving, and even exceeded the required outputs. These were clear indications that the scaffolding built into the new programme worked well. It must be mentioned, however, that by the time this research took place, the students were technologically proficient and had the necessary basic knowledge and confidence to experiment.

Real-world context

The new programme provided work related to issues such as function graphs used in the design of valentine cards, as illustrated above, and we could sense the enthusiasm of the students as they experimented. They expressed satisfaction and excitement and one very reserved student even remarked,

> "*I feel so privileged, so glad to be part of this.*"

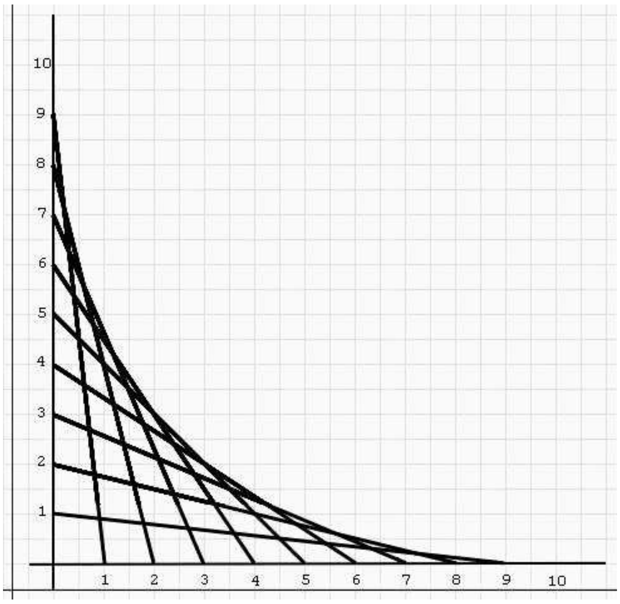

Figure 2

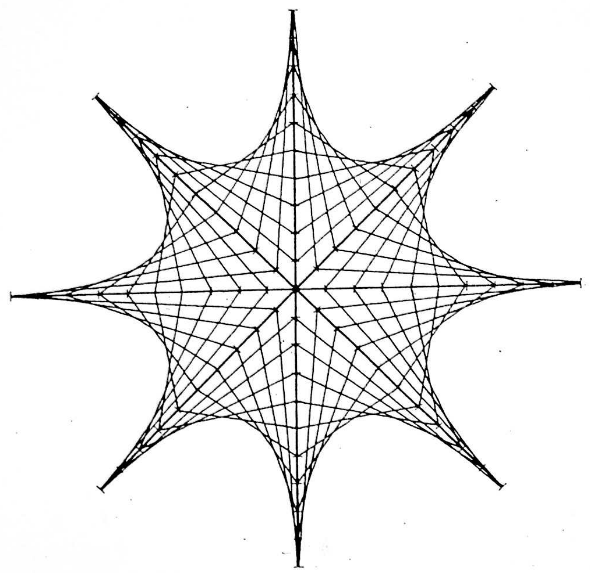

Figure 3

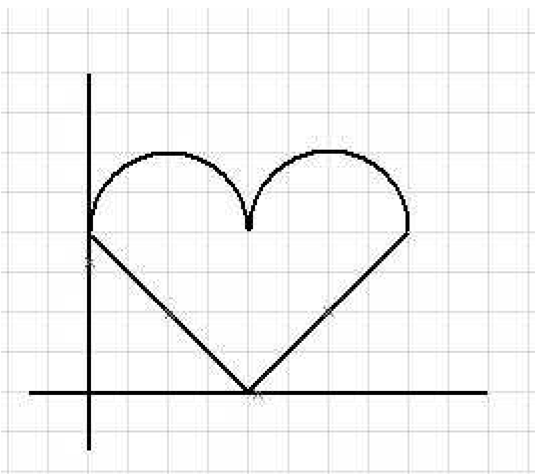

Figure 4

Creativity

It was observed that the students enjoyed the creative approach offered by the new programme which stimulated their curiosity and sense of daring to do something different, to the point of one group adding their own ideas and not wanting to leave even long after completion of the basic exercise. The following are two typical remarks:

> "*It is so much more interesting.*"
> "*I like the challenge.*"

Usefulness

Students were excited and expressed enthusiasm about the application of the new programme in their future teaching careers. They also commented on the change in their idea of the role of a teacher.

> "*I now have ideas of how I would use a program like this in my teaching.*"
> "*Now I can really see it as part of my teaching.*"

Cost

The cost of the new package was not discussed, but it is expected that the new material will cost far less than the current material.

Time pressure

This problem was observed to be largely solved due to rapid progress resulting from group synergy and focused involvement.

Group work

Observations included a high degree of involvement, interest and enjoyment of each group member. The group discussions and reasoning were focused and relevant. Typical remarks included

> "*This was a lot of fun*"

and

> "*The peer teaching aspect was great*"

Venue (Availability)

Each group worked separately in a lecturer's office and, in contrast to the previous situation, a significant interaction resulting in synergy and positive progress was observed. The new course will be portable and independent of venue.

Discussion

The primary issue underpinning this study was the desire to investigate the possibility of providing, albeit in a limited way, more innovative educational opportunities to mathematics students in the Education Faculty, University of Pretoria. However, we fully realise that only five students were involved and that lecturers' offices were the only venues available, and that this limits the inferential potential of our study.

These days modern mathematics (calculus in particular) is presented visually. Over the past 10 to 15 years this has been the case in First World countries where graphical calculators are affordable — even in schools. In South Africa, only state of the art private schools can afford this luxury. At the University of Pretoria this facility is only implemented in the course where the first year can be taken over two years (WTW 130). The large number of students taking this course presents a major problem; too many even for the Goldfields Centre. University textbooks that are in use have been based on these principles, but this is not so in the case of textbooks used at schools. The researchers wanted to introduce the visual approach but could not afford the graphical computers. Although we were able to obtain the Master Grapher software from UP free of charge, the course was designed to suit the needs of engineering and similar courses and contained too much detail for use with education students.

Teaching interacts with learning styles to discourage or encourage certain types of students. In this regard we feel that the history of rote learning at schools in South Africa has put many university students at a disadvantage (Zaaiman, Van der Flier & Thijs, 1998). Students who attended the previously black-only schools, in particular, probably have not had (and, by and large, still do not have) adequate opportunity to develop their academic potential compared with students who attended the previously white-only schools. We believe that the South African goal of equal education can only be realised once the need for innovative approaches in teaching and learning is addressed appropriately. It also seems necessary for university mathematics educators to rethink their design and delivery approaches when dealing with learners who have various learning and thinking style preferences.

The study reported here paved the way for further research to determine whether students' attitudes towards the study of mathematics could be improved by offering an innovative approach to learning facilitation in mathematics. It is clear that the attitudes of the students were transformed to being positive, following the implementation of the intervention programme. Students indicated that they believed that they had moved onto a higher level of technical competence to meet the challenge of a techno-driven society. At the same time, their own need for creative expression was encouraged and developed. These results probably suggest that a need exists for the design of a new course that will be more appropriate for the mathematics practicals of student teachers.

Planned future outcomes of this study include providing some evidence-based information for the revision of the current course for the Mathematics Pre-calculus practicals for student teachers at the School of Teacher Training at the University of Pretoria (and, hopefully, similar institutions across the country as well). Currently 153 students have enrolled for this course, and the number of students in these classes is not expected to change significantly over the next few years. Hopefully the results of this study could serve as a guideline for the implementation of similar programmes at tertiary institutions throughout South Africa. Furthermore we plan to formalise an integrated computer-assisted course for the development of graphing sense that will be distributed at an affordable price on CD for the use of public schools, private schools, home schools, and individuals. Lastly, workshops for in-service training of teachers are envisaged.

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Appendix A
Survey sheet

The main aim of this questionnaire is to determine the attitudes of students towards the use of the Mastergrapher programme during mathematical practicals. Please help us to determine where we can raise the quality of these practicals by marking the appropriate block with a tick..

Year group	First		Second	
Gender	Male		Female	
Do you have a personal computer at home	Yes		No	

1. How often during the last year have you used a computer for the following?

E-mail	Often		Sometimes		Seldom		Never	
Internet	Often		Sometimes		Seldom		Never	
Assignments	Often		Sometimes		Seldom		Never	
Other programs	Often		Sometimes		Seldom		Never	

2. Indicate your emotions and perceptions during the practical classes in which you used the Mastergrapher programme.

Made mathematics more enjoyable	Always		Sometimes		Never	
Made mathematics easier	Always		Sometimes		Never	
Lessons were creative	Always		Sometimes		Never	
Learned a lot about functions	Always		Sometimes		Never	
Valuable for my teaching career	Always		Sometimes		Never	

3. Do you think you have a better understanding of functions because of your participation in the Mastergrapher programme?

Yes		No	

4. Do you think the programme needs to be changed to a more creative programme in the future?

Yes		No	

THANK YOU!

Appendix B
Research instrumentation

Semistructured individual interviews

Background questions:
1. Why did you decide to become a mathematics teacher?
2. How did you experience mathematics at school? What teaching style did your teacher use most?
3. Briefly describe what teaching approach/style you wish to use to make sure that learners grasp mathematics.

Mastergrapher practicals:
4. How much opportunity did you have of being creative in the practicals?
5. Was there sufficient opportunity for group work and discovery?
6. Did the programme make mathematics, in particular the functions, easier or more comprehensible?
7. Did the classes make sense to you from a learning facilitation perspective?
8. Do you think the programme is praxis/teaching directed?
9. A new student wants to know what was done during the practicals and what they were like. What would your response be?
10. What was the most pleasant part of the practicals? The worst?
11. What would you change about the practicals to make them more effective and enjoyable?

Appendix C
You have now worked in two different modes or ways during the mathematics practical sessions. Please compare the two ways on the basis of the following questions:
1. What are the advantages of the second mode (way) for you?
2. Which mode retained your attention the best and why?
3. This programme is especially designed to facilitate more adequate concept formation. In which cases was this ideal more adequately achieved? In your opinion which factors facilitate more adequate concept formation?

Compare your self-confidence and level of enjoyment/relaxation in the two different cases.