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The identification of conceptual and strategic difficulties encountered by students when using an electronic spreadsheet

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The Identification of Conceptual and Strategic Difficulties Encountered by Students When Using an Electronic Spreadsheet

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Abstract

The call for the use of computer technology in mathematics education has been heeded by the Ministry of Education in Western Australia. The syllabus documents for the Upper Secondary mathematics courses recommend the use of computer software packages for the teaching of the concepts involved in these courses. In particular, the electronic spreadsheet is suggested as a versatile and useful tool for simulations and problem-solving by students, although very little formal study has been undertaken to support or refute such beliefs.

This study involved teaching a group of four Year 12 students to operate a spreadsheet, and then examined the way the spreadsheet was used by the students to represent and solve certain mathematical problems. In this way, it was hoped to identify and explain any conceptual and strategic difficulties encountered by the students when using the spreadsheet.

In order to achieve this aim, a constructivist teaching experiment was chosen. This method is especially suited to investigations of this nature. It provides for the required interaction between tutor and students, and allows for the observation of behaviour which continually serves to refine the models devised for the explanation of such behaviour. The researcher acted as tutor during the four learning episodes.

It was found that many of the difficulties encountered by the students were typical of those seen when students attempted to solve mathematical problems without an electronic spreadsheet. However, the spreadsheet

environment was seen to be a useful aid as it allowed a series of calculations to be performed, with the results available on the computer monitor. This is in contrast to hand-held calculators which can usually only display one result at a time. The students tended to look back over previous results and were happy to modify their approach when necessary.

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed . 5/10/1994

Craig Clapham

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Chapter 1: Introduction

The increasing use of computers in industry has lead to a call for the introduction of computers into educational institutions in order to familiarise students with their use and potential. It has also been recognised that computers are useful teaching aids. Sullivan (1988, p. 27) reports that "both a government economic strategy (Victoria: the Next Decade) and a major trade union report (Australia Reconstructed) have recognised technology, education and training as important for the future". In response to this perceived need, many Western Australian secondary (and primary) schools have acquired computers for student use.

Most of the new upper secondary school tertiary entrance mathematics courses introduced by the Western Australian Ministry of Education (now the Education Department of Western Australia) in 1991 contain a significant time allocation for modelling or simulation problems, and built into this is the expectation that computer applications will be used extensively. The syllabus documents for the courses *Modelling With Mathematics* and *Mathematics in Practice* are especially concerned with activities and real-world problems that lend themselves to representation with a spreadsheet. In fact, the recommended text for these courses (Lowe, 1988) is heavily involved with the spreadsheet simulation of many situations in various topics. This represents the recognition by the Ministry of the importance of such technology, and also the need to use computers in a meaningful and realistic setting.

However, very little research has been done in the field of applying spreadsheets to mathematics learning and so the classroom teacher does not have a solid knowledge base from which to operate. As yet teachers do not know how students learn with these programs, or even the best manner in which to deploy them.

The spreadsheet itself may represent an example of a "microworld", a term coined by Papert (1980) to describe the view of computers as "environments for exploring ideas and stimulating higher order thinking" (Olson, 1988, p. 6). In considering the Logo computer language, Papert (1980, p. 117) asks if there is a "danger of mystifying children by placing them in an environment of sophisticated technology whose complexities are only partially understood by advanced computer scientists". Hence there is the danger that such microworlds may confuse students because they fail to comprehend the correspondence between the initial problem and the computer representation of that problem.The same concerns may be voiced with regard to spreadsheets. Thus there exists a need to analyse students' understanding of the representation of problems by electronic spreadsheets so that educators may utilise computers and spreadsheets in the most effective manner possible.

Chapter 2: Literature Review

2.1 Introduction

The first electronic spreadsheet was called Visicalc, and was conceived by a graduate business student named Dan Bricklin. This electronic spreadsheet was a computer model of the large paper spreadsheets used by business-people. A spreadsheet is a way of setting out rows and columns of numbers in such a way that they can be reworked repeatedly in order to see the effect of changing one number (Hall, 1991). Each number has its own cell, or location, and the numbers in some cells may be dependent upon the numbers in other cells. This dependence is handled by the computer through the use of formulae, which link cells in certain previously defined ways, and it is this interdependence of cells that gives electronic spreadsheets their power. Since the tedious and repetitive calculations are handled by the machine rather than by the user (and with much greater speed), many more so-called "what if?" calculations may be performed. For example, a spreadsheet may be created to analyse mortgage repayments, with columns representing interest payable and the balance for each month. Since the computer is handling the recalculation of each step, it is easy to change the interest rate or monthly repayment and immediately see the effect on the term of the loan and the monthly interest. Potential loan customers are frequently asking such questions as "What if interest rates rise?" or "What if I pay a bit more each month?" Some banks have set up spreadsheets to allow customers to simulate such scenarios and view the results over the term of their loan.

Arganbright (1984) provides a diverse range of algorithms from various mathematical topics which are suitable for spreadsheet implementation, although they are probably well beyond the level required for most secondary school students. However, many other authors have suggested ways in which the spreadsheet may be used in secondary or primary school mathematics classrooms, emphasizing simpler applications which are suitable for secondary and primary school students (e.g. Dubitsky, 1988; Peasey, 1985; Straker, 1989; Sullivan, 1988).

Arganbright (cited in Straker, 1989, p. 33) suggests three methods of using a spreadsheet in the mathematics classroom. These methods involve:

(a) pupils inserting appropriate data into a teacher-prepared template, with limited capacity for changing data and no direct control over the output.

(b) pupils imitating pencil-and-paper algorithms with the spreadsheet, but usually still within the confines of a teacher-generated template.

(c) pupils being given a spreadsheet program with which to create their own techniques and solutions.

The third of these possibilities requires a great deal of sophistication on the part of the student and almost certainly occurs after experience with the other two approaches.

The methods listed above are pupil-centred, and the literature tends to focus on applications for spreadsheets which utilise one of these approaches. However, another way of using the spreadsheet is as an electronic blackboard which is under the control of the teacher. Ransley (1990) describes how to use a spreadsheet to demonstrate a mathematical idea to a class. This method involves the use of a display adaptor to project the computer screen using a conventional overhead projector. Ransley (1990) believes that this will appeal to conservative teachers who are reluctant to use computer technology in other ways, or who find it difficult (for whatever reason) to work in a computer laboratory setting. Also, the mere availability of the expository method adds another facet to the teaching of mathematics with a spreadsheet.

Ash-Mott and Rudolph (1989) use spreadsheet templates to allow students to perform elementary row operations on matrices when solving systems of linear equations. They believe that computers "can save time and frustration" when tackling problems which involve a great deal of arithmetic (p. 37). While they recognise that dedicated programs exist which perform the same functions their spreadsheet templates perform, the spreadsheet was chosen because of two perceived disadvantages with the dedicated approach. Firstly, the layouts of the dedicated matrix manipulation programs do not accurately reflect the way students tackle the task with pencil-and-paper. This lack of correspondence may hinder the students' development since the computer representation might well be seen as yet another problem to solve. Secondly, Ash-Mott and Rudolph (1989) believe that matrix manipulation programs are designed to quickly and efficiently produce an answer after the input matrix has been defined. The computer has thus made all of the decisions, and so the students' learning "has not been reinforced" (p. 37). The spreadsheet program requires the student to make the decisions, but performs the arithmetic to reduce the need for time-consuming and potentially error-prone manual calculations. In this way, the students can concentrate on the concepts and the overall goal without becoming obsessed with the arithmetic.

Of course, this assumes that the initial goal was to have the students understand and be able to apply the elementary row operations, with the computer performing only the arithmetic under the direct control of the student. If the goal was merely to have students be able to solve a system of linear equations, then the dedicated matrix manipulation program would be acceptable. Such uses of computer technology raise questions similar to those put forward when calculators were introduced. That is, is it really necessary to teach students skills (such as matrix manipulation) when a computer is available which does the job faster and possibly more accurately? (Ball, 1989, p. 40). The use of computer software (especially the generic spreadsheet) raises methodological and philosophical questions which need to be addressed by educators.

Very little systematic research has been done on the use of spreadsheets in mathematics education (Bright, 1989). Many of the studies that have been published are concerned with tertiary level students, and/or have informal evaluations based primarily on achievement and enjoyment in whatever is being taught (e.g. Dubitsky, 1988; Klass, 1988; Orzech & Shelton, 1986).

As noted previously, the majority of the literature is concerned with putting forward ideas regarding ways in which the spreadsheet may be used in the classroom, but no detailed analysis of the effectiveness of the suggestions has been carried out. For example, Orzech and Shelton (1986, p. 436) note that they have used their spreadsheet approach to teaching mathematical economics with over two hundred tertiary level students and the students have "responded enthusiastically". They also state that in response to a questionnaire students commented that they [the students] were able to "see more clearly how the procedures actually work when they [the students] are not tied to the manual arithmetic computations" (Orzech and Shelton, 1986, p. 436). However, the questionnaire itself was not provided, nor were details of the administration and data collection.

Klass (1988) used spreadsheet templates to teach statistical concepts to tertiary level students studying an introductory statistics course. The researcher assumed that the subjects had no previous experience with computers, and the templates were written so that they emphasized statistical concepts rather than manual computation. These templates were not intended to replace classroom instruction. The majority of the students, in response to a questionnaire, felt that using the computers assisted in their understanding of the course. The study was essentially action research, since the students' responses were used to improve the templates and the use of the spreadsheet in the course. The number of participating subjects was not given.

A major benefit of the use of the spreadsheet in Klass' (1988) study was the instant recalculation when provided with new data, which allowed the students to achieve some familiarity with the sensitivity of certain statistical measures to slight variations in input data. This advantage of the spreadsheet was also identified by McAlevey and Stent (1990) in a paper which suggests the use of a spreadsheet in undergraduate courses in mathematics and modelling. In fact, McAlevey and Stent believe that the "spreadsheet should be a tool of the mathematics major" (p. 759).

Healy and Sutherland (1990) used introductory spreadsheet activities with pairs of students (no details of the methodology were provided) to familiarise the students with the basic necessary features of the spreadsheet. Since the authors believe that many of the advantages of a computer environment are lost if students do not "reflect on processes for themselves", the aim was to "plan spreadsheet tasks such that pupils would always construct their own rules within the spreadsheet environment" (p. 849). There was evidence presented to support the claim that the entry of spreadsheet formulas by pointing and clicking on the cells with a computer mouse "provided a framework for the ultimate generalizing of the rule" (p. 852). It was acknowledged that the language used by the teacher was of particular importance in helping the students focus on the general rule. For example, rules were described in relative terms, such as "add 1 to the cell above", "this cell is the sum of the two cells on its left". The authors imply that a spreadsheet is an excellent way to take students from arithmetic to formalising general algebraic rules. They provide the example of a pair of students who were attempting to find a rule for the triangular numbers. The students identified the numbers to be added by pointing to the appropriate cells, then entered "=B2+C1" as the spreadsheet rule (by pointing and clicking with the mouse). This led these students to write down a statement to the effect that "triangle number = number before + position", with the authors claiming that it "would not be difficult for them eventually to use the equivalent algebraic representation $T_n = T_{n-1} + n$" (p. 858).

Sutherland and Rojano (1993) report the results of a combined Mexican/ British project which examined the ways in which two groups of eight students (who were ten to eleven years of age) used a spreadsheet to represent and solve a range of algebra problems. The authors related this to the students' previous experience with arithmetic and the evolving use of a symbolic language (p. 353). The students involved in the study were chosen because they had received no formal instruction in algebra. The authors concluded that "these pupils had learned to use algebraic code as a means of expressing a general function rule" and that "pupils used the algebraic code when talking and communicating their ideas to each other" (p. 361). Included in the definition of "algebraic code" are statements such as "A1+1" and "B2+C1". This implies that the spreadsheet environment can foster an understanding of general algebraic rules, and that it may be a better introduction to algebra than traditional methods which focus on pronumerals.

Horne (1993) discusses spreadsheet activities which can be used to develop algebraic concepts for students in Years 7 to 10. These activities are aimed at introducing variables and algebraic manipulation in terms of the cells of a spreadsheet. Horne concluded that "the spreadsheet is a powerful tool enabling many algebraic concepts to be developed and particularly lends itself to a problem solving approach" (1993, p. 209).

Steward (1994) reports that the spreadsheet "has become an established software tool in both management practice and studies" (p. 239). However, he has found that spreadsheets are not used as often in mathematics education as might have been expected. Instead, programming languages appear to have made greater inroads into mathematics education than spreadsheets. Steward suggests that when both are available to a student the spreadsheet is easier and quicker to use. He also makes the point that "once written a program can often mask the mathematics that it is intended to represent while on a spreadsheet the procedure is constantly exposed" (p. 239). Abramovich and Levin (1994) support this position when they state that "the spreadsheet is an open interactive learning environment where students can exercise their own creativity", and "spreadsheet-oriented teaching ... boosts students' constructive thinking ... In contrast, the use of a canned program actually is an example of passive rendering of mathematics knowledge" (p. 264).

The classroom uses and potential of spreadsheets appear to have been recognised by the literature, and are generally agreed upon. What is not so clear is the way in which students will react to, and make use of, these tools. In order for the spreadsheet to become a trusted mathematical calculating device (and thus be used effectively by students), it must be "transparent", in a similar fashion to the way the hand-held calculator is now accepted. That is, students need to be able to see beyond the spreadsheet so that they are tackling the initial problem and not the spreadsheet itself. However, while the literature identifies a variety of spreadsheet activities, none of the research has addressed the identification of the barriers or difficulties which might prevent the spreadsheet being used effectively by the students.

2.2 Research Question

What are the conceptual and strategic difficulties encountered by students when attempting to use an electronic spreadsheet as an aid in mathematical problem-solving?

Mathematical problem-solving in this study will include the mathematical modelling processes described by Burkhardt (1984, p. 3), in which it is necessary for the students to formulate a mathematical model from the "real-world problem" (or the given problem statement), solve the model, then interpret the solution in terms of the original problem. Mathematical tasks which involve the immediate demonstration of a specific algorithm for their solution are not considered to be problems in this sense.

Chapter 3: Procedure

This study used a teaching experiment in which four Year 12 students used a spreadsheet to assist them in solving mathematical problems. There were four teaching sessions during which the students worked in pairs, with each session being of approximately 75 minutes duration. At the completion of the four sessions, one 30 minute interview was held with each student individually in which a teacher-provided spreadsheet template was used. The first session was an introduction to the spreadsheet to ensure that the students had knowledge of spreadsheet terminology and the basic features of the spreadsheet that they would be using. This session was the initial instruction phase.

The teaching experiment is broadly defined as clinical research with the inclusion of "an instructional component and the co-operation of the teacher and the researcher" (Johnson, 1980, p. 22).

The literature identifies two main types of teaching experiment; macroschemes and microschemes (Cobb and Steffe, 1983; Hunting, 1983). A macroscheme is defined by Hunting (1983, p. 53) as "the study of mental changes in a pupil's school activity and development during transition from one age level to another". The microscheme is the study of an individual pupil's transition from a state in which the student lacks knowledge to one in which knowledge has been attained (Hunting, 1983). This transition is assumed to occur with respect to some previously defined subject matter. Cobb and Steffe (1983) consider microschemes to have a psychological orientation, while macroschemes are generally curriculum oriented. However, Hunting (1983) believes that combinations of methods are common, and identifies other forms of the teaching experiment, such as the study of entire classes over long periods of time, and the study of curricular changes. Thus there can exist some blurring of the categories in describing teaching experiments.

The constructivist teacher is one who makes a conscious effort to understand both their own and their students' actions from the point of view of the student. Teaching is seen in this context as communicating with students. Teachers have intended meanings, and the students create actual meanings for themselves based on the interpretation of the teacher's actions (Cobb & Steffe, 1983, p. 86).

Non-constructivist teachers, in contrast, believe that it is the direct result of adult intervention that influences children's construction of knowledge, rather than the "children's experiences of these interventions as interpreted in terms of their own conceptual structures" (Cobb & Steffe, 1983, p. 88). Thus in a non-constructivist teaching experiment (e.g., Kantowski, 1977) the processes which are under investigation have been decided upon before the commencement of the study, and any other processes which may bear upon the study are of secondary importance. However, in a constructivist teaching experiment, there is no *a priori* notion of what will be found or considered. In other words, there is an attempt to "understand the constructions children make while interacting with us [teachers]", whatever those constructions happen to be (Cobb & Steffe, 1983, p. 88).

Successful communication is deemed to have occurred when the actual meaning fits the intended meaning. Communication is more likely to be successful when the teacher's actions are the consequences of considering models of the students' mathematical realities. A model in this sense is an explanation of a student's mathematical behaviour. Thus the contradictions between the model and the observed behaviour of the students serve to refine the model. Such refinements can only occur when the researcher has prolonged or repeated interactions with the students, ideally as the instructor.

The teaching experiment is especially suited for the construction of such models, since it allows for the required interaction between researcher and student, and for the observation of such interaction (Hunting, 1983). Since the study examined (and attempted to explain) the progress of individual students as they used a spreadsheet in mathematical problem-solving, a constructivist microscheme was the most logical methodology.

A teaching experiment was therefore conducted over 4x75 minute sessions with four students who elected to study *Foundations of Mathematics* in 1991 in Year 11 and *Discrete Mathematics* in Year 12. The students were chosen from an existing class, and only students who achieved a satisfactory grade after one year's study of *Foundations of Mathematics* were considered. The final selection from those students who satisfied this criterion was based on each student's perceived willingness to be communicative. The students were asked if they wished to take part in the study, and the four students who were selected all agreed. There was no formal pre-test to determine the students' existing knowledge of spreadsheets, although they had probably studied the school's compulsory computing unit in Year 8, which has a small spreadsheet component. The researcher acted as tutor during the learning episodes. The students worked in pairs, with each pair having access to a computer. The sessions were conducted after school in an available classroom, on days when the four students and the researcher were available. There were three female students, and one male student.

The spreadsheet module of the Clarisworks package running on Apple Macintosh computers was used throughout the experiment. This spreadsheet was chosen because it was readily available, and because it was considered by the researcher to be representative of the spreadsheets currently available for computers. The ease of use of this system and the method of using a mouse to point at required cells for their inclusion in formulae were also considered to be useful for beginners. Healy and Sutherland (1990) applied similar criteria in choosing the Excel spreadsheet package on the Macintosh (p. 859).

The four teaching sessions referred to above involved using the spreadsheet to assist in the solving of real-world mathematics problems. The students were taught the mechanics of operating the spreadsheet during the first session. They were taught how to load the spreadsheet into the computer, how to type information into particular cells, and how to navigate around the spreadsheet before they attempted to use it as a problem-solving aid. In a similar way, Kantowski (1977, p. 164) used a "readiness instruction phase" in her study of the processes observed as students solve non-routine geometry problems, to ensure that they were acquainted with the heuristic method of problem-solving.

The initial instruction in spreadsheet terminology and navigation described above was conducted according to the outline presented in

Appendix 1, and was conducted for the first 75 minute session. For the following three sessions the students tackled the problems listed below. There was no specified time limit on any single problem. The students had the opportunity to spend all of the sessions on the one problem, or several problems could have been dealt with in that time. It was therefore possible for each pair of students to be working on a different problem at any given instant, although this did not occur. Inter-pair interaction was not actively discouraged, but rarely took place.

The problems themselves are listed below in the same order and using the same wording as when they were presented to the students. Each problem or situation is labelled as P1 for the first problem, P2 for the second problem, and so on, for future reference. The initial instruction phase (described in Appendix 1) is labelled IIP.

IIP: Initial instruction phase.

P1: (a) Use the spreadsheet to set up two columns which show the first eleven whole numbers (i.e., from zero to ten) and the first eleven multiples of eleven respectively. Describe any patterns you see. Adjust the spreadsheet so that it displays the 50^{th} to the 60^{th} multiples of eleven. Are the patterns still evident? What is the 3400^{th} multiple of eleven? Try to find patterns in multiples of other numbers.

(b) Show the first twenty terms of the geometric progression that has two as the first number and a common ratio of two.

(c) Set up the spreadsheet so that you only have to type in the first term and the common ratio once and the computer will give the first twenty terms of the progression.

P2: A box to hold lollies for a child's birthday party is to be made from a square sheet of cardboard of side length 12cm by cutting squares from the corners, folding up, and joining the edges. The box does not have a lid. What size of square cut out of the corners will produce the box that can hold the most lollies? If the volume of the box must be 128cm^3, what size square needs to be removed from the corners?

P3: A manufacturer finds that the firm's income in dollars per month is $1800 + 3000n - 30n^2$, where n is the number of workers employed, while his expenditure in wages and material is $2200 per month for each worker. How many workers should be employed in order to obtain the maximum monthly profit?

P4: A closed rectangular box with square ends has a total surface area of 600cm^2. Find the greatest volume it can contain.

P5: Using the provided spreadsheet templates for simulating coin tossing.

At the end of the four sessions a clinical interview of approximately 30 minutes duration was held with each of the students individually to assess their understanding of spreadsheet representation and use. During the interview two spreadsheet templates were provided. Both of these templates were adapted from *Mathematics at work: Modelling your world* (Lowe, 1988). The first simulated the tossing of a single fair coin, and displayed the "success fraction" (experimental probability) for each possible outcome. The second template simulated the tossing of two fair coins. The students were encouraged to explain the template (i.e., what each cell represented, the significance of formulae, and the ways in which the template represented the problem), and how the template could be used to solve the problem. The students were also asked to modify the template to demonstrate their proficiency and understanding.

The use of clinical interviews in the identification of cognitive processes is described and defended by Ginsburg (1981). Hunting (1983, p. 48) defines the clinical method as "a dialogue or conversation held in an interview session between an adult, the interviewer and a child, the subject of study", and states that it is structured in such a way that the subject has every opportunity to "display behaviour from which mental mechanisms" may be inferred.

The students were observed and tape-recorded while they solved the problems to provide a tentative model for describing their difficulties in applying the spreadsheet. The instructor asked the students to explain what they were doing (and why) at certain points during the students' solution attempts. The instructor also asked questions to help clarify the problem for the students, or to gain insight into the students' reasoning.

Chapter 4: Results

4.1 Introduction

A list of the difficulties encountered by the students was made through observing the students while they were working, and listening to the audio-tapes of the students working together. These difficulties were then categorised by identifying common sources of error. Five categories were decided upon to group all of the difficulties. These categories are described as:

1. Operating the spreadsheet (the mechanics)
2. Algebraic difficulties
3. Formulating a suitable model (getting started)
4. Relating spreadsheet results to the original problem
5. Lack of trust or belief in themselves or the spreadsheet.

Each of the above categories is explained below, and the specific examples of each category are included. The problem where the difficulty was identified is shown in parentheses after the description. Where a particular difficulty was repeated in the same problem, only one listing appears. If the same difficulty was observed in a different problem, then more than one problem number will be included in the parentheses following each listing. Therefore, no conclusions may be drawn concerning the frequency of each perceived difficulty. Also, only the difficulty itself is reported, and not the student who encountered it.

4.2 Operating the spreadsheet (the mechanics)

Difficulties were experienced by the students, especially in the initial stages, when they attempted to actually operate the computer. This category includes any instances of error that occurred as a direct result of inadequacy or misunderstanding when the physical manipulation or operation of the spreadsheet and computer was required including the paper model of the spreadsheet used in the initial instruction phase. The paper model was the handout shown in Appendix 2, which the researcher used to familiarise the students with spreadsheet terminology and the underlying method of operation.

- A student had trouble manipulating the mouse to get the cursor to point at the desired location (IIP).
- Not being able to locate the menu command to centre text in a cell (IIP, P1).
- Recalling from prior knowledge that a menu command existed to automatically fill in a sequence of numbers, but could not remember that it was called "fill down" (P1).
- Incorrectly addressing a cell through going "off track" when tracing the row or column back to the header (IIP, P1).

4.3 Algebraic difficulties

Instances of difficulties in this category indicate weaknesses in the algebra skills of the students. Such weaknesses prevent the formulation of a correct algebraic expression to mathematically describe a situation, and they interfere with the correct manipulation and simplification of such expressions. Lack of familiarity and confidence with the creation of number sentences and their solutions are also included here.

- They calculated the mean of a set of test scores by using the formula C3+C4+C5+C6+C7/5. The students realised the answer was wrong but could not work out why (IIP).
- The students obtained a correct expression for the volume of the box but simplified it incorrectly, then used the incorrect simplification for the spreadsheet calculations (P2).
- Obtaining a sequence by adding or multiplying each preceding term by a constant was not initially represented in general terms (P1).

4.4 Formulating a suitable model (getting started)

Before a problem can be solved, it is necessary to understand what has to be found and to recognise and utilise important information which is given as part of the problem statement. Failure to understand the initial situation either leads to an incorrect solution because of a faulty premise, or results in the student "getting stuck" and not being able to proceed since they are unable to find any possible solution method. This includes a demonstrated lack of reading comprehension or simply misreading the problem statement.

- A student misread question four on the handout during the initial instruction phase. The phrase "for each test" was ignored (IIP).

- The students immediately attempted to find the maximum value of the expression for the income rather than the profit (P3).

- The students did not recognise a need for an expression for the profit. They had to be told that they needed to subtract expenditure from income (P3).

- The students tried to immediately solve the problem using the spreadsheet, but could not see how to begin (P1, P2).

4.5 Relating spreadsheet results to the original problem

When a model has been created on the spreadsheet and the data are entered for the particular problem being solved, the spreadsheet returns the results of various calculations. These results are usually numbers displayed in the cells of the spreadsheet. It is necessary for the operator of the spreadsheet to interpret the numbers in terms of the original problem. Difficulties involving meaningfully relating or understanding the computer output in the context of the original problem are listed here.

- The students did not, at first, realise that they could extend a range of values, or use a different range, in order to locate the desired result (P2, P3).

- The students did not, at first, consider the possibility of refining a solution in order to increase accuracy (P3).

- The students refined the answer to problem four to several decimal places, then wanted to know how many places the researcher would accept as an answer. After questioning by the researcher, they realised that the problem required a whole number in order for the answer to make sense (P3).

4.6 Lack of trust or belief in themselves or the spreadsheet

This category lists any display of lack of confidence, either in their own ability to process information correctly or to operate the spreadsheet (including the paper version in the initial instruction phase), which diminished the students' chances of obtaining a correct solution. While checking possible solutions is an important strategy in the solving of mathematical problems, it is believed by the researcher that scepticism of results and solutions becomes a hindrance when these results and solutions are discounted or not considered to be correct solely because they were obtained through the use of a computer, or because a particular student obtained them.

- The students wanted their original paper spreadsheets so that they could compare those answers with the answers obtained with the computer (IIP).
- The students wanted to repeat every calculation made by the computer using their calculators (IIP).

Chapter 5: Conclusions

5.1 Introduction

The aim of this study was to identify the conceptual and strategic difficulties encountered by students when they attempted to solve mathematical problems using a spreadsheet. The study was exploratory in nature, as it was intended that it form a framework for further investigation. The five categories which grouped the observed difficulties are described in Chapter four (p. 19), and are discussed below.

5.2 Operating the spreadsheet

While no conclusions may be drawn concerning the frequency of any particular error or difficulty, it is apparent that the difficulties in this category occurred almost exclusively in the first two problems. As the students gained experience with the spreadsheet their mechanical skills improved to the point where they could concentrate on the problem itself instead of worrying about relatively minor issues like manipulating the cursor. While not totally proficient in the use of the spreadsheet at the end of the study, the students made remarkable progress when it is remembered that the learning episodes gave them only a few hours experience.

Horne (1993, p. 203) reports that Rojano and Sutherland (1992) found that "the Year 7 children with which they [Rojano and Sutherland] were working had no difficulty accepting and using the spreadsheet package."

Although the phrase "no difficulty ... using the spreadsheet" sounds a little optimistic, it is probable that the authors were referring to the students' willingness to approach technology without fear. This attitude was also observed in this study, with the students not appearing to be discouraged by computer error messages or unexpected responses from the computer. Lack of co-ordination and dexterity caused some initial frustration, but this feeling was quickly overcome by the desire to master the required movements.

Horne (1993, p. 204) believes that "specific skills related to spreadsheet use such as copying cells should be introduced early so that students can use them whenever they desire but the focus should be on the mathematical development rather than the use of the spreadsheet." This is a sound principle, but thought needs to be given to the introduction of the spreadsheet and its associated skills, so that they can be assimilated by the students in such a way that they become automatic, in the same way that many calculator operations have become automatic. In this way, the students' attention may finally be focussed completely on the mathematics rather than, for example, trying to repeatedly solve the problem of getting information into a particular place in the spreadsheet. Although much of this knowledge may be acquired through experience as the student uses the spreadsheet for simple mathematical tasks, spreadsheet operation can be a stumbling block which draws attention away from the desired mathematical situation. Therefore, it may be necessary to provide some initial instruction (perhaps using familiar mathematics) which focusses solely or primarily on operating the spreadsheet, and which constantly re-inforces the notion of the spreadsheet as a general calculating tool.

5.3 Algebraic difficulties

The difficulties in this category highlight the students' lack of understanding of algebraic concepts and their weaknesses in algebraic manipulation. These deficiencies tended to hinder their chances of obtaining a correct solution despite having a correct approach to the problem. These difficulties are obviously not unique to spreadsheet solutions. The students would have had the same trouble even if they were not using the spreadsheet to solve the problem. However, the spreadsheet enables many calculations to be performed quickly and repeatedly, and there was always a willingness to try again if the results of a particular calculation seemed to be incorrect, or if the researcher pointed out a deficiency in a particular formula or expression. This willingness to recalculate and try again was not observed in these students when they were not using the spreadsheet, which implies that the spreadsheet may be an important motivational factor in its own right.

The students also found it difficult to relate the concept of a variable to the cell of a spreadsheet. They either formulated expressions in terms of x and y, and then could not transfer their expressions to the spreadsheet, or they set up the spreadsheet to calculate only specific instances instead of providing a general expression. The latter situation resulted in major revisions whenever the problem was changed slightly, or a new initial value was to be tried. This situation did improve over the course of the study, with assistance from the researcher, but the students still persisted in initially using traditional pronumerals (such as x and y) and then attempting to translate such expressions into general spreadsheet formulae. A similar occurrence is reported by Horne (1993, p. 203), who states that "in the beginning, the students did not think spontaneously in terms of general formula but they learnt to do this with support from both the spreadsheet environment and the teacher." It is interesting to compare this result with those observed by Healy and Sutherland (1990) and Sutherland and Rojano (1993), who found that the students had little difficulty in generalising their rules. The students involved in these reports were second-year students from a British comprehensive school (who presumably had had little formal algebra instruction) and students who were ten or eleven years of age. These students were specifically chosen because they had received no formal algebra instruction. Healy and Sutherland (1990) believe that the spreadsheet provides students with a "framework within which they can begin to think about how to generalize and formalize" (p. 859).

Horne (1993, p. 203) also comments that "in the computer context the students seem to be able to make the transfer to a symbolic language to represent mathematical relationships more easily." This resulted from the students to which Horne refers being taught algebraic concepts with the aid of a spreadsheet. This leads to the notion of a variable being represented by a spreadsheet cell, which perhaps has more meaning and relevance than a pronumeral. Hence it seems that the spreadsheet may be a useful tool in the development of both the concept of a variable and the process of generalisation.

5.4 Formulating a suitable model (getting started)

The only difficulty encountered here that could be attributed to the spreadsheet was the students' tendency to "jump in" and try to use the spreadsheet to solve the problem without really considering how it could be used. This was most probably because the students were aware that they were being studied and believed that the spreadsheet should be used under all circumstances. This situation was remedied to a certain extent through assurances from the researcher that it was not necessary to solve the problem with the spreadsheet alone (or even at all). The students also seemed surprised at first when they discovered that the spreadsheet did automatically provide the correct solution. It appears that these students had only previously used specialised commercial software in their school core subjects (i.e., Mathematics, Social Studies, Science, and English), and these programs always gave the same (presumably correct) answers when given the appropriate data or instructions. It is not known to how much of this type of software the students had been exposed, nor exactly in what areas.

The other difficulties encountered in this category may apply equally to situations where a spreadsheet was not available. However, the students anxiousness to get immediately to the solution, and the tendency to misread problem statements, may have been a result of the circumstances surrounding the study. The students were almost certainly nervous, at least in the initial sessions, which could explain some of their mistakes.

5.5 Relating spreadsheet results to the original problem

This area of weakness tends to appear with the use of any calculating device. Students tend to write down every single digit displayed without considering the number in the context of the original problem. For example, if a student is required to calculate the number of workers needed to complete a particular job within a specified time limit, they will use their electronic calculators and conclude that "the answer" is 5·5. No thought seems to be given to the notion that it's not possible to have 0·5 of a person. The same lack of thought, or reflection, was observed when the students were using the spreadsheet, which is perhaps not surprising. It would appear that by using such a device to free the student from tedious and possibly lengthy manual calculations we are allowing them to devote more of their energy to concentrate on strategies and "see the big picture", but at the expense of ignoring the meaning of numerical results. It may be that numbers are just strings of digits with little meaning to the students, and that whatever is produced at the end when a calculating device is employed must be the final result.

While the students were working on a slight variation to Problem 4 (calculating the maximum volume of a box) the researcher needed to provide some encouragement before the students refined their original results. They seemed to be willing to accept that their first attempt was either correct, or the only possible result. It was also noted that the students took some time (with some assistance) to realise that the range of test values could (and should) be varied in order to locate the areas of interest. This technique was actually covered in their usual mathematics lessons to maximise or minimise certain functions, but the students were required to perform the calculations themselves using their calculators. This seemed to confuse the issue when they tried to use the spreadsheet, since the students did not seem to recognise it. Once the similarity was pointed out, the students had no further trouble (except for refining too far, as pointed out above). In fact, using the spreadsheet seemed to clarify the technique and an improved performance was noted by the researcher in this area during their normal mathematics lessons.

5.6 Lack of trust or belief in themselves or the spreadsheet

There were definite indications that the students had very little confidence that the spreadsheet was giving them the answers they felt they were supposed to get. It is unclear whether this was the result of mistrusting the spreadsheet itself or a belief that the student could not possibly have done it right. One student initially said that "with a computer you always get the right answer". However, this statement seemed to be at odds with what was observed when the student was required to provide the framework and the data for a solution. During the times when a teacher prepared template was used, the students appeared to be more willing to accept the results as true or accurate, even when those results were wrong. It was interesting to note that the students wanted their electronic calculators in order to verify the calculations performed by the spreadsheet. The results obtained in this manner were virtually never questioned. It appeared that their experience and familiarity with electronic calculators made these devices a trusted ally. If spreadsheets were used to the same extent then an electronic spreadsheet may just be considered a much more flexible calculator, with a consequent increase both in the students' desire to use it and in their confidence in the results obtained.

However, these students (from the researcher's experience with them) tended to have a disturbing lack of confidence in themselves both in and out of class, anyway. Therefore, it is unclear whether or not the spreadsheet actually exacerbated the condition. There is the possibility that the lack of confidence was an existing trait of these particular students. Nevertheless, this issue needs to be kept in mind by educators since the students' beliefs can have a powerful effect on their success and their desire for success (Schoenfeld, 1992).

Chapter 6: Limitations

As has been noted previously, this study was an initial attempt to investigate the conceptual and strategic difficulties encountered by students when solving mathematical problems with the aid of a spreadsheet. The sole focus was on identifying such difficulties and attempting to provide some means of categorizing them.

Four students were chosen by the researcher from an existing class. The selection process was biased to include only those students who were perceived by the researcher to be co-operative and communicative. Therefore, the sample is not necessarily representative of any particular student group. Also, gender differences cannot be inferred due to the low number of subjects.

The researcher attempted to interact with the students in a non-judgemental way, and to refrain from providing direct answers. When students appeared to be incapable of further progress leading questions were asked that were intended to stimulate thought and discussion amongst each pair of students. However, this study was the first of its kind undertaken by this researcher, and thus the researcher's inexperience may have resulted in body language or comments that acted in opposition to the desired result.

The sessions were held at irregular intervals because of the difficulty in finding a common meeting time. This resulted in a somewhat disjointed presentation, and may have created problems for the students since any skills learned in one session might not have been reinforced in time for those skills to have been assimilated. This irregularity also meant that the students were involved in their usual daily subject classes, including mathematics sessions (the researcher was also their regular mathematics teacher). Therefore, the students' knowledge of any required processes and prerequisite information would almost certainly have changed during the course of the study. Perhaps more importantly, the external pressure involved in keeping up with their studies, as well as participating in various extra-curricular activities, could have lead to the students performing differently than they may have done otherwise. Hence, the types of difficulties encountered by the students may have been shaped by these external influences.

There was only just over six hours of instruction time in total, with the students using the computer for most of that time. This is almost certainly insufficient for the effective teaching of spreadsheets, and more time would need to be spent if the teacher wanted the students to become proficient and confident in the use of a spreadsheet. The time allocation for this study was a compromise between what was seen as sufficient for the students to reveal any difficulties and the time available.

Since it was not necessarily the intention to increase the students' proficiency in mathematical problem-solving or in using a spreadsheet, there was no testing done to ascertain their pre-study or post-study level of expertise in either area. However, the initial instruction phase (see Appendix One) was conducted in order to ensure that the students had a common minimum base from which to work. Therefore, no conclusions may be drawn as to what type of student might encounter the difficulties identified through this study. That is, they are not necessarily associated with beginners, or experts, or any other such label. In fact, these difficulties may only be associated with the students involved in the study at the time the study was conducted. However, it is hoped that the types of difficulties identified will prove useful in providing a basis from which further studies may be launched, as well as giving teachers some "food for thought".

Chapter 7: Implications

7.1 Implications for the classroom

The literature and the indications from this study imply that a spreadsheet is an excellent tool for the introduction of algebraic concepts. Most of the difficulties identified in this study would probably have existed without the use of the spreadsheet, since they seemed to relate primarily to the students' problem-solving skills. The difficulties that could be attributed to the spreadsheet were apparently overcome relatively quickly, although the students would require much more experience before the spreadsheet was accepted the way the electronic calculator is accepted. Healy and Sutherland (1990, p. 858) believe that if students can experience successful spreadsheet use they will eventually be able to decide for themselves when it is appropriate to use a spreadsheet for a particular problem. If this situation is to occur, then the spreadsheet needs to be available at all times, and the teacher needs to provide considerable initial support in the form of appropriate introductory activities.

However, as pointed out by Horne (1994), most of the research has focussed on small groups of children who were not learning in "their normal classroom as part of their normal mathematics program" (p. 348). Horne questions the effectiveness of the computer approach when implemented in a "normal school environment with the normal classroom teachers operating the program" (p. 348). This implies that for success in schools the teachers need to support the idea wholeheartedly, and require expertise in using computers and spreadsheets so that they are confident enough to use them as part of their usual teaching strategies, or at least make them available for their students. In this way the spreadsheet can be integrated into the classroom environment.

Unfortunately, there are other constraints limiting the acceptance and use of spreadsheets in schools. Some of these constraints are discussed by Ellerton (1994), who identifies such factors as lack of teacher in-servicing, teachers being faced by students with a wide range of computing ability, and computer access being limited through the computers being placed together in a special computer room. An example of these factors is provided by Horne (1994), who relates the instance of two Year 7 mathematics classes that "were timetabled against the computer science classes so what previously and in initial planning had been excellent computer access was suddenly reduced" (p. 349). Access to the computers is difficult when a school's computers are set up in a specific area and many classes require the room at the same time, or when the computer rooms are under the control of a particular department that has total control over access. In a similar way, normal classrooms which are upstairs may deter the teacher from lugging the computers into the room because it is seen to be too much trouble or too difficult to arrange. Newhouse (1994) believes that computer use in the classroom needs to be "optional; associated with significant rather than peripheral, activities in the course; available when and where it is needed" (p. 161). That is, the computer needs to be in the students' usual classroom so that students can use it when the student feels it is required. Teachers also need to provide activities which relate to the mathematics course being taught, rather than provide artificial activities so the students can use the computer. Given that these difficulties can be overcome, the use of computers in general, and spreadsheets in particular, seems to have merit in teaching mathematics, especially algebra.

7.2 Future research

The next step would be to examine a larger group of students in order to survey the extent of the difficulties identified here, and thus provide a firmer basis for further study. It would also be of benefit to examine how spreadsheets would fit into a normal classroom situation, under the control of the usual classroom teacher, since it has been identified that most of the research has been conducted in highly artificial environments (Horne, 1994).

Future investigations could also look at the ways in which the students' beliefs affect their readiness and willingness to adopt the spreadsheet as a calculating tool, and compare these with the teacher's beliefs and attitudes. Ultimately it is the teacher who must be convinced of the worth of computers and spreadsheets before they will be accepted and adopted into mainstream classes. In fact, Newhouse (1994) states that "teacher characteristics are the most significant determinants in whether classrooms will involve computer use and what types of classroom learning environments are developed" (p. 160).

It would also be useful to examine in more detail the use and effectiveness of using a spreadsheet to teach basic algebraic concepts, since there is already evidence which implies it may be a better strategy than traditional methods. However, as pointed out by Horne (1994, p. 353) "Techniques and instruments for monitoring the students' algebraic development need to be refined so that the meaning students attach to the tasks can be studied in relation to their interaction with the algebraic environment of the spreadsheet."

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Appendix 1

Initial Instruction Phase

Objectives:

At the end of this session each student will be able to

1. load the spreadsheet program into the computer.
2. navigate around the spreadsheet using cursor keys and the mouse.
3. locate particular cells based on their address (e.g. A4, C7).
4. edit particular cells, including deletion of cell contents.
5. use the menu to save and load spreadsheet templates or files to a floppy disk.
6. correctly use the terms: column, row, cell, label, data, value, formula.

Methods of Achieving Objectives:

The teaching method will essentially be that described by Brown (1986-87). The chart and student handout are based on Brown's (1986-87) examples.

1. With reference to the chart provided in Appendix 2, the instructor will explain

    (a) columns, rows, and cells

    (b) the method of addressing cells through the intersection of rows and columns.

2. Each student will be given a copy of the chart and the handout (see Appendix 3).

3. Each student will complete the questions on the handout by filling in the appropriate cells on their own copy of the chart, and perform the calculations manually.

4. The instructor will show the students how to load and run the spreadsheet program.

5. The students will then use the electronic spreadsheet to enter the values and the labels in the appropriate places. Methods of spreadsheet navigation will be demonstrated by the instructor and practised by the students.

6. The students will then be shown how to enter a formula to perform the required calculations, after considering their manual method.

7. The student handout will be completed using the computer.

8. The resultant spreadsheet will be saved for future reference.

Appendix 2

	A	B	C	D	E	F	G
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

Appendix 3

Student Handout

1. Fill in the chart using the following information:

A1 NAME	A3 SMITH
C1 TEST	B3 JOHN
C2 ONE	A4 SMITH
D1 TEST	B4 MARY
D2 TWO	A5 SMITH
E1 TEST	B5 LEANNE
E2 THREE	A6 SMITH
F1 EXAM	B6 TYSON
G1 AVERAGE	A7 SMITH
B7 DIANA	A9 CLASS
B9 AVERAGE	

2. Enter the following data into the appropriate cells.

NAME	TEST ONE	TEST TWO	TEST THREE	EXAM	AVG
SMITH JOHN	95	100	97	100	
SMITH MARY	92	93	90	93	
SMITH LEANNE	82	85	87	92	
SMITH TYSON	75	82	89	90	
SMITH DIANA	100	85	90	94	
CLASS AVG					

3. Calculate each student's average and enter the result in the column labelled AVG.

4. Calculate the class average for each test and place the results in the row labelled CLASS AVG.

5. Some incorrect information was recorded. Some cells need to be changed.

   DIANA scored 78 on TEST THREE.

   TYSON scored 100 on TEST ONE.

   LEANNE scored 68 on TEST TWO.

   Enter the new data and recalculate where necessary.