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Exploring the mechanisms through which computers contribute to learning

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Abstract Even though it has been established that the incorporation of computers into the teaching and learning process enhances student performance, the underlying mechanisms through which this is accomplished have been largely unexplored. The present study aims to shed light on this issue. Two groups of 10 secondary school students were tutored by their geography teacher in how to solve correlational problems. Students in the one group used paper and pencil while students in the other group used a computer spreadsheet. All tutorials were videotaped, transcribed verbatim, and subsequently all transcripts were segmented and coded. The mean frequencies for teacher and student behaviours between the two conditions were then compared. Results indicated that teacher behaviour in the two conditions differed in terms of error feedback, factual and conceptual questions asked, regulation of students, and task management. Regarding student behaviours, the findings showed that the two conditions differed in terms of task engagement, goal setting, and explanations given. On the basis of these findings the issue of mechanisms is discussed and three main implications for the teaching and learning practice are drawn.

Keywords: Control group; Correlational reasoning; Discourse analysis; Problem solving; Secondary; Spreadsheet

Introduction

The launch of the personal computer into the market in the early 1980s led to the introduction of computers in education according to various rationales (Hawkridge, 1990). Meta-analyses of the effects of computers on learning show a moderate effect with the average effect size ranging between 0.20 and 0.47 standard deviations (e.g. Niemiec & Walberg, 1992; Kulik, 1994; Fletcher-Flinn & Gravat, 1995; Christmann *et al.,* 1997). Despite all this evidence, there is very little evidence of *how* exactly computers do yield this effect.

On the one hand, the *mechanisms through which computers contribute to learning attracted relatively little attention*, mostly due to the initial research orientation towards the instructional effectiveness of computers compared to more traditional instructional methods. Most of the studies conducted were product-oriented ones, focusing mainly on performance improvement (i.e. product). The

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computer assisted learning literature is characterised by a paucity of process research, which involves studying classroom learning on a microlevel.

On the other hand, previous research has mainly focused on performance improvement while there are reasons to believe that computer effects are not confined to boosting learning performance: changes in the teaching and learning practices are also effected. It has often been argued that computers cannot simply be an add on to the classroom, functioning as an additional instructional medium and a few studies have confirmed this (e.g. Brown *et al*., 1993; Waxman & Huang, 1996). Despite such findings, there is very little solid evidence of the how technologies impact on learning (Saljo, 1999) and on teaching and learning practices.

Because the impact of computers on student performance is indirect, that is it is effected through instruction, one way of examining the mechanisms through which computers contribute to learning is to focus on instruction and investigate how the computer influences teacher and student behaviours.

The present article aims (a) to address the issue of the mechanisms through which computers contribute to learning by focusing on teacher and student behaviours, and (b) to discuss the implications of computer use for the teaching and learning practice. Data is drawn from a comprehensive research project (see Karasavvidis, 1999).

Background of the study

To investigate the impact of computers on teacher and student behaviours several questions had to be answered.

What criterion to use in which student and teacher behaviours can be interpreted?
To fully understand the impact of computers on teacher and student behaviours, a criterion is needed against which these can be compared and interpreted. Such a criterion may be teacher and student behaviours when the same task is being solved using a different cognitive tool like paper and pencil.

Which teacher and student behaviours to target?
Given the wide range of possible teacher and student behaviours, three main types of behaviours were selected as being particularly relevant for the purposes of the study: task-specific, task-general and regulatory. Task specific behaviours for both teacher and students are of essential importance, as they refer to actions required to perform the task. General task behaviour for both teacher and students is equally important and refers to explanations, elaborations, references, interpretations, and providing and requesting factual and conceptual information. Finally, regulatory behaviours are also considered to be important because learning a new task involves not only the acquisition of cognitive strategies but also of regulatory skills.

What sort of task and computer software to use?
Given that one of the primary objectives of education is to make students efficient problem solvers and one of the most prominent uses of computers across the curriculum is for problem solving purposes, it was decided to focus on computers and problem solving. Moreover, it was decided to focus on the computer spreadsheet since it is an application that has been widely used in various curriculum areas (e.g. Mokros & Tinker, 1987; Lambrecht, 1993; Rinhard *et al.,* 1997).

Given the importance of correlational reasoning for both school and real world settings it was decided to use a correlational reasoning task. Correlational problem solving can be defined as 'finding the degree of association between two or more variables that cannot be physically manipulated by the problem solver' (Ross & Cousins, 1993a, p. 44). Moreover, the choice of correlational reasoning was very convenient because (a) appropriate tests and instructional materials for the teaching of correlational reasoning had been developed, and (b) a series of studies comparing the instructional effectiveness of a computer spreadsheet with that of paper and pencil for the teaching of correlational problem solving had been carried out (Cousins & Ross, 1993; Ross & Cousins, 1993a; 1993b).

How can teacher and student behaviours be operationalised?

It should be emphasised that the interest was not only in what teacher and student did during the instruction but also in why they did it, and what their understanding of it was. The focus was on the moment-to-moment unfolding of the instructional intervention, the aim was to see how the computer is used by the student in the learning process. To this end, the whole instruction was recorded so that the eventual focus could be not only on observable behaviours but also on the accompanying discourse because it constitutes a complete record of everything that transpired in the course of the instruction (Karasavvidis, 1999).

What sort of experimental design to employ?

As referred to above, the focus was on teacher and student behaviours, comparing the solution of a correlational reasoning task with a computer spreadsheet vs. a more commonplace paper and pencil solution. It should be noted that the same group of students cannot be used in the two conditions because if students learn how to solve correlational problems it is impossible to unlearn it. Given that different groups were required, those students should be of comparable age and cognitive skill.

Ideally, a large scale experiment would be appropriate, using an experimental design where 15 teachers with their classes would be involved in the treatment and 15 other teachers with their classes would be involved in the control condition. Practical and methodological considerations, however, did not allow the conduct of such a study. From a practical standpoint, a major concern is the logistics involved in carrying out such a study. From a methodological perspective, the whole class would have to be used as the unit of analysis and conceptual tools for analysing whole learning environments are currently unavailable (Salomon, 1996). Moreover, focusing on a whole class does not allow one to examine the behaviour and reasoning of all students at all times. Even if one focuses on a single student in a whole class setting, it is still not possible to know the student's reasoning and understanding. In such a case all one sees is some form of student activity the reasoning of which cannot be traced (Karasavvidis, 1999).

These considerations led to keeping the comparison between the computer spreadsheet (CS) and the paper and pencil (PP) conditions as simple as possible. This is why a tutorial format was employed. The advantage of using a tutorial format is that it counters potential problems of experience and order effects. More specifically, in a tutorial format, the repetition of the same instruction would cancel possible experience and order effects out. What is more, the tutorial format enables one to record and study individual student behaviour, having student behaviour and reasoning constantly in focus.

To conclude, to study the mechanisms through which computers contribute to learning the focus was on student and teacher behaviours: task-specific, task-general, and regulatory, using a correlational reasoning task and comparing a CS condition with a PP condition. Additionally, discourse was employed as a tool for recording the behaviours and reasoning of teacher and students. Finally, the comparison was kept simple by using a tutorial format. A geography teacher tutored two groups of students in how to solve correlational problems. Students in the one group learned how to solve correlational problems using a computer spreadsheet while students in the other group learned how to solve correlational problems using paper and pencil.

Research question

The goal of the study was to investigate the mechanism(s) by means of which computers contribute to student learning by studying how they impact on teacher and student behaviours and to consider their implications for the teaching and learning practice. The present paper addresses the following question: are the student and teacher task-specific, general, and regulatory problem solving behaviours differentiated and to what extent when students learn how to solve correlational problems using a computer spreadsheet as opposed to using paper and pencil?

Method

Subjects

A group of 10 students (school year 1995–96) participated in the paper and pencil (PP) condition (8 boys, 2 girls; mean age: 15 years 5 months, *s.d.* 10 months) while another group of 10 students (school year of 1996–97) participated in the computer spreadsheet (CS) condition (6 boys, 4 girls; mean age: 16 years 2 months, s.d. 7 months). All students were secondary school students (grade 10) and attended the International School of Eerde, a private boarding school located outside the city of Ommen, in the mid-east of the Netherlands. Approximately half of the students were Dutch nationals. Students were informed about the study by their teacher and expressed interest in participating, while participation was neither compulsory nor did students receive any credit for it.

Instructional materials, software & correlational reasoning test

A set of correlational problems was initially selected from a correlational reasoning module (Brash *et al*., 1991). These exercises were of a problem based format, accompanied by a table with data on two or more variables. An example of such a correlational problem: find out the relationship between smoking and lung disease using the following statistics: (a) tobacco consumed (Kg/capita): 1.4, 1.7, 2.8, 3.5, 4.7; (b) lung disease deaths (20 years later): 5, 12, 24, 36, 56 (Brash *et al.*, 1991). A three step algorithm can be used to solve such a correlational problem: (a) make a graph (b) put information on graph, and (c) read the graph. After some initial piloting with two subjects, eight exercises were eventually maintained and were used for both conditions. Graph paper, the globe and a physical map of Canada completed the list of instructional materials used in the study. Correlational reasoning performance was measured with an instrument developed for the Ross & Cousins (1993a; 1993b) studies. The computer software used in the CS condition was Microsoft Excel version 6.0.

Procedure

The school was officially contacted and the Geography teacher expressed interest in participating in the study. She had been teaching English and Geography for approximately nine years and received payment per hour of participation.

Ideally both conditions would have to be carried out concurrently but there were two main difficulties with this. First, the teacher was neither familiar with correlational reasoning nor did she have any knowledge about spreadsheets. Thus, it was deemed appropriate to introduce her first to correlational reasoning and then to the use of the spreadsheet. Second, there were not enough subjects to allow the formation of two conditions in the 1995–96 school year so students from two successive school years were involved.

Paper and pencil condition (PP)

The teacher was provided with the exercise set and detailed accompanying information. All teacher questions concerning correlational reasoning were answered in detail while no teaching guidelines were provided. An initial set of exercises was piloted with two pupils to provide the teacher with the opportunity to try things out.

During the tutorial, the teacher would assign an exercise for the student to work on. When the exercise was completed, a new one was assigned and this process continued for about three hours with a short 15 minute break after the first one and a half hour. For the sake of consistency, upon the completion of the three hour period the teacher and student simply finished the exercise they were working on. For most subjects this meant finishing their seventh exercise while three subjects solved an eight one. All students solved seven exercises at a minimum. During the tutorials the first researcher was present videotaping the instruction and administering pre-post tests.

Computer spreadsheet condition (CS)

The bulk of preparation involved the extensive familiarisation of the teacher with the computer spreadsheet. Even though she was computer literate she was not familiar with computer spreadsheets. Over a period of 10 hours she was introduced to the spreadsheet application of the Microsoft Office suite: Excel version 6.0. After both supervised and individual practice, the materials, software, and procedure were piloted with one subject.

The same instructional procedure as in the PP condition was followed and teacher–student interaction was videotaped by the first researcher.

Segmentation and coding

All tutorials for both conditions (approximately 60 hours) were transcribed verbatim by the first researcher. In total, about 750 densely typed pages of transcripts were discourse analysed using a quantitative approach. A bottom-up approach was employed in developing a coding scheme. A number of broad teacher and student categories related to teacher and student task-specific problem solving, general problem solving, and regulatory behaviours were initially constructed. After considerable testing and refinement, experts in the fields of discourse and protocol analysis were consulted and a native speaker of English tried out the coding scheme.

The final coding scheme included eight general teacher and six general student categories. More specifically, 31 teacher codes and 38 student codes were used in an attempt to tap the most important teacher and student instructional and learning, problem solving, and regulatory behaviours. It must be noted that because different tools were used in the two conditions, most of the codes were common for both conditions while some were by definition specific to each condition. Teacher categories are presented in Table 1 and student categories are presented in Table 2. More information concerning definitions and examples may be found elsewhere (Karasavvidis, 1999; Karasavvidis *et al*., 2000).

Table 1. Teacher categories

Category	Code	Description
Task-specific problem solving action	TR	Teacher reads
	TM	Teacher marks/takes notes/counts
	TPNI	Teacher provides new information
	TPII[b]	Teacher provides interface information
	TPE	Teacher provides example/explanation
General problem solving action	TREF	Teacher refers
	TESK	Teacher evaluates student's knowledge
	TRAI	Teacher requests additional information
	TIN	Teacher interprets
	TEL	Teacher elaborates
Direct regulation	TFA	Teacher focuses attention
	TSG	Teacher sets a goal
	TSIG[b]	Teacher sets interface goal
	TSST	Teacher summarises step
	TCE	Teacher corrects error
	TCS	Teacher confirms step
	TCT[a]	Teacher covers the table
	TCON[a]	Teacher calls out the numbers
	TSS	Teacher starts sentence
Indirect regulation	TRPL	Teacher requests planning information
	TREV	Teacher requests evaluation information
	TRIN	Teacher requests interpretation
	TRFI	Teacher requests factual information
	TRCI	Teacher requests conceptual information
	TRE	Teacher requests explanation
	TIE	Teacher indicates error
	TAS	Teacher alerts student
Check of understanding	TCSF	Teacher checks if student is following
Confirmation of understanding	TCNF	Teacher confirmation
Emotional support	TSUS	Teacher supportive statement
Task-irrelevant utterance	TCOM	Teacher comment

(a) Codes unique to the PP condition; b. Codes unique to the CS condition

Behaviour segmented according to *speech functions*: every time the utterance of a speaker served a different purpose a new segment was created. The meaning of the term function, however, as used here, is not exhausted by the notion of speech function in the sense of the speech act theory (Searle, 1969). More information as well as explicit segmentation rules can be found in Karasavvidis (1999) — cf. Karasavvidis *et al*., 2000.

Analysis

Two undergraduate students received 40 hours of training in segmentation and coding and independently segmented and coded all the PP condition transcripts.

Segmentation agreement was 97% for all transcripts and the remaining 3% of the segments were removed from further analysis. Cohen's Kappa for interjudge agreement was found to be very reliable: 0.77 for student codes and 0.82 for teacher codes. Disagreements were resolved through discussion between the judges.

Table 2. Student categories

Category	Code	Description
Task-specific problem solving action	SR	Student reads
	SP	Student predicts
	SDIV	Student determines independent variable
	SDA[a]	Student draws an axis
	SLA	Student labels axis
	SDVP	Student determines which variable goes where
	SDCV	Student determines the control variable
	SSD[b]	Student selects data
	SDU[a]	Student determines what the unit is
	SDAU[a]	Student divides axis into units
	SPS[a]	Student puts in scale
	SPL[a]	Student plots
	SDT	Student draws a trendline
	SCT[b]	Student calculates a trendline
	SCLA[b]	Student changes the length of the axis
	SPG[b]	Student produces a graph
	SRG	Student reads the graph
	SSC	Student reports variable relationship
	SCCC[b]	Student calculates the correlation coefficient
	SCPC[b]	Student calculates the partial correlation coefficient
General problem solving action	SEL	Student elaborates
	SPFI	Student provides factual information
	SPCI	Student provides conceptual information
	SFTI[b]	Student follows interface instruction
Self-regulation	SSG	Student sets goal
	SSIG[b]	Student sets interface goal
	SPE	Student provides explanation
	SID	Student indicates difficulty
	SRE	Student requests explanation
Other-regulation request	SRAI	Student requests additional information
	SRCI	Student requests conceptual information
	SRFI	Student requests factual information
	SRII[b]	Student requests interface information
	SAGE	Student requests goal evaluation
	SAGI[b]	Student requests interface goal evaluation
	SAEU	Student requests evaluation of his/her understanding
Confirmation of understanding	SCNF	Student confirms
Task-irrelevant utterance	SCOM	Student comment

(a) Codes unique to the PP condition; b. Codes unique to the CS condition

Because a very thorough and costly approach was followed for coding data from the PP condition, the first researcher segmented and coded all data from the CS condition. The reliability check involved the segmentation and coding of about 10% of the data. An undergraduate student received approximately 20 hours of training in segmentation and coding and coded one randomly chosen transcript. Segmentation agreement was 98%, while Cohen's Kappa was 0.87 for teacher codes and 0.84 for student codes.

Upon completion of the coding, the frequencies of all codes over exercises and subjects were aggregated using GSEQ (Bakeman & Quera, 1995; cf. Bakeman &

Gottman, 1997). This manipulation entailed that each subject had only one frequency per code. To compare the code frequencies in the two conditions is was necessary to remove unique codes in each condition from further analyses and ascertain that the two conditions were comparable. The two conditions were comparable: 13553 events for the PP condition and 14203 events for the CS condition, the difference being not significant (PP mean = 1353.3; *s.d.* = 185.43; CS mean = 1420.3, *s.d.* = 246.265; Mann–Whitney U = 44, $p = 0.684$).

Results

Correlational reasoning performance

Table 3 features student performance on the correlational reasoning test for the PP condition. As can be seen from the table, while students were unable to solve the correlational problem in the pre-test, they managed to do so in the post-test which suggests that they had acquired the requisite knowledge.

Table 3 Pre/post-test performance on the correlational reasoning test for the PP condition

		Pre test		Post test				
		mean	***s.d.***	**mean**	***s.d.***	***t*-value**	**d.f.**	**P**
Organising	[0–4][a]	0.80	1.03	3.10	1.66	4.86	9	0.001
Locating	[0–2]	1.10	0.73	1.80	0.42	4.58	9	0.001
Synthesising	[0–3]	0.70	0.83	1.70	0.94	3.00	9	0.015
Concluding	[0–3]	1.10	0.31	2.10	0.99	3.35	9	0.008

(a) Ranges are given in brackets

Students also failed to solve the pre-test correlational task in the CS condition. As CS students were allowed to use the spreadsheet to solve the post-test task, it was impossible to compare student performance on the skills of organising, locating, and synthesising. Therefore, the only possible pre/post test comparison amongst the four component skills was for the skill of concluding. The comparison indicates that CS students also performed significantly higher on the post-test in concluding (pre-test: m: 0.60, *s.d.*: 0.51; post-test: m: 2.40, *s.d.*: 0.51; *t*-value: – 13.500, $p < 0.000$).

Behaviours

Because a number of teacher and student codes differed significantly between the two conditions they will be grouped in an attempt to discern the underlying patterns for both teacher and student behaviours.

As far as *teacher behaviour* is concerned, the differences between the two conditions can be grouped in three main categories: (a) teacher feedback (b) factual and conceptual questions, and (c) goal setting and task management.

As can be seen from Table 4, the *teacher corrected significantly more errors (TCE) in the PP condition, whereas she indicated more errors (TIE) in the CS condition*. On the other hand, the teacher alerted the students that a mistake was about to be made (TAS), evaluated their knowledge (TESK), requested additional information (TRAI), and provided them with supportive statements (TSUS) significantly more in the PP condition compared to the CS condition.

The *second category* is task-related and involves factual and conceptual information as well as interpretation. As Table 5 shows, the teacher requested conceptual (TRCI) and factual information (TRFI), interpreted student utterances (TIN) and checked student's understanding (TCSF) significantly more in the CS condition.

Table 4. Teacher feedback in the two conditions

		PP condition		CS condition			
		mean	***s.d.***	**mean**	***s.d.***	**M-W U[a]**	***p***
TCE	Teacher Corrects Error	17.8	5.4	11.1	8.9	18.5	0.015
TIE	Teacher Indicates Error	20.2	6.5	32.1	9.8	18	0.014
TAS	Teacher Alerts Student	2.9	2.7	0.9	1.6	24	0.042
TESK	Teacher Evaluates Student Knowledge	11.1	4.3	5.0	2.3	11	0.002
TRAI	Teacher Requests Additional Information	31.8	14.8	11.7	5.9	8.5	0.001
TSUS	Teacher Supportive Statement	3.8	1.6	2.4	3.1	23.5	0.043

(a) Mann–Whitney *U*-test

Table 5. Teacher factual and conceptual questions in the two conditions

		PP condition		CS condition			
		mean	***s.d.***	**mean**	***s.d.***	**M-W U[a]**	***p***
TRCI	Teacher Requests Conceptual Information	71.6	18.7	113.8	21.2	6	0.000
TRFI	Teacher Requests Factual Information	27.3	12.1	40.9	13.1	22	0.033
TIN	Teacher Interprets	11.6	4.9	17.5	6.1	21.5	0.030
TCSF	Teacher Checks If Student Is Following	11.6	4.6	22.5	8.7	10.5	0.001

(a) Mann–Whitney *U*-test

The *third category* involves teacher goal setting and the overall management of the environment. As Table 6 indicates, the teacher set significantly more goals (TSG) and provided more confirmatory feedback (TCS) in the CS condition.

Table 6. Teacher goal setting and task management in the two conditions

		PP condition		CS condition			
		mean	***s.d.***	**mean**	***s.d.***	**M-W U[a]**	***p***
TSG	Teacher Sets Goal	31.1	6.0	49.4	9.9	2	0.000
TRPL	Teacher Requests Planning Information	28.0	6.7	31.2	8.0	40	0.466
TCS	Teacher Confirms Step	84.1	19.6	194.9	34.4	0	0.000

As far as *student behaviour* is concerned, the differences can be grouped in two main categories: (a) general problem solving, and (b) task-specific problem solving behaviours. The task-specific problem solving behaviours can be seen in Table 2. The rest of the behaviours are taken to denote general problem solving behaviours.

With respect to the *first category,* as Table 7 shows, there was only one instance where the mean CS frequency was significantly higher than the corresponding mean PP frequency: the *students set almost twice as many goals (SSG) in the CS condition than in the PP condition*. In all other observed significant differences, the mean PP frequency was significantly higher compared to the mean CS frequency.

Table 7. Student general problem solving behaviours in the two conditions

		PP condition		CS condition			
		mean	***s.d.***	**mean**	***s.d.***	**M-W U[a]**	***p***
SSG	Student Sets Goal	25	7.3	47.8	13.4	5.5	0.000
SRCI	Student Requests Conceptual Information	5	1.9	1.2	0.8	2.5	0.000
SRAI	Student Requests Additional Information	25.8	13.5	10.4	4.8	7.5	0.001
SPE	Student Provides Explanation	38.6	8.8	24.50	10.5	17	0.011
SID	Student Indicates Difficulty	29.4	7.6	19.2	10.6	16	0.008

With regard to the *second category*, i.e. task-specific problem solving behaviour, the mean frequency for student behaviour in the CS condition was significantly higher than the corresponding frequency for the PP condition in most of the cases, as can be seen from Table 8.

Table 8. Student specific problem solving behaviours in the two conditions

		PP condition		CS condition			
		mean	***s.d.***	**mean**	***s.d.***	**M-W U[a]**	***p***
SR	Student Reads	3.8	5.1	10.6	3.9	16.5	0.009
SP	Student Predicts	9	2.2	11.1	2.0	21.5	0.027
SDIV	Student Determines Independent Variable	7.5	2.2	12.4	3.5	10	0.001
SDVP	Student Determines Variable Position	6.2	2.3	8	5.8	47	0.840
SDCV	Student Determines Control Variable	1.7	1.7	1.9	1.3	42.5	0.572
SLA	Student Labels Axis	2.8	2.6	23.1	3.5	0	0.000
SDT	Student Draws Trendline	6	1.9	11.5	4.3	8	0.001
SRG	Student Reads Graph	31.2	5.7	17	3.1	0.5	0.000
SSC	Student States Conclusion	16.2	7.1	27.9	5.5	9.5	0.001

Discussion

Performance

While students in both conditions were novices they eventually became competent correlational problem solvers. Even though there appeared to be no performance differences between the two conditions, they differed in one respect: CS students could not solve the post-test task using paper and pencil even though they immediately realised that a graph was required. Therefore, CS students were able to solve the correlational task but *only* with the aid of the computer spreadsheet. By means of illustration remarked: '*I know I have to make a graph, but how on earth am I gonna do it?*'. This student comment is remarkable because it indicates that when the tool is unavailable the problem solver is rather lost.

Teacher categories

The observed pattern regarding feedback suggests that the presence of the computer spreadsheet differentiated teacher feedback in the two conditions. More specifically, error indication (TIE) is an indirect form of error feedback while error correction (TCE) is a more direct form. An error in making the graph in the CS condition does not require much time or effort to correct and is without consequences. On the contrary, an unnoticed graph construction error in the PP condition can be devastating in terms of both time and effort required for its correction. Student learning is differentially affected by these two types of feedback. In the case of error indication the student is expected to figure out what is wrong while in the case of error feedback the student is informed about what is wrong. In the PP condition it was observed that the teacher was very quick in pointing out to the student that an error has been made especially during graph construction. Some errors were deliberately not highlighted by the teacher, often to students' devastation and disappointment (students complained: 'you should have told me!' or 'this is mean!'). This behaviour suggests that the teacher was concerned with the possibility of making mistakes and tried to prevent such mistakes from occurring much more in the PP condition compared to the CS condition.

The fact that in the CS condition there is significantly more teacher confirmatory feedback (TCS) can be accounted for by the fact that the students were using a new environment and at least in the first few exercises they had to be taught certain procedures the learning of which sometimes required step by step confirmation.

The differences in factual and conceptual questions in the two conditions are due to the fact that more graphs were made in the CS condition and therefore many more conceptual and factual information questions could be asked by the teacher for each graph. From a learning point of view, the fact that many conceptual questions (TRCI) are raised by the teacher is very promising because it means that the level of task engagement can be higher. The fact that more factual information questions (TRFI) were asked in the CS condition is related to the spreadsheet interface as a common referential perspective had to be established and several questions were initially asked.

Finally, the fact that the mistakes in the computer environment did not cost much time to repair was expected to lead to more independent and exploratory learning. The teacher was expected to interfere less on the direct level (TSG) and be more involved on the indirect level (TRPL). This expectation, however, was not confirmed by the data, as the teacher set significantly more goals (TSG) in the CS condition whereas no significant difference was found concerning planning questions (TRPL). This finding suggests that the teacher dominated the CS condition much more than the PP condition.

Student categories

The fact that students requested significantly more conceptual information (SRCI) in the PP condition indicates that they were more self-regulated. Moreover, in the PP condition the students requested significantly more additional information (SRAI), a result suggesting that the students were more actively monitoring their own understanding. On the other hand, the fact that the students provided significantly more explanations (SPE) in the PP condition, suggests that the students gave more reasons in that condition. This finding is particularly important, in light of the fact that the difference in teacher explanations was not significant. Finally, *students indicated difficulty (SID) significantly more in the PP condition*. This finding is in line with previous conclusions about how errors were handled by the teacher in the two conditions.

The fact that the mean frequencies for most task specific problem solving behaviours were higher for the CS condition can be accounted for by the fact that more graphs were made. On the other hand, reading the graph (SRG) was found to be occurring significantly more in the PP condition. This finding is difficult to account for, provided that more graphs were made in the CS condition. To conclude, the fact that the students provided more conceptual information in the CS condition is to be expected, given that the teacher requested more conceptual information for the CS condition.

In addition to looking at how the two conditions differed it is also instructive to note how much alike they were. Teacher instruction did not seem to be differentiated between the two conditions for the following behaviours: providing new information, providing explanations, referring to information previously presented, summarising a step, focusing attention, starting a sentence, asking for explanation, evaluation, and for goal setting.

General discussion

On the issue of mechanisms

Three main mechanisms were identified: errors, task engagement and regulation.

Errors In the PP condition the teacher-student dyads needed to detect the errors in the offing. The most common errors were related to graph construction (axes, scale, units, plotting). On the other hand, even though students in the CS condition made a lot of errors as well, these were interface-related: students would drag a graph to the side more than necessary; entering data was inaccurate; clicking on the wrong spot. On the basis of these observations, it may be argued that by using the spreadsheet students are essentially relieved from the anxiety of error making and may freely focus on other important aspects of the task. There is also more freedom for exploration and, thus, the errors acquire a more instructive role, turning to learning possibilities. Thus, one of the main mechanisms through which computers positively contribute to learning seems to be associated with errors and their functions: the types of errors that are likely to occur, the meaning these errors can take, the implications of making errors in terms of time and effort required to correct them, and finally how the errors can be used for instructional purposes.

Task engagement was found to be higher in the CS condition. Most student task specific problem solving behaviours were more frequent in the CS condition because more graphs were made per exercise so there were more possibilities to use the requisite skills for their construction and discuss the outcomes. Of equal importance is that fact that more teacher factual and conceptual questions were asked in the CS condition. These findings suggest that the use of the spreadsheet creates more possibilities for active task engagement in certain respects, especially regarding stating variable relationships and providing task related answers and information. Thus, one of the main mechanisms through which computers positively contribute to learning appears to be related to task engagement: students are more involved with certain task dimensions and are faced with many more conceptual and factual questions to which they should respond.

Regulation. Because the teacher set more goals in the CS condition it appears that she had more control. On the other hand, the fact that students in the CS condition set almost twice as many goals compared to students in the PP condition shows that students' active participation in determining what to do was much higher in the CS condition. Therefore, students seemed to regulate themselves more despite the fact that there were more teacher goals set for the same condition. It should be borne in mind that due to the spreadsheet interface many more possibilities were available in the CS condition and, thus, setting more goals was rather inevitable. Thus, one of the main mechanisms through which computers contribute to learning seems to be associated with regulation: students make more task relevant decisions on their own.

On differential effects on performance. As the performance results indicate, there was essentially a differential learning effect, because students in the two conditions basically acquired different skills. Extending further Salomon's (1992) distinction between effects *with* the tool and effects of the tool, one might speak of effects *without* the tool: when a certain technology does become ubiquitous, at least in some respect certain activities can only have meaning in relation to it.

Implications for designing instruction

On the basis of the outcomes of this study, three main suggestions for the design of computer based instruction can be made. *Firstly*, if exploration and experimentation are explicit learning goals, it is suggested to use the spreadsheet because it relieves the anxiety of making mistakes. *Secondly,* if the learning goals include higher order aspects of the task such as interpretation, reflection, and meaning making it is suggested that the spreadsheet is used. On the other hand, if instruction is aimed at developing basic skills then the use of the spreadsheet is not recommended. *Finally*, when more independent decision making on the part of the students is desirable, it seems appropriate to use the computer spreadsheet as students are likely to exhibit more self-regulatory behaviour.

To conclude, this research is seen as a first step in a new direction by exploring the mechanisms through which computers contribute to learning. Three main mechanisms were identified by comparatively examining how correlational problems are solved using two different cognitive tools: paper and pencil vs. computer spreadsheet. Those mechanisms involve the dimensions which seemed to be differentiated in the computer spreadsheet condition: (a) errors become unimportant having no significant consequences (b) task engagement increases at conceptual levels, and (c) student self-regulation increases as students take more independent decisions. Based on these mechanisms, it is suggested that the computer spreadsheet be used when exploration, higher level engagement, and independent decision making is sought after. It is the task of future research to inquire the proposed mechanisms further.

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