LEARNING TO SOLVE CORRELATIONAL PROBLEMS
A study of the social and material distribution of cognition

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On the surface, this dissertation appears to be the product of individual work. After all, *my* name is on the cover. This is misleading, however, because the work not solely the product of individual effort: two categories of people have irrevocably contributed to it and, thus, my debts are twofold. On the one hand, I wholeheartedly wish to thank all those people who assisted me in various ways in actually completing this work. People falling under this category include teachers, colleagues, and friends who worked with me, offered support, suggestions, criticism, skepticism, counter arguments, feedback, cooperated with me and practically assisted me in every conceivable way. On the other hand, my debts are also huge to a second category of people whose thinking has had a profound influence on my own and, consequently, on the ideas and research reported in this book. These are people I've never met or worked with (in most of the cases this would have been downright impossible) but who developed most of the theories, ideas, and methods used in this research. Most of the ideas expressed in *my* dissertation were instantiated through a dialogical interplay with theories and ideas put forward by *others* decades or even centuries ago.

Therefore, the presence of *my* name the cover does not tell the whole story. In a way, *my* name manifests *my* contribution but *not* the contribution of *others* to *my* thinking and *my* understanding. *Their* contribution to *my* thinking can be clearly seen in the list of references and, hopefully, should also be conspicuous throughout the text. Due to the fact that ideas are dialogically interrelated, the confines between my ideas and theirs are undoubtedly blur. Of course, as it is customary to say on such occasions, omissions, misinterpretations, and mistakes are all mine.

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Enschede,
Ilias Karasavvidis
7-1-1999

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“Do not ask how it can be like that. That, nobody knows”
R. Feynman

Overview

This dissertation examines the contributions of teacher and computer spreadsheet to the development of correlational reasoning skills in the context of a computerized instructional intervention.

In chapter 1 the general context of the problem is presented and the research problem is outlined. More specifically, a computerized instructional intervention aimed at improving secondary school students' correlational reasoning skills is thoroughly examined and two main problematic features are identified: (a) a number of computer properties are associated with the improved student performance without any solid data being presented in this respect; (b) the role of the teacher for the success of the computerized instructional intervention is not considered. These two dimensions of the research problem are then generalized to the literature and discussed from a historical perspective.

In chapter 2 the research problem is analyzed from a theoretical and methodological point of view, in an attempt to determine its origins. Two main claims are made: (a) a first requirement in resolving the research problem is a method of investigation which focuses on the process rather than the product of a computerized instructional intervention; (b) a second requirement for resolving the research problem is a theoretical framework which provides constructs for the conceptualization of the main dimensions of the problem, i.e. teacher and computer spreadsheet.

In chapter 3 a theoretical framework according to chapter 2 specifications is laid out. More specifically, Distributed Cognitions theory is examined. The following points are stressed in this chapter: (a) cognition is not only to be found in the head, where it supposedly resides; it is distributed in social and material ways; (b) the social distribution of cognition involves social others (parents, teachers and peers) who have to be taken into account in the process of learning how to solve a task; (c) the material distribution of cognition involves artifacts which embody intelligence and have a significant bearing on the performance of a task.

A set of methodological tools meeting the requirements set in chapter 2 is presented in chapter 4. In particular, two types of analyses are described: (a) discourse analysis, and (b) activity analysis. Firstly, three types of discourse analysis are elaborated: frequency, sequential, and genre discourse analysis, the first two being quantitative while the last being qualitative. A three dimensional model for analyzing classroom discourse is also introduced. Secondly, activity analysis, which involves the representation of activity in three levels, is also presented.

In chapter 5 the research problem is revisited and, in light of the theoretical and methodological specification discussed in chapters 3 and 4, it is cast in a researchable form. Based on the constructs provided in chapter 3, the role of the teacher can be conceptualized in terms of: (a) transition from other to self-regulation, and (b) genre appropriation. On the other hand, the contribution of the computer spreadsheet can be conceptualized in terms of (a) amplification, and (b) transformation. Additionally, two specific research goals are stated, and the rationale as well as the setup for investigating them are outlined. In particular, the design involves conducting two studies, study 1 to investigate the role of the teacher in terms of regulation and genre appropriation, and study 2 to inquire the role of the computer spreadsheet amplification-wise, and transformation-wise. Finally, information about the method and the procedure followed in conducting these studies is given.

In chapter 6 the findings of study 1 are presented. With respect to the transition from teacher regulation to student self-regulation, the results partially supported the theory. Regarding genre appropriation, the analysis suggested that the voice of the teacher is gradually being assimilated into the voice of the student.

The findings of study 2 are presented in chapter 7. With the exception of speeding up one aspect of problem solving, the computer spreadsheet seemed to have no other amplification effect. However, data form study 2 substantially validated the transformation views as far as specific problem solving actions, and communicative actions are concerned.

In chapter 8 a general discussion of the findings follows, and a number of conclusions and implications regarding the research problem are drawn.

Chapter 1

1 The research problem

The present chapter is aimed at introducing the research problem investigated in this dissertation. Firstly, the general context of the research problem is introduced: the issue of computers and learning is discussed and some important literature findings are presented. Secondly, the specific context of the problem is addressed: (a) a computerized intervention aiming at improving secondary school student's acquisition of correlational reasoning skills is presented in detail and (b) two specific problematic aspects of the intervention are identified.

1.1 The general context of the problem: Media, computers and learning

> "*Basically, computers can become partners in cognition with learners, undertaking selected portions of the cognitive processing learners need to do and facilitating other portions in ways that foster higher order learning…computers can make easier and more efficient what might otherwise need to be done in more cumbersome and convoluted ways or – as in the case of constructing multimedia presentations, communicating with overseas peers, searching through archives and rich databases, or building dynamic models – enable that which could not possibly be carried out in their absence…the catch is that a lot depends on the details*"
>
> Salomon & Perkins (1996, pp. 124-25)

The development of the personal computer (PC) in the early 1980s led to the introduction of computers in educational settings according to various rationales (e.g. Hawkridge, 1990). According to one such rationale, computers can revolutionize education and enhance learning in multiple ways, making it more meaningful (e.g. Papert, 1980). Whether computers, and new technologies in general, can influence learning is an issue long debated in education. For instance, it had been argued in the past that technologies like film, radio, and television would revolutionize learning. Despite the fact that it was believed that these new technologies held great promise for education, history showed that in the overwhelming majority of cases these expectations were largely unfulfilled. From the very outset, the issue of how computers might influence learning was deemed to be a special case of the ongoing media and learning discourse[1], the computer being a new powerful technological medium.

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[1] Salomon (1974; 1994) introduced the concept of *media attributes*, and outlined four different factors affecting the use of media for learning: (a) symbol system; (b) message; (c) learner and (d) the task. He argued that symbol systems, i.e. means by which messages are coded, are media's most important attributes because they vary with respect to the mental transformations they require and, therefore, the mental skills activated to extract knowledge from the medium also differ. In this sense, the coding elements of a medium's symbol systems can be made to cultivate the mastery of specific skills by either activating or supplanting these skills. Compared to other media, the computer was considered to be a very powerful one because of its capabilities to process and transform symbols. By virtue of this capacity, the computer was expected to make a significant contribution to learning.

Clark (1983; 1985), who initiated the computers, media, and learning debate in the early 1980s, developed the truck-delivery metaphor, according to which the truck delivering groceries has no bearing on their nutritional value. He argued that in most of the media studies there is a confounding between medium and method, since different teachers are delivering the instruction. He also claimed that the medium *can* be separated from the method (Clark, 1985; 1991; 1994). More recently, he used the medicine metaphor to describe media effects on learning: the same chemical ingredient can be delivered in many different ways in medicine but these have the same effect on the disease; he claimed that the same holds for instructional media (Clark, 1991). He also disagreed with the media attributes argument proposed by Salomon since no single media attribute has or leads to a unique cognitive effect (ibid.). Moreover, he objected to ‘the medium is the message’ metaphor because “the uses of the medium do not limit the method or content it is capable of presenting” (Clark, 1991, p. 36). Finally, Clark (1994) took the extreme position that media will never influence learning.

Kozma (1991; 1994) was among the many scholars who responded to Clark’s claims at a theoretical level. His rebuttal (Kozma, 1991) focused on evidence from various studies suggesting that the processing capabilities of the computer can influence the mental representations and the cognitive processes of the learners. Kozma, accepted the fact that, in principle, some students will learn a particular task regardless of the instructional medium used, while others might particularly benefit from certain characteristics of the medium. As opposed to Clark’s plea to strictly separate medium from method, Kozma (ibid.) argued that Clark’s position creates a schism between medium and method whereas the two have a more integral relationship and, thus, cannot be separated. More recently, however, Kozma took a more radical position by claiming that “if media are going to influence learning, method *must* be confounded with medium” (Kozma, 1994; p. 16; original emphasis).

This theoretical debate aside, numerous computer-based learning (CBL), computer assisted instruction (CAI), computer-assisted learning (CAL) studies have been conducted in all education levels and curriculum areas, using software ranging from drill and practice to simulations, spreadsheets and word processors. Given the objectives of the present study, it is impractical to review any such individual CAL studies, and, therefore, we will only concentrate on quantitative reviews. Results from meta-analyses indicated that *the use of computers boosts student performance*, the average effect size ranging between .20 and .47 standard deviations, which is generally considered to be a moderate effect (see Niemiec & Walberg, 1985; Kulik, Kulik & Bangert-Drowns, 1985a; 1985b; Niemiec & Walberg, 1987; Niemiec, Sikorksi & Walberg, 1989; Niemiec & Walberg, 1992; Kulik & Kulik, 1991; Ryan, 1991; Liao & Bright, 1991; Khalili & Shashaani, 1994; Kulik, 1994; Fletcher-Flinn & Gravat, 1995; Christmann, Badgett & Lucking, 1997). Other related findings for the present discussion: (a) short duration studies yield higher effect sizes; (b) the effect sizes are also higher when different teachers deliver the instruction to the experimental and control conditions, and (c) the effect size varies depending on the curriculum area, the highest effect sizes reported in science.

This meta-analytic evidence has been challenged by Clark (1985). *Firstly*, he argued that with the meta-analysis “the emphasis is on *whether* things worked rather than exactly what it was that made the difference” (p. 391, original emphasis) and, as a consequence, “what meta-analyses do not tell us is what aspect of the treatment may have led to the measured effect” (p. 392). Clark proposed that what is needed is an explication of the treatment so that what makes it work can be determined. Eventually, this specific point came to be accepted by Kulik (1994) who conceded that “statements about generic computer-based instruction are… of limited value” (p. 22).

Secondly, Clark (1983; 1985; 1991; 1994) has interpreted two specific findings of meta-analyses as evidence that it is not the attributes of the medium that make the difference. More specifically, the meta-analyses had showed that (a) short treatments yielded higher effect sizes and (b) when the same instructor taught experimental and control groups, the effect sizes favoring CAI/CBI decreased or disappeared. Clark has interpreted this finding as a clear manifestation of a novelty effect. Recent meta-analyses have confirmed that short treatments do indeed yield higher effect sizes (Kulik & Kulik, 1991; Khalili & Shashaani, 1994). In regard to instructor effects, most of the meta-analyses report that indeed the effect sizes are lower but nevertheless significant compared to controls. On the other hand, recent evidence also confirmed that when the same instructor is used for teaching both experimental and control conditions, the effect sizes are significantly lower compared to when different teachers are used to deliver the instruction (see Khalili & Shashaani, 1994). Yet another meta-analysis supported Clark’s argument since, when identical materials were used in both experimental and control conditions, no CAI/CBI effects whatsoever were found (Fletcher-Flinn & Gravat, 1995).

The meta-analytic evidence discussed above is not conclusive and the debate is clearly far from over. Most of the reviews provide positive evidence for a moderate CAI/CBI effect, but one needs to remain rather skeptical provided that these effects disappear when the same instructor and teaching materials are used. Nowadays, the fact that computers *can* indeed contribute to learning is not debatable anymore, mostly because both teachers and researchers have come to realize that it is *in principle* possible in numerous ways. What still needs to be worked out, however, is *how* or *under what conditions* this may occur. Regarding computers and learning, it is now generally accepted that: (a) computers in and of themselves can do very little to aid learning; learning is dependent upon the activities in which students engage with the computer; (b) no single task or activity affects learning in any lasting or profound way; rather, it is the whole culture of the learning environment which facilitates and promotes learning (Salomon & Perkins, 1996).

1.2 The specific context of the study

Our particular focus in this study is on a specific area of learning, problem solving. Computer-based problem solving has been investigated in areas such as mathematics, physics and chemistry with various computer applications. One such computer application is the spreadsheet. The role of spreadsheets in problem solving has been both theoretically and empirically addressed (e.g. Biehler, 1993; Brasell, 1987; Catterall & Lewis, 1985; Demana et al., 1993; Dibiase, 1996; Dorfler, 1993; Dreyfus, 1993; Ferrell, 1986; Goldenberg, 1988; Hillel, 1993; Jackson, Berger & Edwards, 1992; Joshi, 1993; Kieran, 1993; Lambrecht, 1993; Mokros & Tinker, 1987; Neuwirth, 1995; Ostebee, 1993; Pratt, 1995; Quesada & Maxwell, 1994; Reinhard, Hesse, Hron & Picard, 1997; Safrit, 1988; Schwartz, 1993; Stiff, Mccollum & Johnson, 1992; Sutherland & Rojano, 1993; Sutherland, 1993; Tall, 1993; Wood, 1992; Yerushalmy, 1991). For the purposes of the present discussion, there is no specific interest in discussing the specifics of each study. Suffice it to say that, as a rule, the outcomes have been positive with respect to enhancing student performance, compared to more traditional instructional approaches. In the next paragraphs a particular area of problem solving, correlational problem solving, where computer spreadsheets were used for the development of the certain problem solving skills, will be thoroughly examined.

1.2.1 Correlational problem solving

In this section the concept of correlational problem solving will be defined, a series of instructional interventions intended to develop correlational problem solving skills will be presented and a computerized instructional intervention aimed at fostering student's ability to solve correlational problems will be thoroughly discussed.

1.2.2 Definition

> *"Gould…reanalyzed fossil data compiled by the distinguished scientist and physician Samuel Morton…to demonstrate that Morton's finding of a positive correlation between race and cranial capacity was based on a failure to control for such factors as physical stature. The pernicious outcomes of this failure lived on for more than 80 years as the scientific foundation for eugenic social policies"*
>
> Ross & Cousins (1993b, p. 192).

One of the primary goals of education is to make students efficient problem solvers and the importance of correlational problem solving is aptly illustrated by the anecdote above. Correlational reasoning problems are frequently encountered in a variety of school and real world settings. Correlational reasoning both constitutes an essential part of school subjects like science, geography and mathematics and is required in dealing with several real life situations.

Correlational problem solving is 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). Inherently intertwined in the process of finding a correlation is variable controlling, for as much as determining the correlation between two variables involves controlling for variables that affect the relationship. Controlling variables is defined as "the ability to remove the distortion of intervening factors from the observation of a relationship between two variables of interest" (Ross, 1988, p. 406).

Ross & Cousins (1993a) developed a conception of correlational problem solving and an instrument for measuring correlational reasoning skills. According to this approach, correlational problem solving is made up of four dimensions or component skills. *Organizing*, which includes rearranging the information given in the problem statement in ways that facilitate further problem solution. *Locating*, which consists of selecting a number of cases sufficient for checking the relationship between the variables at hand. *Synthesizing*, which involves summarizing the relationship. Finally, *concluding*, which involves the drawing of a conclusion about the relationship that holds for the variables under consideration[2].

1.2.3 Instructional interventions aimed at developing correlational reasoning

Despite the significance of correlational reasoning, Ross & Cousins's (1993a; 1993b) reviews indicated that *students' performance on these skills was generally very low and that in the context of compulsory education students do not acquire the skills for dealing with correlational problems*. The researchers examined whether a series of instructional interventions would improve students' correlational reasoning performance (Ross & Cousins, 1993a; 1993b). Because of the importance of these studies for the present research, they will be reported in some detail.

The first experiment was part of the instrument development and is reported in Ross & Cousins (1993a). The objective of the experiment was to test the discriminant validity of the instrument (detecting differences between instructed and uninstructed students) and to achieve this an instructional intervention was implemented. Two hundred and seventy eight grade 7

[2] Example of a correlational problem and its solution algorithm: "Parents and teachers are always telling kids that they shouldn't quit school. Some students think that the sooner you are out in the work world the better off you will be. They say that if you hang around in school all the good jobs will be taken. Use the statistics information provided below to find out if staying in school make a difference to how much money you make".
Years of Schooling: 16, 4, 7, 10, 20, 13, 2, 14, 9, 21, 15, 19, 5, 8, 12, 6, 10, 14, 1, 17
Annual income ($): 17500, 5329, 4217, 18110, 23700, 11229, 3110, 24300, 9229, 19739, 15100, 20150, 6000, 9135, 6200, 3200, 7830, 13000, 5000, 15000. (Source: Brash et al., 1991).
An algorithm for solving the problem: (a) make a graph, i.e. draw two axes, label them, and put in scale for both, give graph a title; (b) put information on graph, i.e. locate the first case on the horizontal and the

students from 13 intact geography classes participated in the experiment. All teachers were experienced geography teachers and had volunteered. The teachers delivered a correlational reasoning module over nine 40 minute periods.

The instructional intervention was comprised of three distinct parts. The first aimed at motivating students, the second at presenting new concepts and strategies, and the third at providing practice to consolidate learning. The first part of the treatment was intended to enlist student attention and to motivate students for participating and learning. This was accomplished by demonstrating the usefulness of the cognitive strategies and skills to be acquired and also by selecting real life – and, thus, more meaningful – examples. The second part of the treatment involved the presentation of new ideas, concepts and strategies. The teacher demonstrated the procedures for solving correlational problems by presenting an algorithm. The algorithm was basically comprised of a visual approach to solving correlational problems: the procedure was a detailed guide of how to construct a scattergraph on the basis of which the nature of the relationship could be determined. A written summary of the requisite steps was also provided to the students so that the cognitive burden of algorithm memorization would be reduced. The third part of the treatment consisted of practice to consolidate learning. Students were provided with correlational problems and were asked to solve them. The problems were both related to the students' geography curriculum and had real life relevance. The written summary of the procedure for solving correlational problems was available to the students during this practice phase. After the completion of each task students were given group feedback.

Students were pre and post tested in both experimental and control groups, pre test performance being extremely low. All post test means were higher for the experimental groups but not for the control ones. These mean differences in all skills were statistically significant. Therefore, *the outcomes of this first study showed that an instructional intervention delivered by regular classroom geography teachers was very effective in fostering student correlational reasoning ability*.

A second study is also reported in Ross & Cousins (1993a). Its major objective was to test the sensitivity of the instrument being constructed to instruction. Twelve grade 10 geography teachers participated in the experiment. The teachers attended an in-service workshop on correlational reasoning, and then taught the correlational reasoning module to their classes. Students were pre and post tested, and after the post test each teacher selected randomly 10 students from his/her class. Only data from these students were used for the purposes of the experiment, the total number of subjects used being 120 students. The same instructional strategy described above was used in this second study as well. *Results indicated that students*

first case on the vertical and place a mark at the intersection point, repeat for the rest of the cases; (c) read the graph, i.e. draw a trendline and decide the nature of the correlation. (cf. Ross & Cousins, 1993a).

in the treatment groups outperformed students in the control groups in three out of four correlational reasoning skills (organizing, locating, synthesizing).

A third instructional intervention study is reported in Ross & Cousins (1993b). Twelve grade 9/10 teachers participated in a two-hour correlational reasoning workshop and were willing to field test a correlational reasoning module in their classes. The teachers decided whether they wanted to teach the module immediately after the workshop or 6 weeks later, the late treatment group serving as a control for the early treatment group. 120 students participated in the treatment studies. The 12 teachers taught the correlational reasoning module developed by Hogaboam-Gray et al., (1991) in five 70 minute periods. The same instructional strategy followed in the earlier two intervention studies was used for the third one as well. *Results indicated that instructed students outperformed uninstructed ones on all correlational reasoning skills*, while there were no differences between early and late treatment conditions.

1.2.4 A Computerized instructional intervention to develop correlational reasoning

In the Cousins & Ross (1993) study, the comparative effectiveness of different instructional methods in developing correlational reasoning skills was examined. The researchers aimed at addressing the following research questions: “a) to what extent does the use of the computer as a tool enhance student performance on higher order thinking skills compared to other instructional methods? b) do software sophistication and task specificity predict student performance on thinking skills? c) do student attitudes and background characteristics predict the performance of students using tool-mode CBI? If so, which characteristics are more salient?” (Cousins & Ross 1993, p. 98).

The study employed a pretest/posttest, multiple-treatment/control group design. There were four treatments and one control condition: a *whole-class condition*, *a cooperative group learning condition*, a *computer task-specific condition* and a *computer general-purpose condition*. The same instructional strategy described above was used and the correlational reasoning module was taught in five 70 minute periods.

In the *whole class condition*, the teachers delivered the module and the students worked individually at their seats. In the *cooperative group condition*, mixed ability grouping was used, groups were balanced for gender and students were not allowed to change groups in the course of the treatment. Within each group, students were encouraged to work in pairs during practice sessions. Whenever one pair would complete the assignment they would have to assist the other pair. The same instructional strategy described above was used, with the teacher initially demonstrating the procedures and practice sessions following. In the *computer task-specific condition,* students worked in pairs at the computer. They were assigned to groups following the same technique used in the cooperative group condition. Instruction took place in a whole class format and students initially worked in the classroom and practiced the skills using paper and pencil and later on in small groups at the computer in the computer lab. The software used was a MS-DOS spreadsheet program which allowed the user to enter data, plot graphs, calculate correlation coefficients, and partial correlation coefficients. Interfacing the program was possible through its command line where the user could type in specific commands. The students were provided with a summary of all the commands that they would need for using the program. In the *computer general-purpose condition* everything was identical to the computer task-specific one except for a general-purpose spreadsheet program used. This software program had more additional features like color graphics, labeling, trendline estimation, data-point symbol variation, text labeling facilities, and it could plot lots of different types of graphs. The students were also provided with a written summary of commands they needed for solving correlational problems. The same grouping and instructional procedures were followed.

In total, 483 students participated in the four treatment conditions, from 42 intact geography classes. Ten student responses were randomly selected by the researchers for marking. Of the 42 teachers, 31 had participated in correlational reasoning workshops. These teachers assigned themselves into one of the four treatment conditions. The remaining 11 teachers served as controls. Students were pre tested, the instructional intervention followed, and eventually students were post tested.

The results of the study indicated that student performance on the pre test was very low, which suggests that within the content of compulsory education students do not typically acquire the skills called for solving correlational problems. On the other hand, post test performance was significantly higher for all treatment groups but not for the control, which is an indicator of the effectiveness of the intervention. Most importantly, a comparison of the treatment and control groups showed that, with the exception of computer general-purpose condition on the skill of concluding, *the average treatment group student outperformed 99% of the control group students*. Finally, *students in the whole-class, cooperative group, and computer task-specific conditions performed significantly better on all four skills than students in the computer general-purpose condition*. No further performance differences were found for students in the whole-class, cooperative group learning and computer task-specific conditions.

1.3 The research problem

The preceding description of the Cousins & Ross (1993) study suggests that the study is methodologically sound. Nevertheless, *there are two main problematic features,* which will be elaborated upon in the following paragraphs.

1.3.1 Spreadsheet's contribution to learning

With respect to the *first aspect* of the research problem, Cousins & Ross (1993) reviewed three distinctive properties of computer tools: (a) state resurrection, the ability to quickly revise documents; (b) time compression, the ability of computers to perform tasks which would normally take lots of time and effort to complete and (c) graphical representation, which enriches interpretation and facilitates understanding of abstract elements. As already discussed, the results were positive in the sense that students in the treatment conditions performed significantly better than students in the control condition. In their interpretation of computer effectiveness we read: "Teaching correlational problem solving 'with' the computer was very successful[3] in the present study. The computer TS [task-specific] group performed equally well to whole-class and cooperative group learning treatment groups and outperformed the control group by 99% even in the face of start-up problems, technical problems with hardware, and relative inexperience of teacher and students with the software. These results are particularly encouraging because the advantages of time compression state resurrection, and graphical display enhance student opportunities to pursue using the computer with open-ended correlational problems where meaningful data can be gathered, processed, and analyzed" (p. 111). It should be noted that *although the objective of the study was not to determine if any of the theoretically identified computer properties would enhance student performance, the improvement found is nevertheless associated with these theoretical properties and discussed in their terms*. It is very difficult to see how the results are "particularly encouraging" or in what sense they "enhance" student learning opportunities as the researchers suggest. It is not even known whether the positive results are attributable to these computer properties. This is considered to be an important deficiency of the study, especially because there is no actual data[4] to support this association.

[3] It must be noted that there appears to be some slight exaggeration in the interpretation of the results. Although computer using students performed better than control ones, computer using students, especially those in computer task-specific condition, did not perform higher than students in the whole class or the cooperative group learning conditions. The size of the treatment effects across conditions shows that only in one skill (locating) was there a bigger effect size for the computer task-specific condition compared to the whole class and cooperative group learning conditions. In the case of the remaining skills (organizing, synthesizing, concluding) the effect sizes for the computer task-specific condition are smaller than the whole-class and cooperative group learning conditions. It is worth noting that, although these differences are not statistically significant, particularly for the skill of organizing there appears to be a remarkable difference between computer task-specific and cooperative group learning conditions: the effect size for computer task-specific condition is 2.82 while for the cooperative group learning condition is 3.85! Thus, even though the difference is not significant, it is nevertheless impressive. In this sense the effectiveness of the computer task-specific treatment condition is much exaggerated as computer tool use did not result in any better performance than the traditional whole class instruction method.

[4] Student measures in the Cousins & Ross (1993) study included correlational reasoning performance and background measures. Teacher measures involved perceived teaching efficacy and background variables.

There is definitely a big chasm between the three computer properties theoretically identified and the attribution of the learning outcomes to these properties. In fact, at a somewhat different level, Cousins & Ross (1993) have fallen in the same vicious circle out of which they were attempting to break. More specifically, in their literature review one of the identified deficiencies of previous research was that "the internal validity of most studies has been threatened by an inability to rule out alternative hypotheses. There is a need for more research employing tight methodological control to rule out novelty effects, especially from using the computer and working in individualized and small group instructional setting. The appeal of state resurrection, time compression and graphical representation capabilities underscores this necessity" (p. 97). The same conceptual error was committed when variables - which have not been actually considered (i.e. state resurrection, time compression and graphical representation) – were evoked by the researchers to account for the positive outcomes. By the same token (i.e. uncontrolled factors), it could well be that the effectiveness of the computer task-specific condition is attributable to other computer properties or, worse, to factors unrelated to the computer itself. These factors may include novelty effects, a change in the classroom structure and climate, and a differentiation of teacher and student roles in the learning process. Needless to say, of course, that the whole reasoning does not hold up to closer logical analysis because the three computer properties were ineffectual to higher performance in the computer general-purpose condition. Hence, it is debatable whether these computer properties can be credited for the improvement in one of the computerized conditions and not the other.

Extending this discussion to the literature, it must be noted that this type of attributions and associations between improved student performance and a set of computer properties (affordances, or capabilities) is by no means unique to the Cousins & Ross (1993) study presented here. On the contrary, the literature is replete with examples of papers thoroughly discussing certain computer properties and explicating their potential for contributing to learning. The effectiveness of computers for instruction and their beneficial effects on learning have been repeatedly confirmed in a number of meta-analyses, as discussed above. The problem with meta-analytic evidence is that the reasons for the influence of computers on student performance are not examined. This is because initially the major interest was in instructional effectiveness, and the study of computers and learning has been very technocentric. It must be emphasized that most of the impetus in this direction, i.e. ascertaining whether computers do assist student learning and improve their performance, has been given mostly during the introduction of the computers into educational systems in the early 1980s. The major concern was to examine whether computers were effective instructional tools. Comparatively little emphasis has been placed on examining the reasons why computers do improve student learning. Certain computer properties have been considered to be very helpful and conducive to learning (e.g., visualization, time compression, multiple representation capabilities) and, while such ideas have been around for long, they have never been explicitly investigated or experimentally tested[5].

Consider, for example, Kozma's (1994) paper which would supposedly explicate how computers uniquely contributed to student performance and, thus, would furnish evidence for the effectiveness of computers for instruction. Kozma reviewed two studies in which different computer programs were successfully used in boosting student performance, and gave a number of reasons for and accounts of how computers have made a unique learning experience possible. Essentially, his analysis is *post hoc*. The two studies were neither aiming at providing evidence concerning the particular computer features contributive to higher performance nor were they designed in such a way that conclusions about these computer features could be drawn. Provided that no evidence whatsoever about the claims Kozma made can be found in the original studies, it may be argued that his account is speculative. To determine whether and why these computer applications-tools worked in a certain way or in the hypothesized way, one needs to investigate how exactly the students worked with the tools and perhaps vary some tool properties to ascertain how or, perhaps, under what conditions they do support student learning. Despite the fact that Kozma's (1994) arguments are both profound and plausible, there is no solid evidence and one needs to remain skeptical, especially in light of evidence from meta-analyses indicating that short treatments yield the highest effects, which is more suggestive of novelty factors rather than of an essential computer contribution.

To conclude, it may be argued that *there is a need to investigate the mechanisms through which the computer is contributing to learning in the context of a computerized instructional intervention*. It appears that there is a set of assumptions about what computers can do to support learning which have been around for long and are perfectly reasonable but, nevertheless, have never been systematically explored, despite the profound learning impact this type of research could have on both understanding computer-based/assisted learning and on designing and delivering instruction. This constitutes the *first part* of the research problem presented in this chapter. In view of this, the first goal of this dissertation is to address the following question: *how does the computer spreadsheet contribute to and impact on the development of correlational reasoning skills?*

[5] Perhaps one of the reasons why there is very little research on the topic is that as a species we are not inclined towards investigated the obvious. No one can dispute the fact that tasks like accounting have been revolutionized with the use of spreadsheets. On the other hand, recent studies show that a number of readily made assumptions about the impact of computers on work productivity remain unjustified (Gibbs, 1997).

1.3.2 Teacher's contribution to learning

Regarding the second aspect of the research problem, the teacher is a treatment component present in all four treatment conditions. That the teacher is undoubtedly influencing student learning is obvious from the design of the Cousins & Ross (1993) study: including the teacher as an 'element' in the research design, implicitly recognizes that his/her role is important for the development of correlational reasoning skills. If the researchers were to test whether the teacher is needed for the development of correlational reasoning skills, a different approach would be required, e.g., use either a computer tutorial or an expository text to deliver the instruction.

Even though it can be inferred from the research design that the teacher is a fundamental part of the instructional process, the teacher as a 'factor' is not actually taken into account, that is, teacher's contribution to learning is not considered. Teacher's influence on student learning is *assumed* or *taken for granted*, but it is not examined per se. Because of the fact that different teachers were involved in teaching in the various treatment conditions, *teacher effects are averaged out, so that the influence of individual teachers is cancelled out.* This experimental manipulation doesn't amount to taking teacher's contribution into account. The teacher effect on the development of correlational reasoning skills is confounded: the teacher 'factor' is largely ignored, as its not part of any subsequent analysis[6]. Averaging out is not the same as considering what the teacher influence is.

Extending the discussion to the literature, this type of approach is common. The importance of the teacher for the success of CAI, just as with every educational innovation, was not readily appreciated. In the beginning the teacher was not under consideration as a research factor, and the emphasis was pretty much on the technology itself. In a way, the teacher was a taken-for-granted factor in research studies in the field. The root of the problem is that the computer was perceived of merely as another 'variable' to be manipulated and, thus, other variables like teacher, instructional materials, etc. could remain unaltered. Only when it was understood that whether or not computers boost performance is heavily dependent on teacher education and training did the emphasis shift on the teacher and the instructional method. Thus, it was only with the passing of time that it was understood that the most decisive factor for the instructional success of computers is the teacher. When the significance of teacher's role was appreciated, a number of measures were taken to deal with the problem, e.g., in-service courses for teachers were established and new teaching materials and ideas for organizing classroom learning were provided.

[6] It must be emphasized that in case any correlations between teaching efficacy measures and student performance were found, then these effects would be removed by means of MANCOVA. Even in that case, however, and because of the research logic, an attempt would be made to remove the effects, to cancel them out and not to understand them, or try to account for them.

To conclude, it may be argued that *there is a need to study the role of the teacher in the context of a computerized instructional intervention*. As a rule, in the literature on computers and learning, the teacher has not been taken into account. How exactly the teacher contributes to the acquisition of correlational reasoning skills – other than in the obvious way of simply providing new information – is largely unknown. This constitutes the *second part* of the research problem. Therefore, the second goal of this dissertation is to address the following question: *how does the teacher contribute to the development of correlational reasoning skills?*

In chapter 2 we will closely examine both parts of the research problem in an attempt to determine its origins.

Chapter 2

2 Analyzing the problem

The aim of this chapter is to analyze the research problem and determine its origin. More particularly, the research problem is analyzed both theoretically and methodologically. It is basically argued that the root of the problem can be traced back to both the inappropriateness of the method employed in the Cousins & Ross (1993) study and the lack of a theory concerning teacher's and computer's role in learning.

2.1 Determining the problem origin

2.1.1 On the methodology of investigation

"All methodologies, even the most obvious ones, have their limits"
Feyerabend (1975, p. 33).

The first claim made in this chapter about the method employed in the Cousins & Ross (1993) study is that it is a product-oriented method[1]. Below, we will discuss how the logic and assumptions of the analytic-experimental research paradigm fit best only certain types of research problems and questions.

Firstly, we will examine the Cousins & Ross (1993) study in an attempt to consider the rationale for the selection of the treatment conditions. As already discussed, there were four conditions. The whole class instruction condition was chosen because it constitutes a commonplace traditional teaching method. The computer task-specific condition was chosen because the researchers wished to test the contribution of the computer spreadsheet. Because of the fact that students in the computer task-specific condition worked in small groups, the authors chose to have a cooperative group learning condition which would function as a control. Finally, no explicit reasons were provided for the selection of the computer general-purpose condition. The reasons, however, can be inferred from their literature review where it is stated that there are no studies comparing "the relative merits of sophisticated multifunction software for specific applications as opposed to task-specific software" (Cousins & Ross, 1993, p. 98).

[1] At this point we need to define what is meant with the specific terminology used. Assuming that an intervention (treatment) of some kind has been carried out, a product-oriented approach can be defined as one which is mostly focusing on outcome measures, be it performance, productivity or any other measures taken *after* the intervention, and usually combined with measures preceding it (e.g. any type of pre tests). On the other hand, given the administration of a certain treatment, a process-oriented approach would mostly – *but not exclusively* – focus on measures or data gathering reflecting the *course* of the treatment itself, its moment-to-moment unfolding in time.

Thus, even though not stated, this condition served as some sort of control for the computer task-specific treatment condition. The research design is presented in table 2-1.

Table 2-1: Treatment conditions & components of the Cousins & Ross (1993) study

	TREATMENT CONDITIONS				
TREATMENT COMPONENTS	Whole Class	Cooperative Group Learning	Computer Task Specific	Computer General Purpose	Control
Teacher	√	√	√	√	
Correlational Reasoning Instruction	√	√	√	√	
Group Work		√	√	√	
Spreadsheet – Base Features			√	√	
Spreadsheet – Extended Features				√	

Therefore, it can be inferred that *there were only two genuine treatment conditions*, namely the whole class condition and the computer task-specific condition: the cooperative group learning condition was more of a control condition for the computer task-specific and general-purpose conditions, because students in these conditions would work in small groups; the computer general-purpose condition was more of a control for the computer task-specific condition, because some of the software features were varied. It must also be borne in mind that the only data collected in the study involved student correlational reasoning achievement. Therefore, *correlational reasoning performance was the yardstick by which the effectiveness of the various treatments would be measured*. Stating pretty much the obvious, according to the design logic, in case any differences were found between the whole class treatment condition and the cooperative group learning condition, these would be attributed to the fact that students were working in small groups. By the same token, potential differences between the whole class treatment condition and the computer task-specific condition would be necessarily attributed to the use of computers. Finally, if any differences between the computer task-specific and the computer general-purpose conditions emerged, they would be attributed to the computer properties varied. What is the limitation of this approach? *Although it is ostensibly easy to answer the question 'what caused the differences?' between any two conditions in such a design, as Salomon pointed out, upon closer and critical examination the question is rendered "unanswerable"* (1992a, p 259).

As can be seen from the logic of this research paradigm, every new treatment condition is comprised of "one" more treatment component[2], and in this way it is possible to determine the

[2] Whether it is one more component or it can be identified at all is debatable. For instance, Salomon (1992a; 1992b) argued that performance achievements cannot be isolated or attributed to particular components of the learning environment. In social science a 'factor' is hardly ever comprised of a single, clear-cut, and identifiable component. More particularly, an instructional intervention is a factor made up of a finite number of elements/properties which either cannot be meaningfully identified or alternatively their identification is viewed as irrelevant, once they just provide the "setting". As Altman & Rofoff

cause of differences between any two treatment conditions, and to isolate the treatment component which may be credited for the positive influence. It must be emphasized, however, that the cause of the differences is not actually determined; rather, the factor *inducing or being associated with* those differences is being identified.

Metaphorically speaking, *a treatment condition is some sort of input which is expected to yield certain output(s).* With every new treatment condition (i.e. whole class instruction; cooperative learning; task-specific spreadsheet; general-purpose spreadsheet) the input is varied in some way and the resulting output (i.e. student performance) is examined and measured. The only conceivable differences between different inputs is in terms of the measured outputs, and, therefore, it easily follows that *the comparison of inputs is basically a comparison of outputs*. Because the inputs are determined by design and only the outputs are compared, the main problem is that *whatever transpires between the input and the output is beyond the reach of the investigator.*

To understand the limitations of this research paradigm, it is worthwhile examining its underlying logic. The hallmark of scientific method is the time-honored '*vary-one-thing-at-a-time'* approach. The methodology of the physical sciences has been adopted in the social sciences as well, in their quest for objectivity and 'hard data', but as Conway (1991) argues, because this methodology was developed for the study of physical and not intentional states "it seems unlikely that by happy accident this methodology would also be ideal for the study of knowledge, meaning and intentionality" (p. 24). This methodology can be traced back to the beginnings of scientific method and logic. While it has definite advantages, Devlin (1997) argues that it does not come without shortcomings. With such an approach a lot has to be discarded or ignored given this logic of simplification[3]. A certain situation with multiple dimensions has to be stripped down of many of its properties in order to fit the vary-one-thing-at-a-time line of reasoning. Identifying 'one thing' entails singling out a certain property of a situation on the basis of certain criteria. Specific problematic features of this research paradigm will be discussed next.

Firstly, every new addition of a treatment component is treated as having the same importance, as bearing "one" more differentiation. *It is, therefore, assumed that every addition*

(1987) argued, "the whole is composed of inseparable aspects that simultaneously and conjointly define the whole" (p. 24).

[3] Devlin (ibid.) distinguished two types of mathematics: 'hard mathematics' and 'soft mathematics'. In the domain of physics, mathematics is used as the skeleton of the argument and the specifics of data, measures, and experimental setup are filled in; mathematics provides the backbone of the argument (e.g. physical law) itself, the general structure upon which the argument is cast. According to Devlin this is an instance of '*hard mathematics'*. Devlin (ibid.) argued that the type of mathematics needed in social science is '*soft mathematics'*, where mathematics is used as a tool, (e.g. like a screwdriver) which would allow researchers to look only at those aspects of the data which are unclear or *can* be investigated by using mathematics. For such very specific purposes, the use of mathematical method can be very useful:

is of a quantitative nature and, consequently, the initial set of components remain unaltered or unaffected. This assumption, however, may or may not be true, or even hold for some cases only depending on the nature of the study. It could well be that the addition of one more component affects the existing components in a way that two inputs, even though differing in terms of a single component/element, are fundamentally different from one another[4]. We need to explore the possibility of a *qualitative change* in the input when one more treatment component is included, and with the present vary-one-thing-at-a-time approach it is quite hard to detect these qualitative changes. *It could be the case that whenever a new treatment component is added, the resulting treatment condition is not only quantitatively but also qualitatively different*[5]. Since water is not the aggregate of hydrogen and oxygen but an entirely new entity maintaining none of the properties of the initial components (Vygotsky, 1987), it seems likely that merging two components in a single treatment condition may result in a condition which does not bear any resemblance to the two initial components. Perhaps the most insightful criticism of this approach may be found in Feyerabend (1975) who, in discussing the analytic approach western medicine employed in studying herbs, argued: "the approach consists of two steps. First the herbal concoction is analyzed into its chemical constituents. Then the specific effects of each constituent are determined and the total effect on a particular organ explained on their basis. *This neglects the possibility that the herb, taken in its entirety, changes the state of the whole organism and that it is this new state of the whole organism rather than a specific part of the herbal concoction that cures the diseased organ*" (p. 51-52, emphasis added).

Secondly, there is the assumption that *a factor (or input) is neutral, so that interaction with the environment is impossible*. As Salomon (1992b) pointed out, when an input is introduced into a classroom, almost everything in the classroom is influenced, as a whole set of interrelated variables are affected. The input is related to the context, affecting it and being affected by it, defining it and being defined by it at the same time. Salomon (ibid.) concludes that "in this light, *we totally violate the very essence of experimental research, particularly its rock-bottom*

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looking for underlying patterns, representing them with mathematical symbols and examining the patterns as represented by those symbols.

[4] In the Cousins & Ross (1993) study, in terms of input, the whole class treatment condition and the cooperative group learning condition are different only regarding group work. It could well be that because of the addition of small group learning, the two inputs are substantially different in a number of dimensions: the passive or active role of the student, the classroom climate, teacher and student roles, what learning is and how it is taking place, teaching and learning activities. If this holds, then there are a lot of important implications for the output.

[5] It is worth mentioning that this approach in itself is not without problems in terms of how a factor is conceived as well as in terms of how factor interaction is interpreted. According to Cronbach (1975), however far we may go in terms of order, it is still possible to consider interactions of a still higher order. What stretches issues even further is the knowledge that in the study of behavior "the principal main effects are likely to be interactions" (Bronfenbrenner, 1977, p. 518) which makes the interpretation of factor interactions even more problematic.

assumption that 'other than the independent variable, everything else is kept equal or unchanged'" (p. 176, emphasis added; cf. Salomon, 1990; 1991; Papert, 1987).

The importance of context has also been stressed by Cronbach (cited by Salomon, 1996a, p. 404) who argued that *the observed effects of an educational treatment are not really just its own because the circumstances surrounding the treatment are part of its cause*. Partialling these effects out by means of statistical or experimental means results in describing a '*counterfactual'* treatment which '*denatures'* the intervention. He argued further that *such an intervention is very difficult to design, and even if it can ever be designed, it can never really work because some of its most essential contextual features are left out*. Carver (1978) also noted that contextual factors might determine the effectiveness of a certain intervention to such a large extent, that replicating it in another context might be impossible.

The *third* feature involves the *criterion of comparing the outcomes*. This criterion in itself is unrelated to the logic of the analytic-experimental research paradigm. A discussion or reference to it, however, is inevitable, as it provides the grounds for deciding which condition is more effective in terms of performance. The effectiveness of one treatment condition over the others is judged on the basis of a probability index, known as *statistical significance*. This probability index is the ultimate criterion[6] for determining whether the mean differences are greater than chance, given that the null hypothesis is true[7]. A significant result in itself does not

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[6] The use of statistical significance presupposes the concept of arithmetic averages and using averages today is hardly ever questioned. As Mulaik (1994) noted, however, 19th century statisticians were truly puzzled with providing a logical account of using averages: they were being used all the time, but there was no clear rationale for using them and not e.g. the median or the mode instead. There was no reason why the average, a fictitious concept, was any better than the actual data values collected. Venn even argued that the average cannot possibly take the place of all the many values from which it was derived (as cited in Mulaik, pp. 272-273). The same holds for statistical significance whose use today is widespread. Gigerenzer (1991) pointed out that in the early 19th century significance tests were already in use by astronomers, who used them for the purposes of rejecting data (especially outliers) but not for rejecting hypotheses. According to the practices of the time, astronomers assumed that the theory was correct and mistrusted the data, while the current practice is to assume the data to be correct and mistrust the theories.

[7] It is very instructive to note that statistical significance has been subject to harsh criticism. Over the years, the null hypothesis significance testing (NHST) approach has been severely criticized on a number of counts: "[statistical significance] is still used in a manner that corrupts the scientific method" (Carver, 1993, p. 287); "[statistical significance] does not tell us what we want to know…[but] nevertheless we believe it does!" (Cohen, 1994, p. 997); "the time has come to exorcise the null hypothesis" (Cronbach, 1975, p. 124); "NHST has not only failed to support the advance of psychology as a science but also has seriously impeded it" (Cohen, 1994; p. 997); "reliance on statistical significance testing in the analysis and interpretation of research data has systematically retarded the growth of cumulative knowledge in psychology" (Schmidt, 1996, p. 115); "can you articulate even one legitimate contribution that significance testing has made (or makes) to the research enterprise?" (ibid., p. 116); "significance testing has become a substitute for a more complete critical evaluation of study methods and results" (Savitz, 1993, p. 98). Furthermore, Gigerenzer (1991) pointed out that current statistics textbooks conceal a great deal of the underlying tension between statisticians regarding three important aspects of significance testing. More specifically, he argues that textbooks are written: (a) as if there is only one logic of inference, (b) as if there is only one interpretation of probability, and (c) the general tendency is to use the statistical tests anyway, without checking the underlying assumptions of the models as statisticians recommend.

really communicate very much, especially in terms of the reasons and/or the underlying mechanism(s) leading to improvement. As Cohen (1994) argues "if we…learn from a research that A is larger than B ($p < .01$), we have not learned very much. And this is typically *all* we learn" (p. 1001, emphasis added). In this sense, simply knowing that an instructional intervention produced significant results may warrant its effectiveness but does not convey anything at all regarding the components of the intervention which have mediated and can be credited for this improvement. As Thompson (1997) noted in his criticism of the current approach to significance testing, paradoxically enough, researchers are more certain of whether they have a noteworthy effect (i.e. statistically significant finding) than where the effect originates (i.e. what exactly caused the finding).

Of course, the preceding discussion of limitations does not mean that the time honored vary-one-thing-at-a-time experimental approach is of limited value to social science. Nor does it imply that simplification by isolation or null hypothesis significance testing are useless tools. What it does mean, however, is that the dominant research paradigm draws our attention to controlled experiments and measurable entities. In a sense, it *invites* researchers to focus on outcome/product measures and it introduces a dichotomy of significant vs. non significant results. The bottom line is that the whole research logic, assumptions, and practice of the analytic-experimental research paradigm are not always necessarily appropriate for the study of human cognition[8].

How exactly do these features render the analytic experimental approach inappropriate for resolving the research problem? On the one hand, determining which computer properties might facilitate learning and to what extent, requires *looking at the moment-to-moment interaction of the learner with the computer*. Looking at the outcomes alone is, at best, insufficient because it will never reveal enough information about the process. One the other hand, *finding out how the teacher affects learning by simply looking at the outcome measures is not enough* either. Again, what is needed is an examination of the course of the interaction per se.

Extending this discussion to the literature, the need for a change in the methodology employed in evaluating learning with computers has been repeatedly stressed. Calls for the incorporation of alternative research methods for studying the effects of computers (and new technologies in general) on learning have been frequent (Salomon, 1992a; 1992b; 1996b). For instance, Kozma (1994) argued that future research might make use of methods such as: think-

[8] We have confined our discussion to issues related to method only and deliberately overlooked the ongoing discussion concerning the proper way to study human behavior. For example, the experimental practice of studying individuals outside their contexts (termed the decontextualized study of the individuals) has also been challenged over the last two decades and the discussion seems to be far from over (Lave, 1988; Lave & Wenger, 1991; Banaji & Crowder, 1989; Ceci & Bronfenbrenner, 1991; Loftus, 1991; Neisser, 1991).

aloud protocols; log files; Guttman's smallest space analysis; ethnographic/naturalistic methods; observation; interviews, and artifact analysis. It is obvious that these methods (research techniques) are not product or outcome-oriented, but process-oriented ones. Another example of the emphasis on the process is reflected in Christmann, Badget & Lucking's (1997) conclusion: "educational researchers *must develop ways to measure patterns* that reflect how students best learn through computers...CAI research restricted to controlled environments may not adequately explain what happens in natural settings; but *qualitative research methods*, such as ethnography, could help determine when students grasp information or become confused during CAI activities" (p. 292, emphasis added). Methodological tools for the detection of such patterns have not yet been developed.

To conclude this discussion, *a first requirement in addressing the research problem is the use a process-oriented method for studying an instructional intervention*.

2.1.2 Why looking is not enough: the necessity of a prism-theory

"One could not simply look and see. One had to act"
Gooding (1990, p. 31)

In the preceding section it was argued that we need a method of investigation which would allow us to focus on the *process* of an instructional intervention rather than its product-outcomes. The question then is: *how exactly can we study processes?* One obvious method of studying an instructional intervention is *observation.* Of course, as it has been repeatedly emphasized observation is neither pure nor passive[9] and, thus, "it is hard to know where to look and it is very easy to be overwhelmed" (Bakeman & Gottman, 1986, p. 20). The bottom line is that without a theoretical framework making sense of data is an "*unguided affair*" (ibid., p. 22).

[9] At an epistemological level it is generally accepted that: (a) observation is selective and influenced by previous experience and (b) observation is not a passive but an active process. In regards to the former, previous knowledge and experience have a bearing on observation. As it has been succinctly stated, 'one does not embark on a trip around the world if one believes that the world is flat'. Popper (1965) pointed out that observation is not objective in the sense that is always influenced by attention and, thus, is primarily selective: "twenty-five years ago I tried to bring home the same point to a group of students in Vienna by beginning a lecture with the following instructions: 'Take pencil and paper; carefully observe, and write down what you have observed!' they asked, of course, what I wanted them to observe. Clearly the instruction, 'Observe!' is absurd. (It is not even idiomatic, unless the object of the transitive verb can be taken as understood). Observation is always selective. It needs a chosen object, a definite task, an interest, a point of view, a problem" (p. 46). In regards to the latter, Gooding (1990), advanced the argument that there is not such thing as pure "observation" in the sense of looking and seeing. He pointed out that observation is very much intertwined with action (agency as he calls it): what the observer observes is actually the outcome of his/her manipulations on the world. For example, Gooding examined the situation of electromagnetism in the early 1820s where the magnetic needle behavior seemed initially to be chaotic. He concluded that, when Biot through experimental manipulations found that the magnetic needle behavior is structured (rule based), what he was attending to was not the needle behavior only: his agency (in terms of manipulation) had actually become part of the observation but was no longer referred to. In this sense, it is misleading to think of an "observation" of the structured behavior of the magnetic needle: this structured behavior of the needle was not a property of the needle directly but rather a property of the behavior of the experimenter.

Having identified observation as a method of studying the process is merely one side of the coin. *A theoretical framework furnishing us with constructs for conceptualizing the research problem is required*. Viewed in a paradigmatic sense, the theoretical framework would provide us with both a worldview and with a set of research problems worth investigating (Kuhn, 1970).

If one examines the Cousins & Ross (1993) study from a theoretical point of view, then one reaches the conclusion that it is basically *atheoretical*. Their interest was both methodological (i.e. conducting the study with a tightly controlled research design so that no alternative hypotheses can be put forward) and practical (i.e. they were interested in finding out which treatment condition would yield the highest performance). As already stated, the three computer properties were the only theoretical constructs discussed and were eventually associated with student performance.

Extending this discussion to the literature, it can be argued that the lack of a comprehensive and sound theory does not exclusively characterize the Cousins & Ross (1993) study we've been discussing thus far. The absence of a theoretical framework is also typical of most of the studies in the field[10]. Understanding the reasons calls for a consideration of the broader historical context.

Firstly, *examining instructional effectiveness was the primary focus* in the overwhelming majority of CBI/CAI/CAL studies. The bulk of research was carried out with the launch of the PC in the early 1980s and the driving force behind most of this research was the overriding concern with the effectiveness of computer-based instruction. An improvement in student performance would justify the argument that computers indeed enhance learning and, as a consequence, legitimize the expensive hardware and software purchases made. According to this logic, it was imperative to conduct research on whether the computer indeed boosts learning, especially when compared to traditional instruction. Despite the knowledge we've

[10] Generalizing may greatly compromise accuracy. On the one hand, it is very difficult to define what a theoretical framework or a theory is. For example, we've argued that the Cousins & Ross (1993) study is *atheoretical*. A literal interpretation should, of course, be avoided since they conducted a very thorough literature review, identified certain methodological deficiencies and carefully designed a tightly controlled study to address these problems. By atheoretical, we mean that the study was based on no specific theory or view of what learning is and how it can be fostered and developed in a classroom setting, in conjunction with the teacher, peers and artifacts. On the other hand, in some fields of computer-based-instruction like LOGO research, there is theoretical underpinning. For instance, Papert's (1980) work on LOGO was heavily influenced by Piagetian theory. As a rule, constructs from various theoretical perspectives on cognition have been incorporated in the discourse on computers and learning on both theoretical and empirical levels. For example, the construct of the Zone of Proximal Development has been introduced in the literature and computers have been conceived of as functioning as partners within students' zone of proximal development (see Salomon, Globerson & Guterman, 1989; Salomon, Perkins & Globerson, 1991). On the other hand, programs like Intelligent Tutoring Systems and Expert Systems have been largely influenced by work within cognitive science, and have been perceived of as experts capable of tutoring and coaching students, providing detailed feedback and instructions (see Lajoie, 1993, for a discussion of two such tools). Nowadays, a new set of epistemological perceptions of learning seem to provide the background for most of the research (e.g. constructivism) but a coherent theory is still not worked out.

acquired over the last two decades concerning what computers can do to assist learning, no comprehensive theory is yet available. Theory building on the basis of research outcomes has not considerably progressed. It is worthwhile noting that the need for a theory to explain literature findings had been stressed early on: “theory integration and theory building are critical to the development of the field to explain fundamental processes and effects of computer use for learning” (Krendl & Lieberman, 1988; p. 380). From an instructional viewpoint, knowing that a certain teaching method employing specific materials/new technologies leads to higher learning outcomes in a given domain is sufficient for adopting it. Of course, knowing why is only of secondary importance, at least from a teaching perspective.

Secondly, research in the area of computers and learning has been primarily technocentric as has already been repeatedly emphasized by many researchers. The potential of new technologies for contributing to learning was investigated simply because these technologies ‘were there’, and not because there were any theoretical reasons. There is no organized or systematic research agenda: studies are being carried out with almost every new technology that comes up. Recent examples of this trend include the case of multimedia/hypermedia in the late 1980s and the case of LANs, Internet and WWW in the mid 1990s. Despite various calls for integration of theory and practice, the emphasis is still mostly on technology itself and not on learning, even though this emphasis is gradually shifting. Teachers and researchers have come to realize that the problem with technocentric or technology-oriented approaches is that the focus rarely shifts to learning because technology itself *is* the starting point. As it has been argued, the focus should be on what learning requires and not on what technology can do (Salomon & Perkins, 1996). Focusing on what technology can do is the wrong starting point, mostly because of the fact that if something can be done it does not necessarily mean that it should be done (Kerr, 1996).

Studying both teacher and computer contribution to learning requires a perspective-viewpoint of learning. It requires some conception of what cognition is, how it is developed, and what the role of teachers and tools/artifacts is in development. To conclude, *a second requirement for addressing the research problem is to employ a theoretical framework for conceptualizing the roles of teacher and computer spreadsheet*.

To meet these two requirements, we examine such a theoretical framework in chapter 3 and a set of methodological tools in chapter 4.

Chapter 3

3 Theoretical framework

The objective of this chapter is to lay out a theoretical framework providing us with constructs for conceptualizing the influence of both teacher and computer spreadsheet on learning to solve correlational problems. More specifically, this chapter is concerned with Distributed Cognitions theory. The idea that cognition is or can be distributed has proponents in sociocultural psychology and recently in cognitive science as well. For the sake of completeness we examine both traditions. The main positions and assumptions of cognitive science about cognition are initially presented, and a contemporary cognitive science trend examining issues of the distribution of cognition is also described. Finally, Distributed Cognition is considered from a sociocultural psychology perspective and discussed with respect to its precursor cultural-historical psychology. The second half of this chapter is entirely devoted to exploring the two types of distribution of cognition: social and material. The former includes parents, teachers and peers while the latter involves the use of both natural tools and invented artifacts.

3.1 The study of cognition

Nowadays, the idea that cognition is distributed has proponents both in cognitive science (e.g. Hutchins, 1995a) and in educational psychology (e.g., Salomon, 1993d). Nardi (1996c) seems to put both traditions under the same category, i.e. Distributed Cognition (see page 70 second paragraph; in the last paragraph on the same page, however, she refers to Hutchins as a ‘distributed cognitivist’). Even though such a categorization is globally accurate, it is our belief that the two frameworks must be examined separately in order to highlight their similarities and differences and this is the approach we take in writing this chapter. Before we turn to a discussion of the two frameworks, however, the main positions and assumptions of cognitive science are presented. In cognitive science, cognition is mainly treated as being ‘in the head’.

3.2 Cognition in the head: a cognitive science perspective

Cognitive science can be defined as “the study of intelligence and its computational processes” (Simon & Kaplan, 1989, p. 2). This definition requires a conception of what intelligence is and what constitutes intelligent behavior. According to the cognitive science approach, intelligence “is to be judged by the ability to perform intellectual tasks, independent of the nature of the physical system that exhibits this ability” (ibid., p. 2). The major implication of this position, which is known as the *physical-symbol-system hypothesis,* is that intelligence can be ascribed to both humans and computers, provided that the latter can exhibit behaviors which would be considered intelligent if exhibited by humans[1]. Turing's test (1950) can be used to determine whether an inanimate system can exhibit the type of behavior that would be considered representative only of human intelligence.

As a field, cognitive science draws on a number of other disciplines like psychology, artificial intelligence, linguistics, philosophy, logic, and neuroscience. There are largely two approaches or research paradigms within cognitive science: the first perceives of the computer as a system for manipulating mental symbols whereas the second sees the computer as a medium for modeling the mind. In both cases the computer is used as a metaphor for understanding the mind, either as a serial or as a parallel device.

3.2.1 Cognition as symbol-based

Within cognitive science, cognition is usually described on three levels: (a) *knowledge level*: having goals and knowing things about the world; (b) *symbol level*: humans can operate on this knowledge level because it is a symbol system; (c) *neural level*: the symbol level must be realized in terms of a substrate (Pylyshyn, 1989; Newell, Rosenbloom & Laird, 1989).

The mathematization of logic during the first half of the 20th century showed how inference processes could be viewed as symbol manipulation and paved the way for the information processing revolution of the 1950s and 1960s. This revolution introduced a view of thinking and intelligence as symbol manipulating processes, and the mind was deemed to be a symbol-processing system (Simon & Kaplan, 1989). The notion of cognition as symbolic processing was largely influenced by the work of Turing. Turing's theoretical machine was made up of the memory and the processor; the processor could read, write, and alter symbolic expressions already stored in memory. These symbolic expressions are symbols, that is, codes which stand for something. For the most part, these symbols correspond to numbers but, in principle, they could be propositions or knowledge. According to this model, the processor operates on these expressions in a consistent way on the basis of their form alone, namely ignoring their meaning. The outcome of the operations of the processor on these symbolic expressions is that they are transformed into new expressions, but due to the nature of the transformation these new expressions continue to mean something. The meaning (semantic interpretation) of the transformed symbolic codes can be maintained because in formal logic rules can be specified "that operate on symbolic expressions in such a way that the sequence of expressions always corresponds to a proof" (Pylyshyn, 1989, p. 58). For cognitive science, thus, cognition can be

[1] A physical symbol system "is built from a set of elements, called symbols, which may be formed into symbol structures by means of a set of relations" (Vera & Simon, 1993, p. 8).

seen as a symbolic process and intelligence as symbol-based[2]. Overall, the language of thought is considered to be symbolic: knowledge is encoded in a system of symbolic codes and this system may be structured like a language (Pylyshyn, 1989). Thus, one of the most fundamental assumptions in cognitive science is that "computers and (in our view) human beings are symbol systems. *They achieve their intelligence by symbolizing external and internal situations and events and by manipulating those symbols*. They all use about the same symbol-manipulating processes" (Simon & Kaplan, 1989; p. 40, emphasis added).

3.2.2 The architecture of cognition

In cognitive science the mind is perceived of as an information-processing system, and the design specifications of such a system are referred to as its architecture. Due to the fact that the computer is used as a metaphor for understanding the mind, the architecture of human cognition is modeled on the computer architecture. Thus, one essential assumption about the architecture of human cognition is that the computer architecture reveals "the essential mechanisms …of how the mind works" (Newell, Rosenbloom & Laird, 1989, p. 96).

From an information-processing point of view, cognition is made up of: (a) *short-term memory*, which is limited in capacity, only about seven chunks; (b) *long-term memory*, which has unlimited capacity containing declarative and procedural information; and (c) *sensory input*, e.g., eyes. In such a model, the representation of knowledge in long-term memory takes two forms: declarative and procedural. Declarative information is organized in schemata which might have the forms of propositions or pictures. Procedural information takes the form of operators, which are represented as productions. A production is made up of conditions and actions. Finally, a control structure determines the conditions under which particular operators might be activated (Simon & Kaplan, 1989).

Based on information processing accounts of cognition like the one above, a physical symbol system has been considered to be the primary architecture of cognition. Hence, the architecture of such a physical symbol system involves four main elements: (a) *memory* which is composed of symbolic structures; (b) *symbols*: the memory structures are symbolic because they contain symbol tokens, which are patterns in symbol structures providing access to structures elsewhere in memory; (c) *operations*: the system should be capable of performing operations on these symbolic structures so that new ones are created, and (d) *interpretation*, which is the process of applying these operations on symbolic structures (Newell, Rosenbloom & Laird, 1989).

[2] "Symbols are patterns…when we say that symbols are patterns, we mean that pairs of them can be compared (by one of the system's processes) and pronounced alike or different, and that the system can behave differently, depending on this same/different decision" (Vera & Simon, 1993, p. 9).

3.3 Moving the boundaries between the head and the world: alternative approaches

"The everyday world took its revenge on AI as it had on traditional philosophy"
Dreyfus & Dreyfus (1990; p. 324).

Over the last decade, a number of assumptions and positions of cognitive science have been subject to harsh criticism (see Winograd & Flores, 1987; Suchman, 1987; 1993; Dreyfus & Dreyfus, 1990; Greeno & Moore, 1993; Clark, 1997; Hutchins, 1995a; 1995b; Hutchins & Palen, 1998; Norman, 1993). Although this criticism has taken many forms and focused on many aspects of the cognitive science paradigm, for the purposes of the present work we will simply outline two originating within cognitive science.

The first acknowledgment of limitations comes from the thorough work of Hutchins (1995a) on navigation. Hutchins (1995a) notes that in traditional cognitive science the locus of knowledge is assumed to be inside the individual. One of the consequences of this approach is that "the emphasis on finding and describing 'knowledge structures' that are somewhere 'inside' the individual encourages us to overlook the fact that human cognition is always situated in a complex sociocultural world and cannot be unaffected by it" (ibid., p. xiii). He argues that "it is unfortunate that cognitive science left culture, context, and history to be addressed after the understanding of the individual had matured. The understanding of the individual that has developed without consideration of cultural process is fundamentally flawed." (ibid., p. 354).

Hutchins's main claim is that the physical symbol-system hypothesis "is a perspective into which things don't fit" (ibid., p. 370). He argues that in the process of formally representing a world of phenomena with symbols and subsequently manipulating symbols, something got lost. At the outset, the model cognitive system was a person actually doing this symbol manipulation with his hands and eyes: a mathematician or logician interacted with the material world both visually and manually. Hutchins points out that when the symbols are in the environment of the human who is manipulating them, *the cognitive properties of the human are not the same as the properties of the system: the system is made up of the interaction of the human with these symbols, and this interaction produces some sort of computation*. Hutchins emphasizes that the *computation is not necessarily taking place in man's head*. He notes that Turing's great discovery entailed that the actions of the mathematician (which were naturally embedded in a world) could be abstracted in such a way that the mathematician himself could be eliminated, and what was left was essentially the application of rules to strings of symbols. However, "the essentials of the abstract manipulation of symbols are precisely not what the person does. *What Turing modeled was the computational properties of a sociocultural system*" (p. 362, emphasis added). What is modeled is simply the abstract computation achieved by the manipulation of symbols. This observation led Hutchins to conclude that “the physical-symbol-system architecture is not a model of individual cognition. It is a *model of the operation of a sociocultural system from which the human actor has been removed”* (p. 363, emphasis added). For Hutchins (ibid.) the main implication of the failure of cognitive scientists to note that the central metaphor of the physical-symbol-system hypothesis captures the properties of the sociocultural system rather than the ones of the individual agent, was that AI and information processing psychology attempted a radical surgery on the modeled human, whereby *the brain was replaced with a computer*. Even though the surgery was a ‘success’, there was a side effect: “the hands, the eyes, the ears, the nose, the mouth, and the emotions all fell away when the brain was replaced by a computer” (ibid., p. 363). As Hutchins (ibid.) concludes, symbols are not in the head; rather, cognitive science has put them in the head.

Other recent accounts within cognitive science have also highlighted its limitations. For example, Zhang & Norman (1994) noted that within the traditional cognitive science framework external representations (objects, written symbols, beads of abacuses, spatial relations of written digits, visual and spatial layouts in diagrams etc) are considered to be simply peripherals in cognition and are often mixed with internal representations. They argue that these types of representations constitute an essential type of cognitive representations which aid memory, provide information which can be used without any further thinking, structure behavior and change the nature of the task performed (cf. Norman, 1993).

Nowadays, some cognitive scientists propose that *for some purposes it is rather wise to consider cognition and intelligence as a property of the whole system which is not limited by the skin or skull*: “cognitive science…can no longer afford the individualistic, isolationist biases that characterized its early decades” (Clark, 1997, p. 221). As Clark puts it, because cognition has been essentially disembodied from the physical world, “brain, body, and world are going to take a whole lot of putting back together again” (ibid., p. 222). The cognitive science consideration of the sole individual bearing all intelligence is not deemed to be a sufficient unit of analysis because one cannot understand the properties of individual cognition by simply studying it: one should look at the whole system-environment within which the person operates using various tools (Hutchins, 1995a; 1995b; Hutchins & Palen, 1998). For example, having observed memory processes in a commercial airline cockpit, Hutchins (1995b) drew two main conclusions: (a) “significant functions are achieved by a person interpreting material symbols, rather than by a person recalling those symbols from his or her memory” (p. 280), and (b) “the memory of the cockpit…is not made primarily of pilot memory. A complete theory of individual human memory would not be sufficient to understand that which we wish to understand because so much of the memory function takes place outside the individual” (p. 286). What these observations suggest is that *we should look beyond the cognitive functioning within an individual to understand a cognitive function in the individual*. Therefore, the unit of analysis cannot be the individual alone; rather the whole system within which the individual functions with the aid of others and tools should be taken into consideration.

3.3.1 Exploiting the environment as a tool: opportunism

Contrary to what is often hypothesized, the brain does not always devote energy to the direct solution of a problem, but to the control and exploitation of the environment. Exploiting such environmental structures entails that the problem is continuously transformed until it reaches a form which is more manageable (Clark, 1997). More specifically, Hutchins (1995a) argues that humans often behave in an *opportunistic way*, avoiding hard thinking and computations through a process of offloading of computations onto the environment. Consider the following example: 'Suppose today is Tuesday, December 29. What will the date be on Saturday?' Hutchins (1995a) considers a finger-counting solution to this problem. He notes that today counting on one's finger is considered to be a cognitive atavism but four centuries ago finger counting was so common in Europe that arithmetic books had to contain detailed explanations to be considered complete. He argues that "the hand serves as a malleable and handy medium upon which representational states can be imposed and simple operations can be performed. The structure of the hand that results from those operations is a portion of a partial description of the answer to the question" (ibid., p. 315). He acknowledges the fact that the problem can be solved mentally by manipulating the two sequences, but such an approach would place severe memory load and is computationally more demanding.

A colorful example of exploiting the environment as a tool in the performance of a cognitive task was given by Hutchins (1995a) in his description of Micronesian navigators. For over a thousand years long-distance non-instrumental navigation has been practiced in parts of Polynesia and Micronesia, navigators sailing for several days out of the sight of land without using any typical western mechanical, electrical or magnetic resources. While on the surface and by our own standards they are poorly equipped for such a task, they nevertheless navigate very accurately: they know the bearings of the point of departure, the destination, and can indicate other islands off to the side of the course even though these are out of sight. Such accomplishments are admirable by navigators in our culture, mostly because in our own navigational system they can never be made without recourse to tools. Even though in the eyes of the western navigator they are not using any navigational *instruments* (e.g., compass), they actually draw on a number of sources of information available in the environment: (a) the presence of submerged reefs changes the apparent color of the water; (b) the interaction of swells with islands produces distinctive swell patterns; (c) the winds and weather patterns in the sky; (d) seabirds, especially close to or around islands; (d) stars. In the world of the Micronesian navigator, navigation is effected by using these sources of information, while for a western navigator navigation requires a lot of instruments.

3.3.2 Exploiting artificial tools: cognition as enhanced by tools

Hutchins (ibid.) argues that in traditional cognitive science one serious and frequently committed error is the attribution to individual minds of properties which are derived from the use of cultural artifacts. Such artifacts have two main functions: (a) they are representational media upon which the computation is achieved and (b) they provide constraints on the organization of action. Hutchins notes that human environments are not 'natural' ones; rather they are artificial and human cognitive ability stems precisely from *using* these artificial environments. The existence of a wide variety of specialized tools and techniques suggests that a lot of cultural effort is devoted to avoiding cognitive activities like algebraic reasoning and arithmetic. A lot of effort is put in creating specific tools which *save mental effort by crystallizing knowledge and practice*. For example, in the case of navigation, Hutchins thoroughly examined the case of the chart as an artifact. He notes that until the end of the 18th century only descriptive sailing directions were available, which described how to proceed with the voyage and what to expect to see in its course. At the end of the 18th century the improvement of survey techniques led to the construction of pictorial charts. He points out that, even though charts were available since the 13th century, the parallel rule was not invented until the late 17th century because "a straight line had no special meaning on an early chart" (ibid., p. 113). How exactly does a chart reflect the crystallization of knowledge and practice? Hutchins remarks that "the cartographer has already done part of the computation for every navigator who uses his chart" (ibid., p. 173). Furthermore, in his thorough study of the everyday practice in navigation Hutchins (1995a) concluded that the deep computational problems are either transformed by some artifact into shallow ones, or not addressed at all.

Hutchins has explored how tools affect cognition by thoroughly examining two tasks which are computationally demanding and require the coordination of more than one individual: calculation of speeds in a commercial airliner cockpit and computational aspects of navigation of an aircraft carrier. In the former case it was found that the introduction of speed bugs does not change the memory of the pilots per se, but it permits a different set of cognitive processes so that some memory requirements for the pilots are reduced, i.e. the task of remembering is transformed. As he argues, the memory of individual pilots is not enhanced by the use of speed bugs: "speed bugs do not help *pilots* remember speeds; rather, they are part of the process by which the *cockpit system* remembers speeds" (Hutchins, 1995b, p. 282-83, original emphasis). More specifically, "with the salmon bug set, the pilot no longer needs to read the airspeed indicator scale. He or she simply looks to see whether or not the indicator needle is lined up with the salmon bug. Thus, a memory and scale reading task is transformed into a judgement of spatial adjacency" (ibid., p. 283). What is even more appealing in this particular use of salmon bugs is that the pilots behave 'opportunistically' as Hutchins describes it, because the engineer who designed it reported that such a use of the salmon bug is not included in the specifications.

In the latter case, Hutchins argues that the solution a navigational problem[3] in different ways entails that different possibilities emerge. For example, solving the problem with paper and pencil requires knowledge of algebra for the manipulation of formulas and a number of computations. Incorporating a calculator in solving the problem does not result in any minor change in the solution process: formula manipulation is still a requirement but the computation is easier. The use of a nautical slide rule, however, results in a radical transformation of the solution process: computational planning is transformed into a manipulation of an external device, while no algebra knowledge whatsoever is required. As Hutchins (1995a) notes the solution was not really 'computed' with the use of the nautical slide rule: "it seems that much of the computation was done by the tool, or by its designer. *The person could somehow succeed while doing less because the tool did more*" (p. 151, emphasis added). Therefore, the use of the nautical slide rule transforms the task because the use of logarithmic scales uses physical space to represent logarithmic magnitudes; with the slide rule the logarithmic scales are spatially juxtaposed, logarithmic magnitudes being represented by stretches of space. In this way, multiplication and division are implemented "as simple additions and subtractions of spatial displacements" (ibid., p. 171). The interesting effect of this sort of manipulation is that the user operates spatially on scales and the outcomes of these operations are computational.

3.4 Extending cognition beyond the skin: Distributed Cognition

> *"We needed…to step outside the organism to discover the sources of specifically human forms of psychological activity"*
>
> Luria (1979, p. 43)

In her discussion of Hutchins's work, Nardi (1996c) points out that in his account of the distribution of cognition humans and tools are fundamentally the same, i.e. have a symmetrical role, and the same language can be used to describe them both. Our interpretation of Hutchins's work is that he does not use individual cognition as his unit of analysis – and such a position is in many ways similar to the one taken by sociocultural psychology – but he nevertheless seeks to answer old questions[4]. Even though the approach is very interesting and the ethnographic

[3] Example of such a navigational problem: what is the speed of a ship in nautical miles per hour given that the distance between two fix positions is 1500 yards and 3 minutes elapsed between the two fix observations?

[4] c.f. Hutchins 1995b, p. 266: "one can still ask the same questions of a larger, socio-technical system that one would ask of an individual. That is, we wish to characterize the behavioral properties of the unit of analysis in terms of the structure and the processing of representations that are internal to the system".

accounts he gives are very insightful, it still falls short in some respects. What remains problematic is that *Hutchins is still concerned with how information is represented not within the individual head but within the cognitive system, and how information is propagated in the system*. As he puts it, the approach "is explicitly cognitive …such a theory can provide a bridge between the information processing properties of individuals and the information processing properties of a larger system" (1995b, p. 286-87).

Up to this point we have examined the positions and assumptions made in traditional cognitive science about what cognition is, where it resides and how it can be studied. We have also briefly considered a view which is at the moment acquiring momentum in cognitive science, which is more open to the possibility that cognition is not exactly located inside the head but also in the whole system and environment in which the individual is embedded. In this section we will focus on another approach to Distributed Cognition from sociocultural psychology[5].

Within the research tradition of psychology intelligence has been mainly treated as being in the head. The study of cognitive processes in isolation proved to be very helpful in understanding phenomena like information processing, problem solving and learning but the major limitation of this approach is that in real life "people think in conjunction and partnership with others and with the help of culturally provided tools and implements" (Salomon, 1993a, p. xiii). The idea that cognition is (or can be) distributed is certainly not new, as the works of Wundt, Munsterberg and the Vygotsky-Luria-Leontev school suggest (Cole & Engestrom, 1993). The revived interest in distributed cognitions, however, has been attributed (a) to the fact that nowadays people rely on computer tools to handle a variety of intellectual tasks, (b) to the interest in cultural-historical psychology, and (c) to the dissatisfaction with the notion of cognition as a property of the individual mind (Salomon, 1993a).

Cole & Engestrom (1993) note that the basic structure of human cognition as resulting from tool mediation has been traditionally depicted as a triangle, where the subject does not interact with the object directly but by means of a tool. They believe this metaphor to be incomplete as this triangle fails to account for the collective nature of human activities. Their proposal involves a conceptualization which takes into account: (a) the fact that there are relationships between a subject and the community in which he/she belongs; (b) the fact that the relationships with the community are mediated by the artifacts used by the group and (c) that there are rules which regulate the relationships among the subjects and their behaviors. In this sense, communities can be viewed as involving some sort of division of labor among the participants: a distribution of tasks, powers and responsibilities. Cole & Engestrom (1993) argue

[5] For the meaning of the term sociocultural psychology and how it contrasts with the term cultural-historical psychology originally used by Vygotsky and his colleagues, see Wertsch, Del Rio & Alvarez, 1995, and Wertsch, 1991; 1995; 1998.

that this approach to human environments has two main advantages: “first, it provides a conceptual map to the major loci among which human cognitions is distributed. Second, it includes other people who must somehow be taken into account simultaneously with the subject as constituents of human activity systems”, p. 8). This approach highlights the defining role played by others, emphasizing mainly the distribution of cognition in a somewhat *social dimension*. According to Pea (1993) the distribution of cognition can be perceived of as having yet another dimension: a *material* one.

From the standpoint of Distributed Cognitions theory, whenever a tool is used in the execution of a task, it participates in the outcome as well, as it contributes to it in a very unique way: it guides, augments, and structures the activity, saves mental work and helps avoiding errors (Pea, 1993). For example devices like jogger pulse meters, automatic street locators, currency exchange calculators, world time clocks and weight-loss calculators “reify common problem formats and automate solution-finding procedures” (ibid., p. 53). Many of these tools have become mythic in the sense that they “are invisible, un-remarkable aspects of our experiential world”, forming an integral part of our consciousness so that we do not notice them (ibid., p. 53). The major implication then is that “as such tools become invisible, it becomes harder to see them as bearing intelligence; instead we see intelligence as residing in the individual mind using the tools” (ibid., p. 53). According to Pea (1993) this interpretation is inaccurate since the tools literally carry intelligence in them as they bear the patterns of previous reasoning, and they constitute a realization of distributed intelligence.

3.5 The social distribution of cognition: the influence of others

3.5.1 Social influences on the development of cognition

In a detailed analysis of how the principles of Distributed Cognitions theory apply to a cognitive task like reading acquisition, Cole & Engestrom (1993) highlight two principles as important: “a) *the cognitive processing involved in learning to read is not an individual matter*; the requisite cognitive processes are distributed among teacher, pupil, other students, and the cultural artifacts around which they coordinate in the activity called teaching/learning to read; b) *The expected future state, mature reading, must somehow be present at the beginning of instruction* as constraints enabling the development of the to-be-acquired new system of mediation, mature reading” (p. 23). According to Cole and Engestrom the overall organization of the environment serves the objective of creating an interpersonal system of interaction so that “the combined child-adult system...can coordinate the child’s act of reading before the child can accomplish this activity for him-her self” (ibid., p. 24). In this sense, reading acquisition means that the children can “fulfil more goals more often” (ibid., p. 29).

The same line of reasoning can be seen in Pea's (1993) account of how problem solving takes place. In an analysis of a problem solving task, he criticized the notion of the six stage problem solving model which has been proposed by Polya (i.e. finding the problem, representing the problem, planning a solution, executing the plan, checking the solution and reflecting to consolidate learning). Pea (1993) argues that each phase is not a construction of the individual mind but also the outcome of cooperation with and guidance from others and as a consequence the borders between the stages become vague when one pursues an analysis of the problem solving process. On this same issue of the social distribution of cognition, Moll, Tapia & Whitemore (1993) reported that children draw on teachers, fellow students, and academic materials for shaping and directing their activities, and this provides evidence of how cognitions are distributed in that particular context. In another study, Hatch & Gardner (1993) showed that a child who did not have inclination to and experience with drawing got involved with more experienced peers and got advice and assistance from them in accomplishing his objectives. In a sense, this child could accomplish more advanced drawings with the help of his classmates.

The most important implication of these accounts is that the acquisition of a cognitive skill is an issue involving social others as well. Others, e.g. the teacher, are fundamentally involved in that process not only in terms of providing new knowledge and strategies but also in filling in all the steps in the application of these knowledge and strategies that cannot be individually performed by the child. In a way, the acquisition of a cognitive skill is a cooperative enterprise between teacher and student, with the teacher performing all the actions the student cannot individually manage up to the point where the student eventually learns to regulate himself in the application of knowledge or strategies. This type of teacher help has been referred to as *the transition from other to self-regulation* and will provide our focus below both in terms of theoretical underpinnings and in terms of empirical findings.

3.5.2 Cultural-historical psychology and the social distribution of cognition: theoretical foundations of self-regulation

" When I raise my arm I do not usually try to raise it"
Wittgenstein (1976/1958, p. 161)

3.5.2.1 The General Genetic Law of Cultural Development

Within the sociocultural school of psychology the role of others (parents, teachers and peers) in the context of ontogenetic development is deemed crucial. One of the main claims of this school of thought is the general genetic law of cultural development, put forward by Vygotsky several years ago. More specifically, Vygotsky (1978) argued that "every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first *between* people (interpsychological), and then *inside* the child (intrapsychological). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals" (p. 57, emphasis in the original). What does this statement mean? Vygotsky (1987) provided an illustration: "when the school child solves a problem at home on the basis of a model that he has been shown in class, he continues to act in collaboration, though at the moment the teacher is not standing near him. From a psychological perspective, the solution of the second problem is similar to this solution of a problem at home. It is a solution accomplished with the teacher's help. This help – this aspect of collaboration – is *invisibly present*. It is contained in what looks from the outside like the child's independent solution of the problem" (p. 216, emphasis added). For Vygotsky, thus, higher mental functions are primarily manifested between people before they can be exhibited at an individual level. In fact, Vygotsky (1960/1981b) went as far as to argue that solitary thinking is inherently social in nature: "even when we turn to mental processes, their nature remains quasi-social. In their own private sphere, human beings retain the functions of social interaction" (p. 164).

Wertsch (1991) has argued that two specific implications can be drawn from the general genetic law of cultural development. On the one hand, it does not merely imply that individual mental functioning is derived from participation in social life: it means that structures and processes on the intramental plane can be traced back to their genetic precursors on the intermental plane. On the other hand, the notion of mental function can be applied to both social and individual forms of activity. As he (ibid.) points out, in a case of a child who is assisted by his mother to remember where his toy is, it is impossible to say that either of the two participants did the remembering: it was carried out on the intermental plane.

3.5.2.2 The notion of 'voices'

Wertsch (1991) has pointed out that Vygotsky's and Bakhtin's accounts of the development of the individual mental functioning converge on the issue of the social influence on the development of the individual. He argued that, for both of them, mental functioning in the individual is seen as developing in the social and communicative processes. More specifically, Bakhtin saw the social dimension and influence in the development and shaping of the individual consciousness as playing an essential role. He argued: "Everything that pertains to me enters my consciousness, beginning with my name, from the external world through the mouths of others (my mother, and so forth)…I realize myself initially through others: from them I receive words, forms, and tonalities for the formation of my initial idea of myself….Just as the body is formed initially in the mother's womb (body), a person's consciousness awakens wrapped in another's consciousness. Only later does one begin to be subsumed by neutral words and categories, that is, one is defined as a person irrespective of *I* and *other*” (1986, p. 138, emphasis in the original). Bakhtin’s point resonates clearly with Vygotsky’s general genetic law of cultural development.

Bakhtin, viewed this social influence on the formation of the individual mind in terms of voice and dialogicality. Concerning the former, Bakhtin (1986) argued that, while words belong to nobody, our speech “is filled with other’s words” (p. 89). As he put it, when an individual speaks, he/she is not the biblical Adam, assigning meanings to words for the first time: on the contrary, the words used have come from other people, they were not invented and they are not possessed by him/her. The words a person uses are replete with meanings from other’s, the words reflect the voices of others, so to speak. The term voice does not amount to a vocal-auditory signal: through voice Bakhtin generally referred to the speaking consciousness (Wertsch, 1991). Thus, the voice producing the utterance and the speaking consciousness do not always coincide: “each word contains voices that are sometimes infinitely distant, unnamed, almost impersonal (voices of lexical shadings, of styles, and so forth), almost undetectable, and voices resounding nearby and simultaneously” (Bakhtin, 1986, p. 124).

The notion of voice leads us to the notion of dialogicality. Dialogicality is for Bakhtin an inherent feature of human speech communication: an utterance is always a response to a former utterance, being a link in the chain of speech communication. An utterance presupposes former utterances (to which it responds) and precedes future utterances (which will respond to it). Utterances are dialogically related to one-another. According to Bakhtin “the utterance has both an author…and an addressee. This addressee can be an immediate participant-interlocutor in an everyday dialogue, a differentiated collective of specialists in some particular area of cultural communications, a more or less differentiated public, ethnic group, contemporaries, like-minded people, opponents and enemies, a subordinate, a superior, someone who is lower, higher, familiar, foreign, and so forth. And it can also be an indefinite, unconcretized *other*” (ibid., p. 95, original emphasis). Understanding an utterance can never be exhausted by focusing on its thematic content, on the object of the utterance that is: an utterance always expresses, to some extent, a response to other utterances. This particular feature of addressivity of the utterances illustrates that an utterance is filled with “dialogic overtones” and these are called for if any understanding of the utterance is to be expected. As a direct consequence of the dialogical nature of utterances “thought itself…is born and shaped in the process of interaction and struggle with others’ thought, and this cannot but be reflected in the forms that verbally express our thoughts as well” (ibid., p. 92).

3.5.3 Self-regulation: empirical research

> *"It is quite apparent that in addition to performing instinctive reflex acts, we can carry out conscious voluntary acts. Humans can prepare a plan and carry it out. They may wish to raise their hand and they do so. This is self-evident. The main difficulty of psychologists has been to find a scientific explanation for it"*
>
> Luria (1982, p. 88).

In the last two decades, self-regulation has been studied mainly within the context of metacognition, since self-regulation was identified as one of the principal components of metacognition (Brown, 1978). In recent times, however, the emphasis on self-regulation as an individual area of research with its own agenda, is increasingly being manifested (e.g. Pressley, 1995; Winne, 1995; Zimmerman, 1995; Boekaerts, 1997). With the resurgence Western interest in the work of Vygotsky (e.g. Wertsch & Tulviste, 1992), a number of studies have investigated various aspects of social interaction and the development of self-regulation (e.g. Wood, Bruner & Ross, 1976; Wertsch, 1978; Wood, 1980; Wertsch et al., 1980; Kontos, 1983; Rogoff, Ellis & Gardner, 1984; Rogoff & Gardner, 1984; Wertsch, Minick & Arns, 1984; Saxe, Gearhart & Buberman, 1984; Rogoff, Malkin & Gilbride, 1984; Wertsch, 1985; Moore, Mullis & Mullis, 1986; Amigues, 1988; Rasziszewska & Rogoff, 1988; Pratt et al., 1988; Guavain & Rogoff, 1989; Diaz, Neal & Amaya-Williams, 1990; Freud, 1990; Rogoff, 1990; 1991; Tudge, 1990; Diaz, Neal & Vachio, 1991; Rasziszewska & Rogoff, 1991; Elbers et al., 1992; Normandeau & Arsenault, 1994; Werdernschalg, Hernandez & Moely, 1993; Larivee et al., 1994; Gonzalez, 1996; Leseman & Sijsling, 1996; Nilholm & Saljo, 1996; Hoogsteder, Maier & Elbers, 1996). The main findings from this body of research will be presented below.

3.5.3.1 Task simplification: the structuring of the environmen t

How is the child's participation in and mastery of a task made possible, when the task cannot be dealt with autonomously? Through task simplification. The task is structured by the adult in such a way that it becomes manageable for the child, thereby enabling his/her participation in its execution. *The adults handle the difficult aspects of the task and arrange the child's involvement with subtasks that the child can deal with*. This responsibility for managing the task belongs to adults, as they may decide on the problems to be solved, the specific goals for each problem and how the goals will be broken down into small and manageable subgoals (Rogoff, 1990). In this way, the task is significantly simplified (in order to be adjusted to the child's level), so that the number of steps to be taken towards solution is reduced with the student doing whatever is within his/her reach and the adult simply filling in the rest, a process which has been described as the reduction of the degrees of freedom (Wood, Bruner & Ross, 1975).

Why is this sort of task management by the adults an important aspect of the learning situation? Rogoff (1990) argues that the structuring of problem solving activities entails that children are able to take part in a meaningful subgoal which possesses the characteristics of the activity as a whole. Structuring, according to Rogoff, involves the child with the purpose of the activity, while the difficult aspects of the task are becoming manageable as a result of the help and support from the adult. More specifically, the participation in the overall process enables children to see how the sub steps fit together and to participate in aspects of the activity that reflect the overall goals as well (Rogoff, 1990). Rogoff, Malkin & Gilbride (1984) also suggested that the purpose an additional objective of task simplification is to enable children to participate in the activity at comfortable but nevertheless challenging levels.

3.5.3.2 Transfer of responsibility: the transition from other to self-regulation

How is transfer of responsibility occurring? As was shortly analyzed above, the adults perform whatever function the children are incapable of during task execution. With the passing of time, though, children's understanding of the task increases and they are capable of performing more steps independently. The practical implication is that any skill improvement renders the formerly requisite teacher help unnecessary. *The functional implication is that the task management is transferred from the adult to the child, as a function of the latter's skill development and deeper understanding*. Thus, in the course of task execution, there is a transition from other to self-regulation, namely the other-regulated child becomes capable of self-regulation with the passing of time, as manifested by the decreased amount and quality of adult intervention that is called for in performing the task.

This transfer of responsibility is greatly facilitated by the child's increasing skill level and understanding. According to Rogoff (1990) adults allow or even demand the children to assume greater responsibility as skill competence increases. A number of studies have lent support to these views. Wertsch et. al (1980) reported that the adult-child interaction is structured in such a way that the actions are firstly carried out at the interpsychological plane before they can appear on the intrapsychological one. Rogoff & Gardner (1984) found that the transfer of responsibility is typical of mother-child interaction episodes: the responsibility for managing some aspects of the task was mother's duty at the beginning, as the child was not in a position of doing that, but had shifted to the child by the end, as a function of task mastery. Rogoff, Malkin & Gilbride (1984) also reported that responsibility changes in the course of interaction: initially the adult is charged with task structuring and managing the process towards the goal but as time elapses he/she also makes sure that responsibility for managing the task is gradually transferred to the child.

3.5.3.3 Evaluating the child's level of competence

For the transfer of responsibility to occur, child's skill and understanding have to be evaluated. *Adults have to determine how much the child has progressed before they judge that the child can use some more freedom in executing the task.* What the transfer of responsibility practically means is that the scaffold of support is temporarily removed, partially or wholly, which in turn entails that the responsibility for task management and execution is transferred to the child, as little or no support is provided by the adult. Rogoff (1990) points out that adults usually adjust their support to the skill level of the child. Determining the skill level is achieved by means of redundancy: at the initial levels of task execution, a lot of information is provided by the adults, but with the passing of time redundancy is decreasing in response to the child's increased understanding. One of the interesting aspects of scaffolding is that it is never perfectly adjusted to the child's level and mistakes are, thus, not only inevitable but also desirable in determining the child's actual level (Rogoff & Gardner, 1984). For example, the mothers are initially providing a lot of redundant information to ensure correct performance, but an improvement in performance entails that the information provided decreases, while the appearance of an error leads to the occurrence of redundancy again (Rogoff & Gardner, 1984). Rogoff, Malkin & Gilbride (1984) report that the process of transferring the responsibility is a very subtle one: the guidance of the adults is diminishing as a function of the improvement of the skill level of the child. At times, as they argue, the scaffold is completely removed, so that the adult or the teacher has a very accurate estimation of the child's understanding of the task and the child's competence on the task. Pratt et al. (1988) reported that parents consistently adjusted their teaching to child's level of competence and were also very responsive to skill progress by systematically reducing their level of task support. Diaz et al. (1990) reported that mothers' relinquishing was positively correlated with the child's takeover of a regulatory role. It is worthwhile stressing the fact that this process of evaluation of the level of the child does not always originate from the adults: Rogoff (1990) argued that in the course of interaction children are always very active, assuming a lot of initiative, especially when they are interested in the activity performed and, thus, guiding the adults in allowing them more freedom of movement.

3.5.3.4 Instructional and cognitive strategies

Apart from the regulatory aspect of teacher intervention, cognitive strategy and instructional dimensions are also important. With respect to instruction, one of the decisive conditions for its effectiveness is the achievement of intersubjectivity: adults and children share the same perspective and have a mutual understanding of the task before any progress is likely (Rogoff, 1990). Common instructional strategies involve demonstration (Wood, Bruner & Ross, 1975), focusing attention (ibid.), and the use of analogies (Rogoff, 1990).

At the level of cognitive strategy instruction, Larivee et al. (1994) reported that children used more sophisticated strategies at older ages when dealing with the same cognitive task. Werdenschlag et al. (1993) found that instructed children performed better than uninstructed children on a criterion task, exhibiting more sophisticated skills as well as a better understanding of the task. The precise contribution of the mothers was to provide the cognitive strategies required for dealing with the task as well as to help the child improve his/her understanding of the task. These studies also indicate that apart from regulating student's learning the parents also provide cognitive strategies so the students can make use of them in solving the task.

3.5.3.5 Regulation as a function of age, education, and task familiarity

Some properties of the teacher (being it a school teacher, a parent or a peer) have also been found to differ in terms of instructional and regulatory intervention. For instance, the level of education of adults (mothers vs. teachers, mothers having less years of formal education) played a role in how they regulated children, with mothers using more direct forms of regulation (Wertsch et al. 1984). Moreover, parental regulation was also found to vary according to the socioeconomic status (Nilholm & Saljo, 1996; Leseman & Sijsling, 1996). Adult or teacher familiarization with the task was also found to be consistently related with how children were instructed and regulated: Normandeau & Arsenault (1994) reported that task-familiar mothers elicited higher level strategies in teaching their children and they also tended to explain these strategies compared to mothers unfamiliar with the task. The pattern of interaction was also found to vary according to the level of anxiety of the mother: Diaz et al. (1991) reported that high risk mothers used more controlling and more verbal strategies, less distancing and fewer attributions of competence compared to low risk mothers. The age and experience of the teacher also appears to result in a different regulatory pattern: in a study with peer tutors and adult tutors Radziszewska & Rogoff (1988) found that adult guidance was greatly differentiated along the following dimensions: question posing, verbalization of strategies, description of current subgoals and justification of decisions. In a follow up study, Radziszewska & Rogoff (1991) reported that working with a more skilled peer does not lead to better performance than working with a novice peer. On the contrary, children working with adults progressed more than children working with a trained peer. This was attributed by the authors to the fact that adults offer guided participation: they verbalize their strategies and allow more involvement in decision making.

3.6 Material distribution of cognition: artifacts and cognition

> *"We load intelligence into both physical and designed artifacts and representational objects such as diagrams, models and plans"*
>
> (Pea, 1993, p. 70).

The material distribution of cognition provides an account of how cognition is distributed when tools are employed as a means to achieve an end. The main argument is that whenever a tool is used in the execution of a task it participates in the outcome as well, as it bears and contributes to it in a very unique way which cannot be overlooked. When people are engaged in an activity, they often make use of artifacts for guiding, augmenting and structuring their activity, for saving metal work and for avoiding errors (Pea, 1993). The artifacts used by humans constitute an integral part of their intelligence in the sense that on the one hand the surround participates in cognition as a vehicle of thought and on the other in that learning does not reside only in the mind of the learner but also in the arrangement of the surround (Perkins, 1993). The material distribution of cognition has two main facets: (a) distribution using the natural environment as a calculating tool and (b) distribution using specially constructed human artifacts. We will discuss them shortly.

One type of tools people use for augmenting their capabilities and for alleviating cognitive burden are either physical tools existing in the environment or aspects of the environment itself. Consider the well known weight watchers example: "'suppose your allotment of cottage cheese for the meal is three quarters of the two thirds cup the program allows?' The problem solver in this example began the task muttering that he had had calculus in college and then after a long pause, suddenly announced that he had 'got it'. From then on he appeared certain he was correct, even before carrying out the procedure. He filled a measuring cup two thirds full of cottage cheese, dumped it out on a cutting board, patted it into a circle, marked a cross on it, scooped away one quadrant, and served the rest. Thus, 'take three quarters of two thirds of a cup of cottage cheese' is not just the problem statement but also the solution to the problem and the procedure for solving it. Since the environment was used as a calculating device, the solution was simply the problem statement, enacted." (Lave et al., 1984, p. 89). As can be seen from this example part of the cognitive processing for determining how much cheese is allowed per meal, was offloaded onto the environment which in turn was used as a means of simplifying the problem and eventually solving it. Ideally, the problem solver should have figured out that

$$\frac{3}{4} x \frac{2}{3} = \frac{6}{12} \text{ or } \frac{1}{2}$$

cup of cheese. Instead of engaging in 'mathematical' calculations the problem solver literally used the environment as a computational tool.

Consider the following example of environment-based solution to a computational problem: “one shopper found an unusually high priced package of cheese in a bin. He suspected an error. To solve the problem, he searched through the bin for a package weighing the same amount and inferred from the discrepancy between the prices that one was in error. His comparison with other packages established which was the errant package. Had he not transferred the calculation to the environment, he would have had to divide weight into price, mentally, and compare the result with the price per pound printed on the label, a much more effortful and less reliable procedure” Lave et al. (1984, p. 77). The same pattern of behavior recurs in this example where the problem solver is not behaving in a perfect rational way, mentally performing the calculation and solving the problem. As opposed to engaging in mental arithmetic, the shopper resorts to the environment in an attempt to avoid mental effort.

Setting the issue of theory aside, it can be seen that these two examples have a lot in common with Hutchins’s both finger counting example, where mental effort is saved by turning to fingers, and the use speed bugs, where pilots seem to use salmon bugs in a way not intended by the designer.

Humans are not only confined to making use of the direct physical environment per se for avoiding mental effort. Our intelligent activity as a species is largely manifested in the creation and use of tools. Cultural tools invented by humans like language and mathematics have had a significant effect on human cognition and one way or another on man’s problem solving abilities. Take language for example: it is considered to be the most fundamental human cognitive tool, or the ‘tool of tools’. According to Luria (1982) “the ability to transcend the bounds of immediate concrete experience is a fundamental feature of human consciousness” (pp. 18-19). Without words humans would have to deal with things which could be perceived and manipulated directly. The use of language entails that they can deal with things which they haven not perceived even directly. Therefore, with the aid of language humans can: (a) manipulate things internally in absence of the real objects, e.g. comparing the weight of any two objects which are not present in the visual field, and (b) benefit from the experience of earlier generations which is codified in language and transferred through language, because they do not have to rely solely on their own personal experience (Luria, 1982). As Luria (ibid.) argues, humans have a double world because of language: without words humans would be able to deal with things which could be directly seen; animals on the other hand only have one world, one of objects and situations. Vygotsky (1978) argued that when a young child solves a practical task it does so not only with his hands and eyes, but also with the help of speech. It is with the use of speech that the child acquires some freedom from the direct situation, creates a plan, and achieves a broader range of activity (Vygotsky, 1978; cf. Vygotsky & Luria, 1994). “Labeling enables the child to choose a specific object, to single it out from the entire situation he is perceiving…by means of words children single out separate elements, thereby overcoming the natural structure of the sensory filed and forming new (artificially introduced and dynamic) structural centers. *The child begins to perceive the world not only through his eyes but also through his speech*[6]" (Vygotsky, 1978, p. 32, emphasis added).

Regarding mathematics, Mach argued that "the purpose of mathematics should be to save mental effort…when numerical operations are symbolized by mechanical operations with symbols, our brain energy is spared for more important tasks, such as discovery or planning...by relieving the brain of all unnecessary work, a good notation sets it free to concentrate on more advanced problems, and in effect increases the mental power" (cited by Pea, 1987a, p. 96). Vygotsky (1987) argued that algebra serves the purpose of freeing thought from concrete numerical relationships and raises it to the level of more abstract thought. In a sense, algebra represents a higher plane of development of mathematical thought.

3.6.1 Cultural-historical psychology and the material distribution of cognition: theoretical foundations of the influence of artifacts on cognition

In this section the effect of tools on the formation of the psyche will be shortly presented. Vygotsky and his colleagues conducted research on how psychological tools, signs as they were referred to, came to have such a tremendous impact on the development of psychological operations. Vygotsky distinguished between biological and cultural development, argued that the use of tools in performing a psychological task is analogous to the employment of tools in labor and outlined how mediation functions. In the next few paragraphs a brief sociocultural psychology account of mediation will be presented.

[6] It must be emphasized that some of these claims about the effects of language and literacy of cognition have only been partially confirmed. Some of these ideas about the effects of language and literacy on cognition have been investigated by Vygotsky's team and mainly reported in Luria (1976). As the results indicated, illiterate people regarded the logical procedures of categorization as irrelevant, as having no practical value whatsoever. Luria concluded that the responses of subjects indicated that these people were thinking in concrete terms and lacked the verbal logical operations which characterize abstract thinking. In the same study it was found that literate subjects or subjects with some education presented a transition to abstract thinking. Van der Veer & Valsiner (1991) pointed out that the results were not convincing, at least as far as perception was concerned. The results from the first study were rather mixed and this was reflected on how cautiously Luria communicated the findings to his German colleagues. Additionally, Koffka's results during the second study were not in perfect agreement with the results Luria obtained during the first one. As they (ibid.) put it, on the basis of his data Koffka "flatly denied Luria's initial conclusions" (p. 250). Upon comparing Luria's 1976 monograph with Koffka's report, the authors argue that Luria omitted some of his initial doubts. Recent research on the same issues by Scribner & Cole (1981) has only partly replicated Luria's findings.

3.6.1.1 The road to mediation

"Man differs from animals in that he can make and use tools"
Luria (1928/1994, p. 46).

According to Van der Veer & Valsiner (1991), in an attempt to formulate his theory Vygotsky examined philosophical and psychological theories as well as findings from animal psychology and ethnography. At that time two theories were dominant. One theory proposed that animals were fundamentally different from human beings, a view advanced by Descartes suggesting an animal-man dichotomy. The other theory maintained that animals were basically not different from human beings, a view put forward by Darwin in his theory of evolution. Vygotsky rejected the animal-man dichotomy of Descartes because he believed it to be the product of a nongenetic and nonevolutionary conception. For instance, Darwin's evidence contradicted Descartes' ideas and, moreover, Vygotsky had trouble with the introduction of non material factors (i.e. soul) in the explanation of human behavior. Although the Darwinian theory provided a natural alternative to the dichotomous views of Descartes by closing the gap between animal and man, Vygotsky did not wholly agree with it because Darwin had argued that the mental capabilities of man and the lower animals did not differ in kind but in degree. Vygotsky was not convinced that these differences were only quantitative in nature, because, for instance, he was well aware of the fact that, while animals are mostly dependent upon inheritance of genetically based traits, humans both create and transmit culture. Vygotsky firmly believed that Darwin had seriously "underestimated human beings' qualitative uniqueness" (Van der Veer and Valsiner, 1991, p. 202).

To account for the obvious fact that humans are different from animals in qualitative ways, i.e. creation and transmission of culture as opposed to simple transmission of genes, Vygotsky introduced a distinction between biological evolution and cultural/historical evolution, drawing on the theories of Marx and Engels. According to Engels, the history of mankind began when the precursor of man left the trees and developed an upright gait. This new posture freed the hands for the manipulation of various objects and motor actions improved along with visual ability. Eye-hand coordination gradually improved, and hand, sense organs, and brain all developed in a complex interaction. At this stage man started to cooperate in labor, and this new condition created a need for a means of communication: as a result, speech was developed. Group cooperation, tool making and communication through speech led to a gradual transformation of nature. Hence, labor was first and created the need for speech. Labor is the defining characteristic of humans, according to Engels. Even though he acknowledged that some animal species exhibit tool using skills, he pointed out that the main difference between humans and animals is that animals simply use tools while humans create them (Van der Veer & Valsiner, 1991).

The combination of the theories of Darwin and Engels was not without theoretical and empirical problems, as Van der Veer & Valsiner (1991) demonstrated. Vygotsky, however, had two additional resources available to which he turned for circumventing these problems. On the one hand, evidence from Kohler's experiments with chimpanzees provided Vygotsky with a first alternative as to the nature of differences between humans and animals: chimpanzees lacked the 'priceless technical tool' of speech. On the other hand, Vygotsky also used evidence from anthropological findings (e.g. Levy-Bruhl, Binet, Claparede, Durkheim, Thurnwald) indicating that people from different cultures have potentially different higher mental functions which result from different cultural conditions, whereas their lower (biological) processes are essentially identical. Based on these theories and findings, Vygotsky developed and elaborated the idea that *material (technical) tools are in many respects similar to cultural tools* (Van der Veer & Valsiner, 1991).

3.6.1.2 The nature of mediation

Human action has two main defining characteristics. The first is its 'teleological' character, i.e. it is goal directed; the second is its mediational character, i.e. it is instrumental in the attainment of the goal (Wertsch, 1991; 1998). Man typically uses tools in his attempts to accomplish a certain goal, and, thus, interacts with nature indirectly, through tool-use. Marx and Engels had argued that human activity is mediated by material tools and Vygotsky extended this argument to include psychological tools as well: "the invention and use of signs as auxiliary means of solving a given psychological problem…is analogous to the invention and use of tools in one psychological respect. *The sign acts as an instrument of psychological activity in a manner analogous to the role of a tool in labor*" (Vygotsky, 1978, p. 52, emphasis added). These auxiliary means may be called 'psychological tools' or 'instruments' and include "language; various systems for counting; mnemonic techniques; algebraic symbol systems; works of art; writing; schemes, diagrams, maps and mechanical drawings; all sorts of conventional signs" (Vygotsky, 1960/1981a, p. 137). Hence, next to Marx and Engels' argument that human activity is mediated by material/labor tools, Vygotsky proposed that it is also mediated by *psychological tools*.

As Vygotsky (1960/1981a) argued, like any analogy, the analogy between technical tools and psychological ones, has its limitations. The main similarity between tools and signs is "the mediating function that characterizes each of them" (Vygotsky, 1978, p. 54). The fundamental difference between the two, however, is related to the 'reverse action' of psychological tools: "the tool's function is to serve as the conductor of human influence on the object of activity; it is externally oriented…the sign, on the other hand, changes nothing in the object of a psychological operation. It is a means of internal activity aimed at mastering oneself; the sign is internally oriented" (Vygotsky, 1978, p. 55; cf. Vygotsky, 1960/1981a, Vygotsky & Luria, 1994). As a consequence "the child in mastering himself (his behavior), goes on the whole in the same way as he does in mastering external nature, e.g. by technical means" (Vygotsky, 1929/1994, p. 70).

Vygotsky used the case of memory in his attempt to illustrate how the employment of a tool impacts on the structure of a psychological operation and raises it to a higher level. He argued that *natural (biological) memory is different from cultural (artificial) memory as far as the structure of the mnemonic function is concerned*. In the case of natural memory, a certain connection is established between two stimuli A and B, and this association is *direct*, i.e. unmediated. In the case of cultural memory, the connection between A and B is no longer direct: it becomes *indirect*, i.e. mediated. Assuming that a psychological tool X (e.g. a mnemonic scheme) is included in the process mediating the relationship between A and B, two new connections emerge: A-X and X-B. From a natural memory viewpoint, each of these connections presents nothing new because it is a conditioned response based upon the same biological brain properties which made the initial A-B connection possible[7]. The essential difference is that the one initial connection (A-B) is replaced with two new connections, A-X and X-B. This new connection makes it possible to achieve the same result using a different path, i.e. through an instrumental act. What is typically characteristic of the instrumental act is the simultaneous presence of two types of stimuli: object and tool (Vygotsky & Luria, 1994). As this example indicates, the inclusion of a sign in remembering, transforms memory and essentially changes its nature.

3.6.1.3 Mediation as inherently social

All mediated psychological processes are *higher* psychological processes and their basic structure is characterized by "the use of the sign as a means of directing and mastering mental processes" (Vygotsky, 1987, p. 126). A fundamental position of cultural-historical psychology is that higher mental functions "are an aspect of the child's cultural development and have their source in collaboration and instruction" (ibid., p. 213). They first appear as forms of cooperative activity and only subsequently are they internalized by children and surface within their own mental activity. This position is commonly referred to as the general genetic law of cultural development (which was discussed earlier in this chapter). Therefore, "any higher mental

[7] As Vygotsky argued "artificial (instrumental) acts must not be viewed as supernatural acts constructed in accordance with some new, special law. Artificial acts are still natural ones. They can, without exception, be analyzed in terms of natural ones just as any machine (or technical tool) can, without exception, be analyzed in terms of a system of natural forces and processes. The artificial device is a combination (construction) and directing force as well as the substitution and use of these natural processes" (Vygotsky, 1960/1981a, p. 137).

function necessarily goes through an external stage in its development because it is initially a social function" (Vygotsky, 1960/1981b, p. 162).

Mediation is, therefore, of an inherently social nature. For example, adaptation to the environment from the very first days of life is achieved by social means, through the people in the child's environment. These people mediate the interaction of the infant with its environment and, thus, "the road from object to child and from child to object lies through another person" (Vygotsky & Luria, 1994, p. 116). The sign is essentially a 'social organ' or 'social means' because its primary function is social in nature: it is used as a means of influencing and communicating with people in the immediate surround; only later is the sign used to as a means of influencing the self, acquiring, thus, a new and secondary function (Vygotsky, 1960/1981a; Vygotsky & Luria, 1994). In this second case "the sign simply transfers the social attitude toward the subject within the personality" (Vygotsky & Luria, 1994, ibid., p. 138).

3.6.1.4 The impact of mediation on psychological processes

The principle[8] that guided Vygotsky's thinking with respect to the impact of psychological tools/signs on psychological processes was that "the same problem, if solved by different means will have a different structure" (Vygotsky, 1929/1994, p. 61). Based on this principle and on the analogy between material tools and psychological tools, Vygotsky reasoned that, just as the use of a material tool restructures labor, the use of a psychological tool restructures psychological processes (Vygotsky, 1929/1994). In his own words, "mastery of a psychological tool …*always raises the particular function to a higher stage, increases and widens its activity, and re-creates its structure and mechanism*" (Vygotsky, 1960/1981a, p. 143, emphasis added). An instrumental (tool-based) psychological activity is essentially a higher psychological activity (Vygotsky, 1978; Luria, 1928/1994, Vygotsky & Luria, 1994). In a sense, "*any behavioral act then becomes an intellectual operation*" (Vygotsky, 1960/1981a, p. 139, emphasis added) because it is elevated from a behavioral stimulus-response structure to a higher (instrumental) one.

With respect to transformation, Vygotsky described three major changes effected in a psychological process upon tool use. Firstly, the use of a tool *introduces several new functions* which are related to using and controlling the tool. Secondly, the use of a tool *abolishes or renders unnecessary several natural processes* whose work is realized by the tool. Finally, the employment of the tool *changes some aspects of all the mental processes involved replacing*

[8] This view has had proponents in the areas of psychology, sociology, ethnography, and, education. This issue is inherently intertwined with a host of other issues concerning what it means to perform the 'same' task in two different contexts, the 'same' task using different resources/ tools etc. From a psychological-sociological perspective, Lave (1988), in contrast to cognitive science beliefs, demonstrated that "'the same' activity in different situations derives structuring from, and provides structuring resources for, other activities" (p. 122). For a relevant discussion in educational-psychological settings see Newman, Griffin and Cole (1987).

some functions with others (Vygotsky (1960/1981b). These transformations are characterized by two main dimensions (Vygotsky & Luria, 1994). Firstly, *a natural psychological process is transformed into a cultural one*, changing its structure and process. For example, in the case of memory, Luria (1928/1994) argued that "simple, natural memory was replaced by a system of signs and their subsequent reading, and *the maximum work was usually shifted from recollection to a recognition* of series" (p. 51, emphasis added). Secondly, *a natural psychological process becomes 'extra-cortical' when a psychological tool is used* and, thus, moves beyond its natural confines. In the case of memory again, the operation goes well beyond the limits of what is natural in remembering, i.e. the use of brain cells. When a sign/psychological tool is used as a means for remembering, memory becomes 'inter-cortical', in the sense that an external tool – a means which does not constitute a part of the biological makeup of the organism – is used in remembering. Therefore, the task of memory is accomplished by means of employing both natural resources (cortical) and external signs (extra-cortical) (Vygotsky & Luria, 1994). Whatever holds for memory also holds for perception, attention and the other psychological process as well[9].

3.6.1.5 The impact of mediation on established practice

In the previous paragraphs we examined the role of cultural tools and their impact on human psychological processes, i.e. on the self. Below, we will concentrate on the impact of cultural tools on standardized practices and on the environment itself. With the incorporation of a tool in the solution to a problem or in performing a task in general, the problem/task is radically transformed. Pea (1993) noted that we use tools but these are '*unremarkable'*, '*invisible'* aspects of the environment, in the sense that all we see is the tool user. Wertsch (1998) argued further that in many cases where we use cultural tools, we are '*unreflective'* and *'ignorant'* consumers of the cultural tool, in the sense that we are using it but we lack the conscious awareness of the fact that we are actually doing so. As a rule, we ignore its history, we are incognizant of the problems which eventually led its introduction, we are unaware of the people who introduced it into the practice, we are unaware of the physical/mental labor devoted to developing it, we are unfamiliar with how a specific task was performed prior to the introduction of the tool, and finally we are uninformed about the changes in the physical or mental labor that the tool effected. In a very important sense, the tool is an invisible part of the environment and all we focus upon is our activity, driven by our goals and motivation. We are immersed in a culture

[9] For instance, in the case of perception, Vygotsky & Luria (1994) demonstrated that "speech does not merely accompany the child's perception, from the very first it begins to take an active part in it: the child begins to perceive the world not only through its eyes, but also through its speech, and it is in this process that we find an essential point in the development of the child's perception" (p. 125).

replete with myriad tools, and, from our early days in life, we are conditioned to using them and we are counting on them to perform most everyday tasks. The availability of such tools in many contexts makes them ubiquitous, renders them elements of the background so that we take them for granted and, thus, literally ignore them. For instance, in the case of the electric motor technology Kline (1996) noted that “[it] has become literally invisible, embedded inside thousands of everyday products, from hair dryers and pencil sharpeners to dishwashers and toys…[it] is a victim of its own success, ignored precisely because of its ubiquity. It has become a central – albeit invisible – fact of daily life” (p. 98).

Due to the fact that we take all these cultural tools for granted, we cannot really see them, understand them, or appreciate their uniqueness, their contribution, and their participation in our intelligence. Only in cases where a breakdown occurs and the tool is no longer available do we come to understand its usefulness (Winograd & Flores, 1987). A tool can be described in some detail, and an account of the situation can be provided with all the physical and cognitive requirements. For example Wertsch (1991, 1995, 1998) has discussed the historical cases of three such examples: the case of the QWERTY keyboard, the use of fiberglass poles in pole vaulting, and the development of sound bites over the last few decades. Such examples are undoubtedly very captivating but we think it is more thought provoking to make such points with present-day examples. This is because historical accounts concerning examples of tools and practices of the past are somewhat distant. On the other hand, focusing on more contemporary examples has the advantage that we do not lack context knowledge to understand them. It is only when we take as an example an artifact or cultural tool which we do not take for granted, which puzzles us and makes us think about it, which doesn’t block our ability to think about it because we do not see it.

One such contemporary cultural tool which is not standardized yet and under constant development – and, thus, attracts our attention from time to time because of new changes – is the Internet. We will discuss three main cases of transformation which are related to this ‘new’ medium/cultural tool. Although it has been around since the late 1960s, it became popular with the development of the WWW graphical interface in the early 1990s. The internet plays an increasingly important role as an information resource. For instance, in the early 1990s people turned to television (CNN) for information on and live coverage of the Gulf war, while in the late 1990s they visited the NASA web site for checking the latest pathfinder images of Mars because TV networks could not compete with that.

The first such case is related to the impact of the Internet on the size of public encryption keys. Levy (1996) has documented how distributed code breaking pushed cryptography to more stringent standards. When the RSA encryption algorithm was developed in 1977, a message was encrypted and everyone was challenged to read it, in an attempt to prove its bullet-proof security. At that time it was estimated that it would take a single supercomputer 40 quadrillion years to break the code. With the passing of time increasingly more computers were networked and new possibilities emerged. While each and every networked computer stood no chance of deciphering the message, pooling all of them together would create the biggest computer on earth. It must be emphasized that such a possibility was not anticipated by the RSA team in the late 1970s. In 1994 the RSA key was eventually decrypted as part of a distributed brute-force effort using the idle time of thousands of computers all over the world (see Levy 1996 for details). Over the last two years, collective code breaking has made headlines twice (see http://www.distributed.net for more details; cf. Karasavvidis 1997).

The second example concerns the role the Internet played in publicizing the January 1998 White House sex scandal. The news story concerning the alleged sexual relationship of United States President with a former White House intern was first announced on The Drudge Report, an Internet website. This publication is considered to be an Internet ‘controversial’-‘gossip’-‘off-beat news’ website which circulates information fast but not necessarily with any reliability or credibility (Kellan, 1998a; 1998b). The journalist, Matt Drudge, usually attempts to scoop media print giants by releasing the story first and has been accused in the past of playing fast and loose with the facts and for releasing stories with insufficient verification. As Kellan (1998a) reported, “it all started when The Drudge Report passed along rumors that Newsweek was debating whether to run a story about secretly recorded conversations”. Newsweek has been researching the story for months but “[it] was not ready to be published”, as the editor of New Media Newsweek stated (Kellan, 1998a). Right after the publication of the story in the Drudge Report TV stations and other media organizations went public with whatever information they had, and, as a result, Newsweek followed and eventually published the story on its America Online Interactive website four days before the magazine would be available in print. The dilemma of ‘online journalism or gossip?’ emerged for two main reasons. On the one hand, television news shows covered a story developed by other news services before they themselves had the time to confirm it. On the other hand, it was only one week earlier that the Dallas Morning News posted an update on the same story on their website which was retracted four hours later (Kellan, 1998b).

The third example relates to the knowledge required to download files over the Internet by using FTP clients (File Transfer Protocol) over the last three decades. In the early internet years, one needed to have some considerable knowledge and understanding of Unix before any successful file downloading could be assumed. In addition to general operating system knowledge, there are about fifty file downloading commands unique to the Unix FTP client. Therefore, both understanding of the operating system and knowledge of some specific commands was required for downloading a file over the Net. Today, there are FTP clients available for all operating systems and some web browsers have built-in FTP clients. Even though the requirements for working knowledge of the operating system have not changed, no knowledge or understanding of the file transfer protocol is required for downloading a file. No commands are required for selecting the file because clicking the file amounts to selecting it; downloading the file simply requires double clicking or dragging the file to another window/desktop location. In a sense, file downloading *is* mouse clicking because all the intelligent activities which were normally required for file downloading under Unix are carried out with a simple mouse click (Karasavvidis, 1997).

In all three cases a certain development engendered a change in the practice[10]: *the DES 56-bit encryption key is no longer considered to be safe* against a committed attack; *the news cycle changed from hours to minutes and there is less time available for sufficiently checking out the accuracy of a story; knowledge of the file transfer protocol is unnecessary for downloading data over the Net*. All these examples of historical cases are illustrations of the fact that mediation transforms the standard practice in a number of ways.

3.6.2 Computer influences on problem solving: theory and research

Like all other artifacts, computer tools are essentially cultural tools, and the previous theoretical framework applies to them as well. The computer has been described as a new type of cultural technology which, unlike other tools, is expected to have more far reaching effects due to its ability to manipulate symbol systems. Computers have been described in a number of ways in the educational and psychological literature (cf. Salomon, 1990; Pea, 1985; 1987b; 1993; Perkins, 1985). In fact, Reusser (1996) reported at least 15 different views and metaphors of computers in teaching and learning. Generally speaking, computer effects fall under two major categories: (a) amplification and (b) transformation[11]. In the case of the former, the job is

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[10] Wertsch (1991; 1995; 1998; cf. Wertsch, Rio & Alvarez, 1995) argued that to understand cases like the ones presented above, one should look at (a) a host of institutional, cultural and historical factors and (b) on a number of properties of mediation like: *the active character of mediation* (the tool itself is incapable of performing the task, it has to be in user's hands); *the transformative power of mediation* (the use of tools alters the structure of the task thereby transforming it); *empowerment and constraint of mediation* (new mediational means overcome the limitations of old ones but introduce new of their own); *spin off* (quite often mediational means are created in response to factors which are eventually unrelated with their uses); *irreducible tension between agent and mediational means* (reducing the elements of action to either the individual or the tool risks destroying the phenomenon under study); *materiality* (mediational means are of a material nature); *multiple goals of action* (mediated action serves many purposes which sometimes come to conflict); *developmental paths* (the increased productivity due to tool use does not amount to increased intelligence); *power and authority* (mastery of some mediational means is associated with more power than mastery of others). Such a thorough treatments of the cases we have examined is beyond the scope of the present study, mostly because these were used for illustration purposes.

[11] It is worth noting that already in the early 70s Tikhomirov had described three types of conceptions: substitution, i.e. the case where computer replaces human mental functioning, addition, i.e. the case where the computer enhances human capabilities, and transformation, where the set of skills formerly required to perform a certain task are changed (see Tikhomirov 1974). For the sake of simplicity we only focus on amplification and transformation theories.

finished faster and more accurately, while in the second, the changes due to amplification are expected to lead to a transformation of the structure of the activity required to perform the task.

3.6.2.1 Amplification views

> *"The human mind is limited in capability. There is only so much we can remember, only so much we can learn. But among our abilities is that of devising artificial devices – artifacts – that expand our capabilities"*
>
> (Norman, 1993, p. 3).

The main argument of amplification views has been aptly stated by Norman: "physical artifacts make us stronger, faster, and more comfortable. Cognitive artifacts make us smarter" (Norman, 1997, p. 110). Hence, the use of the computer helps transcend the limitations of the human cognition. The main claim is that the human information processing system is limited in its ability to keep track of things in active consciousness (e.g. Norman, 1988; 1993). For instance, in the case of memory Norman (1993) pointed out that, even though it is limited in its capabilities, with the employment of the appropriate artifacts/technologies these limitations can be significantly overcome. More specifically, he argued that "reflective thought requires the ability to *store temporary results*, to *make inferences from stored knowledge*, and *to follow chains of reasoning backward and forward*, sometimes backtracking when a promising line of thought proves to be unfruitful" (p. 25, emphasis added). These reflective operations are too difficult for the unaided memory to perform because the overload is too high. The use of artificial tools, however, can support and greatly enhance these reflective operations by "acting as an external memory storage, allowing deeper chains of reasoning over longer periods of time than possible without aids" (ibid., p. 25).

In the educational-computing literature, there seems to be consensus on the fact that the capabilities of the computer are complementing and enhancing the limited information processing abilities of humans and circumventing them in a number of ways[12] (cf. Salomon, 1985; Olson, 1985; Perkins, 1985; Pea, 1987b; Kozma, 1992; Jonassen 1992; Lajoie, 1993; Jonassen & Reeves, 1996). This process of enhancement is commonly referred to as amplification and is effected through two main mechanisms: *productivity* and *objectification*.

Productivity amounts to efficiency: more work is done, in less time, with less effort and more ease. Firstly, the work is finished faster. Performing certain problem solving tasks with the computer requires significantly less time, e.g. making graphs or performing laborious computations (Vockell & Van Deusen, 1989; Tall, 1993). Secondly, the work is neater and much more accurate, e.g. the computer is an error-free calculatory device (Perkins, 1985; Pea, 1985). Finally, the cognitive load of performing a task with the computer is drastically reduced. This has two aspects: (a) the mental functioning is reduced, e.g. the mental energy required to perform a computation with the aid of the computer is considerably reduced and (b) the easiness with which the task is produced is increased, e.g. a computation becomes, cognitively speaking, less complex (Salomon, 1985; 1992a; 1993b; Salomon, Perkins & Globerson, 1991; Tall, 1993; Pea, 1993; Lajoie, 1993).

Objectification is accomplished through (a) graphical representation and (b) keeping track of previous operations. In regards to the former, objectification of abstract ideas and concepts is made possible through their visual and graphical representation, e.g. an abstract concept like a function is turned into a concrete entity on a graph and can be reflected upon (Sheingold, 1987; Dickson, 1985; Madinach, 1989; Kozma, 1991; Tall, 1993; Rubstov & Margolis, 1996; Saljo, in press). With respect to the latter, the solution process may be recorded and represented in pictorial format and, thus, memory is relieved from the burden of remembering where one has been and what sort of operations were performed (cf. Brown, 1985; Collins & Brown, 1988; Lajoie, 1993).

3.6.2.2 Transformation views

"Tools are not just added to human activity; they transform it"
Tikhomirov (1974, p. 375).

Within the confines of cognitive science it has been acknowledged that artifacts "don't change our cognitive abilities; they change the tasks we do" (Norman, 1993, p. 78; cf. Hutchins, 1995a; 1995b). It is, however, within the field of sociocultural psychology that explicit attention has been paid to the transformative effects of tools. The appropriateness of amplification as a metaphor for describing the effects of cultural tools has been challenged over the last three decades. Cole & Griffin (1980) noted that an amplifier merely *intensifies* a signal which remains unaltered in its basic structure and argued that this is not exactly the case with cultural tools: "we can claim that the pencil amplifies memory power that is in the head. But this … suggests that to use the term amplification is to mislead, for one would quickly object that remembering in the two cases refers to *qualitatively different activities*. The pencil does not amplify any fixed memory capacity…. [writing] *restructured* the [mnemonic] activity so that some index of productivity was larger" (Cole & Griffin, p 350, emphasis added). More specifically, Olson (1985) argued that without written language one's mental resources are devoted to remembering a specific statement, and this commitment entailed that there were no residual recourses to examine the logical implications of that statement. With the introduction of writing, however, the function of memory shifted from focusing on preserving the content to organizing and retrieving it. Hence, with the development of literacy "the demands placed upon the central nervous system changed. A powerful acoustic memory, once a necessity, became a luxury. In its

[12] This should come as no surprise, of course, because the field of computers and learning has been heavily influenced by models and methods of cognitive science.

place came logically connected prose statements, which, because they were perceived as a visible artifact, could be reflected analytically" (Olson, 1976, p. 194-195).

According to transformation views, the effects of cultural tools are not confined to finishing the work more quickly and easily; the actions necessary to accomplish the required task are changed (Pea, 1987a; 1993; Saljo, 1996). The transformation proponents do not reject the idea of amplification. In fact, transformation is only possible through amplification: a certain change in the physical operations is a prerequisite to any subsequent transformation of the activity. The main point of emphasis, however, is that although amplification is primary in time, transformation is primary in importance, when our goal is understanding the phenomenon.

There seems to be consensus on that the incorporation of a computer in an activity transforms the activity (Pea, 1985; 1987a;1993; Perkins, 1985; 1993; Saljo, 1996). A number of studies have shed light on this phenomenon. Pea (1993) concluded that the availability of computers and calculators in school classrooms have led to a transformation of the NCTM standards. For example the traditional emphasis in some domains has diminished: long division operations; paper and pencil fraction computation; making function graphs by hand; paper and pencil solutions to trigonometric equations. On the other hand, a new set of skills has come to be emphasized: estimation; selection of the appropriate calculation methods; meaning of calculations; statistics; probability. Brown et al., (1993) reported that the use of Email transformed a traditional classroom in terms of relieving the teacher from the burden of being the only authority and knowledge carrier in the classroom. A similar finding with respect to changes in the roles students assumed due to the availability and use of computers was reported by Tierney (1996). Pea (1992) reports that a science class was transformed when a graphics program was used with respect to what learning is, how learning is taking place, what are the roles of the students and teacher. Newman et al., (1989) demonstrated how the presence of a LAN and a shared database gave new meaning to the coordination and management of group work. Moreover, it has been reported that when computers are used whole-class instruction becomes less dominant and students spend more time on task (Waxman, & Huang, 1996), classroom dynamics and the role of the teacher change (Mandinach & Cline, 1996), and the whole structure of the learning environment is affected (Salomon, 1996b). All these studies above present circumstantial accounts of transformations (e.g. of teacher and student roles), because they were not aimed at examining the phenomenon per se. The fact that there is very little evidence on the transformatory impact of new technologies on learning has been explicitly acknowledged (Saljo, in press).

Provided that the use of a computer transforms problem solving, the question is: *what is the nature of this transformation*? Tikhomirov (1974) has outlined two major changes. On the one hand, the mental work is transformed into mechanical work and on the other hand man can focus on what he can do best, i.e. come up with ideas and potential solutions, relegating the actual checks of these solutions to the computer.

With respect to the former, Tikhomirov (1974) argued that, as a rule, when man uses the computer for solving a problem he is saved from the mechanical work, i.e. executing the strategy, but not from the creative one, i.e. devising a strategy or attack plan. If a problem is solvable by the computer, then this means that it is algorithmic in nature and, thus, an algorithm must have been developed and stored in memory. Putting the algorithm in computer memory requires the formalization of the procedure, and formalizing a class of problems saves man from the necessity of solving a definite class of problems. Then, the computer may "*carry out 'executive' or 'mechanical' work by transforming into mechanical work non-mechanical work that has been carried out beforehand* … the activity is never purely mechanical (in the full sense of the word), but *comprehension of the activity may cease to be essential to its performance*. In that case, computerization may mean the assignment to the machine of what was earlier formalized in the human activity" (pp. 378-379, emphasis added).

Concerning the latter, Tikhomirov (1974) argued that the use of the computer makes it possible for humans to concentrate on the creative aspects of problem solving. He argued that "there are functional changes in man's mental processes when he solves problems with the aid of the computer" and these changes include "intuitive guesses precede strict logical verification of these guesses, and the feeling of solution-nearness precedes the logical analysis of the solution. How does the use of the computer change this process of functional development? By transforming the formalized activity components of problem-solving into the form of external mediate link, the computer leaves man free to concentrate on the intuitive thought components. *It leaves man free to do what he does uniquely and best, namely to generate the hypotheses"* (p. 380). As Tikhomirov argues, verifying a hypothesis often suppresses intuitive thought processes, whereas, when the task is performed with the computer, the person is free to make a guess or devise a plan and the computer assumes the responsibility for implementing it and testing it out (ibid.).

Chapter 4

4 Methodological tools

The objective of this chapter is to lay out a set of methodological tools according to the requirements specified in chapter 2. More specifically, two methods are presented: discourse analysis and activity analysis. Both qualitative and quantitative discourse analytic methods are discussed. The quantitative discourse approach involves frequency and sequential analysis while the qualitative one mainly includes genre analysis. Finally, activity analysis is also addressed.

4.1 Discourse analysis

In chapter 2 we discussed the use of observation as a means of studying an instructional intervention. Videotape recording of instructional treatments is a very practical method for making observations. However, observation provides us with a record of teacher and student activities but not with the reasoning behind them. This is the reason why observation needs to be coupled with discourse. Looking at the discourse for information related to reasoning and cognitive processes is definitely not a new idea. It has a long tradition in both the cognitive sciences (think aloud methods, e.g. Newell & Simon, 1972, Ericsson & Simon, 1993; Ericsson & Simon, 1980) as well as in the field of educational psychology (e.g. Rogoff, 1990) and CAI/CAL (the reasoning of groups of students working has been analyzed both qualitatively, e.g. Crook, 1994, and quantitatively, e.g. Wegerif & Scrimshaw, 1997). The use of discourse is based on two assumptions. First, *discourse does not reflect the situation, it is the situation* (Holquist, 1990). Moreover, it has been argued that discourse is an ideal tool for providing a full account of the situation as well as a record of reasoning (van Dijk, 1997). Second *the study of the structure of discourse provides sufficient information for the study of the structure of problem solving*. Provided that each utterance is dialogically associated with other utterances and constitutes a link in the chain of speech communication (Bakhtin, 1986), it may also be assumed that, if discourse is indeed the situation, examining the structure of discourse sequentially will reveal to us information about the very structure of the situation itself.

4.1.1 Quantitative and qualitative approaches

Two broad research traditions have been established in studying classroom discourse: quantitative and qualitative. *The main objective in quantitative discourse analysis is to determine the structure of discourse, simultaneously focusing on both form and content*. This orientation towards structure in discourse stems from the fact that this tradition has largely a linguistic-sociolinguistic origin and emphasizes structures and grammatical forms (Schriffin, 1994). Apart from the sociolinguistic legacy, quantitative analysis of learning discourse in educational contexts has been also influenced by the methodologies developed for studying teacher behavior (e.g., Flanders, 1970), systematic classroom observation (e.g., Croll, 1986), and interaction (e.g., Bakeman & Gottman, 1986). In the quantitative paradigm of discourse analysis, *discourse is segmented using some type of unit of analysis and then coded into categories. The frequencies of occurrence are then tallied and statistical analysis follows*. In this sense, discourse is quantified so that it can be statistically analyzed in order to answer specific research questions. The seminal study in this tradition was conducted by Sinclair & Coulthard (1975). The researchers, drawing on the linguistic analogy between words and morphemes, developed an elaborate coding scheme and attempted to study the patterns of teacher and student interaction in classroom. Within this paradigm of discourse analysis, a number of studies have explored various areas of teacher-student or peer discourse: the structure of arguments (Pontecorvo, 1987), the structure of reasoning (Pontecorvo & Girardet, 1993), interactive mechanisms in classroom conversation (Orsolini & Pontecorvo, 1992), peer talk during collaborative work at computer (King, 1989; Kumpulainen, 1996), peer talk during problem solving (Teasley, 1995), the social distribution of arguments during group discussions (Resnick et al., 1993), computer-based text revision (Paoletti & Pontecorvo, 1991), and tutorial help (Merrill et al., 1995).

Qualitative discourse analysis has its roots in hermeneutics and ethnography (Tesch, 1990). Unlike the quantitative tradition where researchers attempt to disclose structures and forms, *researchers in the qualitative tradition are primarily oriented towards communication, that is, the achievement of meaning and understanding in the context of teacher-student discourse*. Due to this orientation, segmentation, coding, and statistical analysis are rather uncommon practices. *Classroom discourse is simply interpreted according to the particular study objectives*. Interpretation is a sufficient way of analyzing discourse because meaning has some very special properties which cannot be overlooked. Firstly, the meaning of an utterance is always context dependent. An utterance cannot have meaning in and of itself. In a teacher-student dialogue, utterances are always dialogically related, each utterance being a link in the chain of speech communication. Thus, to decipher the meaning of any single utterance, one always has to look at the surrounding context (Barnes & Todd, 1977; Bakhtin, 1986). Secondly, the meaning of an utterance is independent of its linguistic formation. The same utterance can have different meanings in two contexts, while two linguistically different utterances may have the same meaning in two contexts (Barnes & Todd, 1977; Bakhtin, 1986). Finally, meaning is not a static entity: it develops in the course of the interaction, it is renegotiated and redefined; meaning develops over time in the form of assumptions and shared knowledge (Barnes & Todd, 1977; Edwards & Mercer, 1987). The pioneering work in this tradition was carried out by Barnes & Todd (1977). They studied children’s group talk and have devised a method of analyzing children’s discourse in terms of social interaction (discourse moves, social skills) and cognition (logical processes, cognitive strategies). A number of studies have been conducted within this paradigm in diverse areas: social organization of classroom (Mehan, 1979), ground rules in the classroom and the development of common knowledge (Edwards & Mercer, 1987), computer-based classroom talk (Mercer & Fisher, 1992; Crook, 1994; Mercer, 1994; 1996; Wegerif & Mercer, 1997b), mathematics discourse (Newman, Griffin & Cole, 1989; Schratz & Mehan, 1993), science discourse (Newman, Griffin & Cole, 1989; Wertsch & Toma, 1995), and language learning (Gustavson, Linell & Saljo, 1993).

4.1.2 Frequency-based discourse analysis

Frequency-based discourse analysis is probably the simplest and most common type of quantitative discourse analysis. Given a certain corpus of data and a research question, the discourse is first segmented into units and then coded into categories. These categories may be derived from a specific theory. When the process of segmenting and coding the data is completed, the frequencies of each code are initially tallied. On the basis of these frequencies, a number of statistics like averages and standard deviations can be computed for each code. Provided that a number of conditions or groups are available, this type of statistics can be used for further statistical analyses, such as t-tests or analysis of variance, depending on the research question addressed.

4.1.3 Sequential discourse analysis

Sequential discourse analysis is a relatively new method for analyzing discourse in a quantitative way. Because of the fact that it is not widely applied in educational-psychological research (for example, we are only aware of two studies which employed the technique: Merrill, et al., 1995; Gonzalez, 1996), a thorough account of the main concepts will be provided.

4.1.3.1 Sequential analysis: an introduction

Sequential analysis is a method for analyzing behavior (see Bakeman & Gottman, 1986; 1997; Bakeman & Quera, 1995). Bakeman & Gottman (1986) argue one of the main properties of interaction (whether it is among people or among animals) is that “it reveals itself unfolded in time” (p. 1). As they put it, interaction can hardly be conceived of independently of time. *Sequential analysis can be used to describe any type of interaction or behavior as it unfolds in time, in its moment to moment course*.

Assuming that some sort of behavior or interaction is available to the researcher, a prerequisite for sequential analysis is the reliable segmentation and coding of the interaction. Thus, as a quantitative type of discourse analysis it presupposes segmentation and coding. When all codes (events) are available after coding, they have a sequential nature, i.e. a certain code is both preceded and followed by other codes. To process this sequence of codes, the first step involves tallying, i.e. determining the frequency of each code (i.e. tallies refer to frequencies).

To take a familiar example from educational discourse analysis, assume that a teacher is instructing a student how to solve a certain problem and we observe this instruction for two minutes. Assume further that we are interested in teacher questions and whether the student responds to them. For simplicity purposes, let us suppose that there are only three types of relevant behavior: teacher questions (A), student answers/responses (B), and teacher evaluations (C). Thus, we have a coding scheme comprised of three main codes: A, B, and C. Suppose that that this coding scheme was used to reliably segment and code these two minutes of teacher-student interaction and the following sequence of codes was obtained:

Sequence 1: A A B A C A C A C B A B C A B A B A C A A[1]

To answer our initial question, all we need to do is to count how many times event B (student response) occurred, that is we are looking for the *simple frequency*. As can be seen from sequence 1 the simple frequency of event B is 5, i.e. in the particular episode, the student responded to teacher questions five times. On the basis of these simple frequencies, probabilities of occurrence of the three events may be calculated for all three codes. Since the total number of events observed is 21, the probability of occurrence of event A is .52 (11/21), of event B .23 (5/21), and of event C .19 (4/21). This statistic is referred to as a *simple probability* (also: unconditional probability; Bakeman & Gottman, 1986; 1997).

Although relevant, simple frequencies - probabilities are not sufficient for answering our initial question because the teacher asked 11 questions in total. To answer the question we need to look at joint frequencies of events A and B (teacher questions and student responses). This amounts to looking for AB sequences or chains in sequence 1. A *joint frequency* AB indicates the number of times event B followed event A. In our particular case, event A (teacher behavior) precedes in time and is, therefore, considered to be the *given* behavior/event/code (i.e. antecedent behavior). Event B (student response) follows in time and is, therefore, deemed to be the *target* behavior/event/code (i.e. subsequent behavior). The joint frequency of two events (i.e. of a sequence of events) shows us how often one of the events occurred relative to the other. The time frame or unit relative to which we look at the joint frequency of events is referred to as

[1] It must be noted that this is a random string of codes generated for illustration purposes and does not necessarily reflect any actual or meaningful teacher-student interaction.

lag. Thus, if we focus on the joint frequency of events A and B for lag +1, then we are looking at whether event B followed immediately after event A, i.e. no intervening events between the two. Correspondingly, lag +2 would denote that we would be looking for occurrences of event B not immediately after event A but two events after event A, that is with any (one) intervening event between the two. The sequence then would have the form of AXB, where X can be any event. (In fact, in our particular case, event X can only be event C because it is the only other code). In principle, had ten other types of events been coded, X could have been any of them. Lags can also be negative, but then they refer to preceding events. The joint frequencies of all events in sequence 1 are shown in the transitional frequency matrix of table 4-1.

Table 4-1: Tallied events for sequence 1 (joint frequencies)

		Lag 1			
		A	**B**	**C**	
Lag 0	**A**	2	4	4	10
	B	4	0	1	5
	C	4	1	0	5
					20

As can be seen from table 4-1, the student responded to teacher questions four times while the teacher asked more than four questions in total. On the basis of these simple joint frequencies transitional or conditional probabilities can be calculated. Given a two-dimensional contingency table with x number of columns (c) and y number of rows (r), the *conditional probability* of a cell located at the intersection of row r (given behavior) and column c (target behavior) is defined as: $p(c|r)=f(r,c)/f(r)$ (Bakeman & Quera, 1995, p. 85). The conditional probability of a cell indicates the probability of the target behavior occurring in conjunction with the given behavior. It is also called transitional probability because it involves a reference to time. Provided that we want to determine the probability of the student answering to a teacher question, we must specify the *lag*, that is the probability with respect to a certain time frame. As can be seen from table 4-1, the probability of student responding to a teacher question (AB sequences) is the frequency of the cell AB divided by the total frequency of the A row (given behavior), that is .40 (4/10). For completeness the conditional probabilities of all events are given in table 4-2.

Table 4-2: Conditional probabilities for the events of sequence 1

	A	**B**	**C**
A	0.20	0.40	0.40
B	0.80	0.00	0.20
C	0.80	0.20	0.00

In response to our initial question, what the transitional probability suggests is that there’s a 40% chance that when the teacher asks a question it will be answered by the student. The implication of this finding is that about 60% of teacher questions are not answered. Although informative, the conditional probability does not tells us how likely the particular sequence AB was. It does not tell us if this particular sequence occurs at a higher than chance rate, i.e. if it is statistically significant.

The calculation of statistical significance is based on comparing observed frequencies and expected frequencies. In testing the statistical significance, two assumptions can be made: (a) events or codes are randomly assigned, and (b) events are equiprobable, i.e. the codes have the same probability of occurrence. The zero order model for testing statistical significance makes both assumptions while the first order model makes only the first assumption, that is, it uses the observed data for significance testing; it does not assume that the codes must occur with the same probability. Due to this, Bakeman & Gottman (1986) suggest using the first order model because it makes fewer assumptions about the data. They argue that because the first order model uses the data for extracting information about the probabilities of events, its predictions about event sequences should be more accurate. If these predictions fail, namely if the differences between observed and expected values are big, then the assumption of randomness can be rejected. In turn, this would suggest that the events are not distributed randomly and, therefore, there is another factor or reason accounting for the observed frequencies. To compute the statistical significance of certain sequences three statistics are needed: expected joint frequency, raw residual, and adjusted residual. They are briefly introduced below.

Given a two dimensional contingency table, the *expected joint frequency* for the cell located at the intersection of row r (given event) and column c (target event) is defined as: *epxf*(r,c) = p(c) *f*(r) (or *f*(c)*f*(r)/N). In terms of our example, the expected joint frequency for sequences AB (teacher question followed by a student answer) is 2.5. All expected cell frequencies are presented in table 4-3.

Table 4-3: Expected frequencies for sequence 1

	A	**B**	**C**
A	5.0	2.5	2.5
B	2.5	1.2	1.2
C	2.5	1.2	1.2

Given a two-dimensional contingency table with x number of columns (c) and y number of rows (r), the *raw residual* of a cell located at the intersection of row r (given behavior) and column c (target behavior) is defined as: res(r,c)=*f*(r,c)-*expf*(r,c). For our example and the sequence AB, the raw residual value is 1.5. For the sake of completeness, raw residuals for all cells are given in table 4-4.

Table 4-4: Raw residuals for sequence 1

	A	B	C
A	-3.0	1.5	1.5
B	1.5	-1.2	-0.2
C	1.5	-0.2	-1.2

Given a two dimensional contingency table with x number of columns (c) and y number of rows (r), the *adjusted residual* of a cell located at the intersection of row (r) and column (c) is defined as: z(r,c)=*f*(r,c)-*expf*(r,c)/($\sqrt{a}$), where a ={*expf*(r,c) [1-p(c)] [1-p(r)]}. Adjusted residuals are distributed approximately normally and, thus, any adjusted residual value exceeding |1.96| is statistically significant at the 0.05 level. The adjusted residual value (z value) of AB sequences is 1.5 and, therefore, is not statistically significant. All adjusted residuals are given in table 4-5.

Table 4-5: Adjusted residuals for sequence 1 (z values)

	A	B	C
A	-2.68	1.55	1.55
B	1.55	-1.49	-0.30
C	1.55	-0.30	-1.49

Evaluating the significance of particular cells (i.e. sequences of events) alone is not sufficient. In the case of our example the sequence did not occur at a higher than chance rate and, thus, no further considerations were necessary. It could have been different, though, and then we would have had to calculate the chi-square test. As Bakeman & Quera (1995) argue, significant results within tables should be “ignored unless the chi-square associated with that particular table is significant…the chi-square is like an omnibus analysis of variance test and a significant result is like a permit, giving us license to explore further” (p. 89). The chi-square test may be used for examining whether the row factors are independent from the column factors. Given a two dimensional contingency table, the *chi-square* is used to determine whether the row factor is associated with the column factor. It is defined as follows: $X^2 = \sum [f(r,c) - expf(r,c)]^2 / expf(r,c)$. The value of the chi-square for the whole table is 8.00, df=4, p= 0.093. Because the chi-square value is not statistically significant, the row factor is not independent from the column factor, i.e. they are unrelated, which suggests a random distribution of events. Thus, in this case neither the chi-square test nor the specific AB sequence were statistically significant. As a consequence, it may be concluded that the occurrence of student responses is random[2]. It should be borne in mind that specific sequences may be significant while the overall chi-square may not. In such cases, significant sequences within tables should be ignored.

[2] It must be noted that for simplicity reasons all main concepts and statistics were introduced regardless of whether the codes can or cannot repeat. For more information on adjustments when codes cannot repeat see Bakeman & Gottman, 1986; 1997; Bakeman & Quera, 1995.

To interpret the value of chi-square for the table, two important issues have to be addressed: (a) sufficient number of tallies, and (b) distributional normality. Regarding the former, Bakeman & Quera (1995) argue that "X^2 or G^2 is distributed only approximately as a chi-square, and that the approximation becomes better the greater the number of tallies. If the number of tallies in a table is small, you should regard the apparent significance level with some skepticism. A common rule of thumb suggests that *there should be at least five time more tallies than cells, and at least 80% of the cells should have expected (not observed) frequencies of 5 or higher*" (p. 89, emphasis added). In terms of our example, and given that we have a 3x3 table, we needed 45 events at a minimum (9 cells times 5 tallies per cell). Sequence 1 was comprised of 20 events in total and, therefore, the total number of events is not sufficient for reliably evaluating statistical significance. Moreover, a standard requirement for chi-square tests is that there should be no cells with frequency lower than 5. As can be seen from table 4-1 this condition is not met either.

Regarding the latter, distributional normality of z values (adjusted residuals) is another prerequisite for interpreting the statistical significance of the results. Considering it in the case of our example, the adjusted residuals were not normally distributed in any of the cells. Normality can be computed using a software program which will be described below.

Whenever these two important assumptions are not met, the values of the chi-square and of adjusted residuals (z-values) should be interpreted with extreme caution.

4.1.3.2 Comparing the occurrence of certain sequences between two (or more) groups

The concepts and statistics introduced up to now refer to issues of sequential analysis within one sequence of data, that is within a group. We have also described the case of one subject only, while in practice it is common to use more subjects. The statistics described are valid only for analyzing sequences within one group (it may be one condition, including one or more subjects) but not for comparing sequences between two different groups (conditions). Provided that the same coding scheme is applicable to both conditions, a point of interest is: *how can we evaluate if certain sequences (patterns) in one of the groups are more likely to happen than in the other?* Such a procedure will be shortly outlined using another hypothetical example.

Assume that the sequence 1 discussed above represented a teacher interacting with a fifth grader. Assume further that the same teacher is observed for two minutes while interacting with a tenth grade student, solving the same task. Suppose that we are again interested in how often the student responded to teacher questions. Let's assume that the following sequence 2 is obtained from such an observation: (again, A denotes a teacher question, B denotes a student response, and C denotes a teacher positive evaluation).

Sequence 2: A B C A A B A B A A B C A C B C A A B C A B C A B A B A C B C A B C[3]

The joint frequencies for this sequence are presented in table 4-6 below. As can be seen from the table, the student responded to many more questions compared to the student in sequence 1.

Table 4-6: Joint frequencies for events in sequence 2

	A	B	C	
A	3	9	2	14
B	4	0	7	11
C	6	2	0	8
				33

Because, overall, more events were observed within that two minute time period, interpreting the joint frequencies alone is quite misleading. Looking at conditional probabilities is a better alternative. The conditional probabilities for all events in sequence 2 are given in table 4-7. As can be seen from the table, in sequence 2 the conditional probability of the student responding to a teacher question is .64, much higher than the corresponding conditional probability for sequence 1 which was .40.

Table 4-7: Conditional probabilities for events in sequence 2

	A	B	C
A	0.214	0.642	0.142
B	0.363	0.000	0.636
C	0.750	0.250	0.000

The adjusted residual value (z value) is 3.24, and the chi-square value for the whole table is 19.9853, df=4, p= 0.000585. Therefore, both the sequence and the chi-square indicate a higher than chance or systematic pattern. The difference in terms of magnitude for the two conditional probabilities in the two sequences is remarkable, while only in sequence 2 does sequence AB occur at a higher than chance rate. This difference does not, however, communicate much regarding sequence differences between the two conditions. We need to know whether the AB sequences (teacher question-student response) differed. Bakeman et al., (1996) have developed a method for detecting group differences in sequential association. The rationale of this approach is shortly described.

Traditionally, one could consider conditional probabilities and use them as individual scores for conducting e.g. a t-test. As Bakeman & Gottman (1986) argued, however, a conditional probability of .33 has potentially very different meaning for two subjects, or for the same subject at different times. Moreover, a conditional probability is 'contaminated' with the

[3] It must be emphasized that this sequence is randomly generated for illustration purposes only and, therefore, it should not be assumed that it reflects any meaningful teacher-student interaction.

values of the simple probabilities. Bakeman & Gottman (1986) had proposed that the best score to use in analyzing differences between two groups is the z score associated with the respective conditional probabilities because "the z score is a measure of the extent to which a particular transitional probability deviates from its expected value, for that subject" (p. 150). They particularly recommended such z scores for all subsequent analyses like analyses of variance because "when z scores are treated just as scores and not tested for significance, issues such as the independence of sequential tallies and the appropriateness of the normal approximation to the binomial distribution are not relevant" (p. 151). More recently, however, and contrary to these early suggestions, the practice of using z scores for testing group differences was severely questioned. Bakeman & Gottman (1997) demonstrated that *the use of z scores is not the most appropriate choice*, since z scores are affected by the number of tallies and, therefore, more tallies entail bigger z scores, other things being equal. They suggested that z scores might be a reliable alternative if and only if the number of tallies for each subject is the same (see also how Bakeman et al., 1996 address this issue). Bakeman et al, (1996) have proposed that the best statistic to use when comparing transitions of events between two (or more) conditions is one which is *unaffected* by the total number of tallies. What is needed is a coefficient expressing the *strength of the association* or an effect size statistic. It has been demonstrated that one such appropriate statistic of association is Yule's Q coefficient. Given a 2x2 table with a, b, c and d denoting observed frequencies in that table, *Yule's Q coefficient* is defined as: ad-bc/ad+bc. Yule's Q is a transformation of the odds ratio coefficient and ranges from –1 to +1. It is, thus, interpreted just like Pearson's correlation coefficient with zero indicating no effect and absolute 1 indicating perfect correlation. Bakeman et al., (1996) concluded that, for testing group differences it does not matter which specific correlation coefficient is used (Yule's Q, Phi, odds ratio, log odds ratio) because they all yield essentially the same results. Yule's Q coefficient is preferred, though, because its interpretation is relatively straightforward.

Let us apply all these to our particular example. In tables 4-8 and 4-9 the frequencies required for the calculation of Yule's Q coefficient for the sequence AB in sequence 1 and sequence 2 are given.

Table 4-8: Tallies for Yule's Q calculation for sequence 1

	B	**Not B**	
A	4	6	10
Not A	1	9	10
	5	15	20

As table 4-8 shows, event B occurred only once when not preceded by event A. Therefore, the residual frequency for the AB sequence is 1. The value of Yule's Q coefficient for sequence 1 is .71, a high positive correlation. As can be seen from table 4-9, event B occurred twice when not preceded by event A. Yule's Q coefficient value for sequence 2 is .87, a very high positive correlation.

Table 4-9: Tallies for Yule's Q calculation for sequence 2

	B	**Not B**	
A	9	5	14
Not A	2	17	19
	11	22	33

In the example we are discussing there are only two conditions with one subject each. Typically, many more subjects are used in the two conditions, but their exact number does not matter. Assume that we have four subjects in the first condition (fifth graders) and six subjects in the second condition (tenth graders). How to compute Yule's Q coefficient for one subject was just demonstrated. The same procedure may be repeated for the rest of the subjects in the two conditions. When these calculations are complete, we have a two arrays of Yule's Q values: four for the first condition and six for the second condition. These have the following form:

Condition 1 (fifth graders): Yule's Q value for subject 1, …, Yule's Q value for subject 4
Condition 2 (tenth graders): Yule's Q value for subject 1,…, Yule's Q value for subject 6.

These values can be entered in any statistical software package and subjected to a number of analyses just like any type of raw scores (Bakeman et al., 1996). For the purposes of comparing the occurrence of a certain sequence between two groups a typical parametric statistical test is commonly used for testing statistical significance (e.g., a t-test in our case).

4.1.3.3 Permutation tests for testing statistical significance

In principle, there are two main ways of calculating the statistical significance of a given statistic: standard parametric tests and permutation tests. It has been argued that the latter are more appealing for sequential analysis (e.g., Bakeman et al., 1996) and we will briefly consider the reasons.

Back in the early 1970s Hays argued: "…the Pearson x^2 tests of association and of goodness of fit give approximations to exact probabilities…*the basic reason for using the chi-square approximation is that actual computation of these exact probabilities is extremely laborious or downright impossible*. However, in some situations where the sample size is so small that the use of the x^2 tests is ruled out, it may be practicable to compute probabilities exactly" (1973, p. 737; emphasis added). According to Bakeman, Robinson & Quera (1996), however, on the one hand current computer technology redefines what is possible from a computational viewpoint, and on the other hand for areas like sequential analysis the traditional assumptions could be somehow problematic. The standard practice when evaluating the statistical significance of values in a two-dimensional contingency table involves the examination of residuals, that is “the number of transitions observed in each cell minus the number which is expected by a model that assumes no sequential influence. Usually these residuals are normalized… and based on assumptions that the resulting z scores are normally distributed, an asymptotic p value is assigned” (p. 5). If sequences are short or if marginal distributions become quite skewed, then the tenability of the normality assumptions is seriously called into question. If the probabilities of the z values are based on a few tallies or skewed distributions, it is highly likely that they are unreliable. For these reasons, as Bakeman, Robinson & Quera (1996) argue, the use of permutation tests provides a reliable alternative, because these tests do not require assumptions concerning the normality of the distribution.

When permutation (or randomization) tests are used one need not make any assumptions about the distribution of any test statistic: the actual distribution can be constructed. Then the p value of the observed statistic can be determined exactly from the constructed distribution. According to Bakeman, Robinson & Quera (1996) “it can be argued that… [exact tests] are always preferable to their asymptotic cousins, but now the speed and ready availability of computers are making exact tests practical in a way they have not been previously” (p. 7). As they argue, the use of the permutations to compute the exact tests entails that, firstly, unlike the parametric tests (z, t, f) *no assumptions about population distributions and parameters need to be made*, and, secondly, unlike nonparametric tests, *they do not rely on asymptotic theory which is valid only if sample sizes are reasonably large and well balanced* (Bakeman, Robinson & Quera, 1996).

As Bakeman, Robinson & Quera (1996) argue, if systematic (i.e. complete) data permutation methods are not applicable – e.g. a large data set is being used which would require an astronomical number of permutations – the use of sub-samples of the whole set of permutations is possible by employing random or Monte Carlo procedures. These tests are called sampled permutation tests and even 1.000 of these constitute reasonably good estimations to the complete permutation set. Therefore, whether or not it is feasible to perform the complete number of permutations, the use of sampled permutation tests constitutes an appealing practical alternative.

How is one permutation conducted for sequential analysis? Assume that N number of events are each assigned to one of K codes and that b_I represents one event and b_1, b_2, b_3 … b_N the entire sequence. These events can be tallied in a two-dimensional KxK table for lag +1. Each tally in every cell in the KxK table represents the joint frequency of two events and the question is: *what is its exact probability?* To address this question using sampled permutations, we need to repeatedly shuffle (randomly order) the observed sequence of the N initial codes. Suppose that the data is permuted once; the frequencies for every cell in the KxK table are tallied. The same procedure is repeated a large number of times (e.g. 10.000). Working in this way we obtain the sampling distribution of each cell in the KxK table. The next step involves determining the position of our initial observed frequency per cell in the constructed sampling distribution of that cell. The result of this procedure is an *estimate of the exact probability of each frequency in a cell* (note that it is an estimation because we have not performed all possible permutations but used a sample instead). If the same procedure is repeated a number of times, the results will somehow vary due to random shuffling but this feature presents no special problems since estimates can be computed to any extent required, given a large number of permutations. A certain sequence might be permuted e.g. 1000 times and the exact probability may be estimated on the basis of the results. Then the same procedure might be replicated a number of times e.g. 50. The mean of all estimations can be computed with its 95% confidence interval, and this constitutes a way of replication. Increasing the accuracy of the estimations (and, thus, narrowing the confidence interval) only requires calculating more estimations (e.g. 100 or more), and, thus, performing more permutations.

The procedure just described is based on sampled permutation tests for the case of KxK tables for testing sequential association. In our case, we have 2x2 tables and Yule's Q is computed for each table. Therefore, we only have 10 scores in total for both groups of our hypothetical example (4 in the one condition and 6 in the other). To perform permutation tests for these scores, the same principle may be used. It must be emphasized that in this particular case we are interested in whether the transitions between the two groups differ significantly. To determine this, we need to perform the standard t-test. The procedure as described by Bakeman et al, (1996) is as follows: "Let N represent the number of scores and r the number in Group 1. Then the N subjects are divided into all possible groups of r and N-r subjects, and a t statistic is computed for each different permutation. The exact probability of a result as extreme as the one observed is simply the proportion of these t statistics (absolute) greater than or equal to the magnitude of the observed one" (pp. 447-448). The total number of permutations to be performed is N!/r!(N-r)!. How does the permutation procedure work in this case? Firstly, Yule's Q scores are ordered from 1 to 10 (i.e. there are ten subjects in total), the first four subjects belonging to the first condition (fifth graders) and the last six subjects to the second condition (tenth graders). The t-test is subsequently performed and the obtained value represents the *observed t-test value*. Then the order of the Yule's Q scores may be shuffled using an appropriate algorithm and after each shuffle the first four subjects are assigned to the first group (fifth graders) while the remaining six to the second group (tenth graders). For every permutation (shuffle) a new t statistic is computed. When all permutations (or a specified number of them) are performed, the exact probability can be computed, by taking the *proportion of the t statistics greater than or equal to the magnitude of the observed t value* (see Bakeman et al., 1996 for more details). As Bakeman et al., (1996) argue, however, there is not even need to compute a t statistic for every permutation. The researchers point out that the difference between the means of the two groups can be used instead, given that it is this very descriptive statistic that one is interested in when comparing two or more groups. Therefore, testing the differences between the two means requires less computations. Bakeman et al., (1996) compared permutation and parametric t tests using 10.000 permutations and concluded that when more than 20 subjects are used and reasonably divided in the conditions, it does not matter so much whether permutation or t tests are used. *If there are less than 20 subjects, however, and parametric assumptions are not met, the use of permutation tests is recommended*.

Bakeman et al., (1996) have developed PGD (Permutation program for testing Group Differences), which is a software program that can be used for testing the differences between two or more groups using sampled permutations. This program is freeware and might be obtained from R. Bakeman upon request.

4.1.3.4 Sequential discourse analysis

Sequential discourse analysis requires that discourse is segmented and coded in various categories depending on the theoretical objectives and the research questions which need to be answered. Because interaction unfolds in time, the coded data inherently include a time dimension and, thus, a reference to time. The raw input is a string of codes, as demonstrated above. This string of codes can be processed in a number of ways in answering certain research questions.

Bakeman & Quera (1995) have developed a software program specifically for the purposes of sequential analysis. GSEQ (Generalized Sequential Querier) handles sequential data using the sequential data interchange standard (SDIS) and computes: joint frequencies, expected frequencies, conditional probabilities, raw and adjusted residuals, chi-square tests, and Yule's Q, Odds, Phi and Kappa coefficients. The software is commercially available from Cambridge University Press.

4.1.4 Genre-based discourse analysis

Genre analysis falls under the qualitative discourse analysis tradition. The viewpoint presented here is mainly influenced by Bakhtin's ideas on genre even though there are more than one approaches to what the genre is and how it can be studied (e.g., Bazerman, 1988; Swales, 1990; Berkenkotter & Huckin, 1995). In the field of educational psychology, a number of studies have focused on the genre for analyzing discourse (see Wertsch 1991; Wertsch & Toma, 1995; Wertsch & Rupert, 1993; Wertsch, 1998). In this section Bakhtin's, Vygotsky's, and Leont'ev's ideas will be laid out and a model for analyzing classroom discourse will be presented.

4.1.4.1 Bakhtin: voice and genre

An introduction to Bakhtin's work was given in chapter 3 so we will confine this presentation to the issue of genre. Bakhtin (1986) proposed that *the utterance is a natural unit of speech communication*. Relatively stable types of utterances in some sphere of communication constitute a speech genre. Genres include: short rejoinders of everyday language, everyday narration, writing (in all its various forms), the brief standard military command, the elaborate and detailed order, the fairly variegated repertoire of business documents, the diverse world of commentary, diverse forms of scientific statements, and all literary genres. The particular importance of genres is that they represent "forms of seeing and interpreting particular aspects of the world" (p. 5). Generally speaking, the wealth and diversity of speech genres are infinite since the possibilities for human activity are limitless too. The style of an utterance is inseparably linked to the genre: "Where there is a style there is a genre" (p. 66). According to Bakhtin, speech genres organize speech the same way the grammatical forms do: "we speak in diverse genres without suspecting that they exist" (p. 79).

4.1.4.2 Vygotsky: concept formation

Vygotsky's theory (see Vygotsky, 1987; 1994) covers psychological dimensions of concept formation, distinguishes between scientific and everyday concepts, and addresses the relationship of words and concepts.

For Vygotsky, the word plays a crucial role in concept formation, and, in fact, *the concept is impossible without the word*. The concept is formed as a result of an intellectual operation the central feature of which is "the functional use of the word as a means of voluntarily directing attention, as a means of abstracting and isolating features, and as a means of the synthesizing and symbolizing these features through the sign" (Vygotsky, 1987, p. 164). Although the word is an inseparable aspect of concept formation, *when the word is learned, the formation of the concept merely begins. This meaning has to develop, undergo several phases before it reaches its final destination, i.e. the true concept*. For the concept to mature, all the mental operations that are required for its formation – voluntary attention, logical memory, abstraction, comparison and differentiation – have to mature as well. This is why direct instruction in concepts yields poor results and leads to 'mindless learning of words'. Through direct instruction, the child learns the word and not the concept, and the word is learned through memory rather than thought. As Vygotsky argues, any such concept learning does not have any meaningful application. In fact, Vygotsky noted that the child is able to dissociate the concept from the word when the true concept is formed: due to the law of equivalence, any concept can be expressed through other concepts and, thus, word meaning becomes increasingly irrelevant for the definition of concept.

Vygotsky argued that there are two fundamental differences between scientific and everyday (i.e. spontaneous concepts). Firstly, the way a scientific concept develops in the child is drastically different from the way an everyday concept does. For example a school child is better able to formulate ‘Archimedes’s law’ than define what a ‘brother’ is. Vygotsky argues that the child has learned these two concepts differently. Filled with rich personal experience, the concept of ‘brother’ is empirically exhausted and spontaneously created. On the other hand, the concept of ‘Archimedes’s law’ has no empirical substance and it entered the child’s consciousness through an abstract verbal definition by the teacher. Therefore, *with the spontaneous concepts, the child moves from the object to the concept, from the concrete to the abstract that is, whereas with scientific concepts, the child follows the opposite path.* As a consequence, the strength of the scientific concept (i.e. its level of abstraction and generality) is the greatest weakness of the everyday concept (i.e. incapacity for abstraction), and vice versa. As far as scientific concepts are concerned, the child has more conscious awareness of the concept than the object it represents, while the opposite is true for everyday concepts.

Secondly, the relationship of the scientific concept to the object it designates is different from the relationship between the everyday concept and its object. An everyday concept corresponds *directly* to the object it designates. On the contrary, the relationship of a scientific concept to its object is not direct: it is *mediated* by another concept. Every scientific concept is a generalization and belongs to a structured system of concepts. Within this system, using a concept to refer to its object encompasses an indirect reference to another concept. Spontaneous concepts do not belong to such systems and, thus, they are characterized by empirical relationships, i.e. relationships between the objects themselves.

4.1.4.3 Leont’ev: Activity theory

Leont’ev’s (1981) activity theory offers a psychological account of human activity. For Leont’ev, activity is comprised of actions, which in turn are comprised of operations. *Activity is always characterized by its object-orientation and it fulfils a specific purpose*. The activity constantly moves toward the object of this need, and stops when the need is met. The driving force for the activity is its motive: the motive is what drives the activity. As Leont’ev put it “there can be no activity without a motive” (ibid., p. 59).

Action is the basic component of activity. *Action is a means of realizing the activity and, consequently, satisfying the motive*. The distinctive feature of an action is the fact that it is always goal-directed, it aims at satisfying a particular goal. Activity is always realized through specific action(s) “[it] exists only in the form of an action or a chain of actions” (ibid., p. 61). Activity and action are different realities and ‘do not coincide’: the same action could be used to realize different activities. As Leont'ev noted "an activity is usually carried out by some aggregate actions subordinated to partial goals, which can be distinguished from the overall goal" (ibid., p. 61). Leont'ev argued that any type of well-developed activity requires the achievement of a sequence of concrete goals, and this sequence is sometimes rigidly ordered. In the case of actions, the person needs to know *what* actions to perform to reach the goals.

"Apart from its intentional aspect (what must be done), the action has it operational aspect (how it can be done)" (ibid., p. 63). *This operational part of action refers to the specific circumstances surrounding its execution*. Operations constitute the means by which an action is carried out. While actions are concerned with goals, operations refer to conditions under which the actions can be carried out. In the case of operations, the person needs to know *how* the operations realizing the action must be performed, that is, the person needs to know the method of performing the actions.

4.1.4.4 A three-component discourse model

For the purposes of the present work, we have developed a discourse model integrating Vygotsky's notion of scientific concepts, Bakhtin's notion of genre and Leont'ev's notion of activity. An integration of the concept of genre with activity theory has been recently attempted (see Engestrom, 1995; Russell, 1997). Science learning has also being studied in terms of the semantic properties of language (Lemke, 1990).

We posit that instructional discourse can be described and analyzed in three main dimensions: activity, genre and principle. From an activity point of view (Leont'ev's activity theory), assuming that a student is being taught how to solve correlational problems, *the goal of the whole instructional/teaching activity is to make the student competent for dealing with such real life problems*. Correlational reasoning competence is, therefore, the motive of the activity. To solve such a problem and, thus, satisfy the motive of the activity, *one has to engage in a series of actions which realize certain goals*. More specifically, these actions are: (a) making a graph; (b) plotting the data; (c) drawing a trendline and (d) drawing a conclusion about the relationship. Each of these actions serves a very specific goal and is a goal directed move in itself. *To realize these actions, one should perform certain operations*. For example, in making a graph, one may draw two axes, give each axis a name, consult the data and determine the unit for the x axis, divide the x axis into units, put in scale and repeat the same procedure for the y axis. The remaining tree actions can also be analyzed in those terms.

From a genre viewpoint (Bakhtinian theory), the overall activity has a very specific name: *correlational problem solving*. Moreover, every specific goal directed action has a name and every operation might have a name as well, depending on the complexity of the conceptual domain. For example, in the action of making a graph, one needs to know that the graph is called a *scattergraph*, that the two entities plotted are referred to as *variables*, that the variable on the x axis is referred to as the *independent variable*, whereas the corresponding y variable is called *dependent variable*. The language used to describe the relationships constitutes a very special type of language which deviates markedly from everyday language and is used in a very special rigid form. For instance, a positive correlation between variables x and y should be reported as follows: ‘as variable x increases, then variable y increases’. We will use the term genre to refer to all these terms and formal language that one has to know to refer to specific aspects the activity of problem solution.

From the point of view of scientific concepts (Vygotskian theory of concept formation), the terms used to denote actions and operations have some sort of special significance: they are abstract entities and denote scientific concepts. On the one hand, these terms constitute scientific concepts which can neither be developed intuitively (i.e. they have to be taught) nor used in the same form in everyday language while preserving their meaning. On the other hand, these terms belong to an organized body of knowledge and exist in a web of relations. For example, the concept of correlation is an abstract scientific concept, and designates a relationship between two (or more) variables. Examining how these two variables are related involves references to other concepts which belong to this complex network: scattergraph, independent and dependent variable, trendline, positive correlation, negative correlation, correlation coefficient and so on. Extending Vygotsky’s reasoning further, all these concepts form a very coherent system, which essentially amounts to a systematic and generic approach to solving correlational problems. These concepts initially originated in the process of solving a correlational task, and they fit together because they realize a particular strategy for solving such a task. These concepts are bound together because they constitute a rationale for all actions. These concepts connect the goal (i.e. solving the problem) to the activity (i.e. actions to solve the problem) in the light of the overall rationale (why the specific actions are performed). We will refer to the interrelationships within this organized system of knowledge as the principle. The model is presented in figure 4-1.

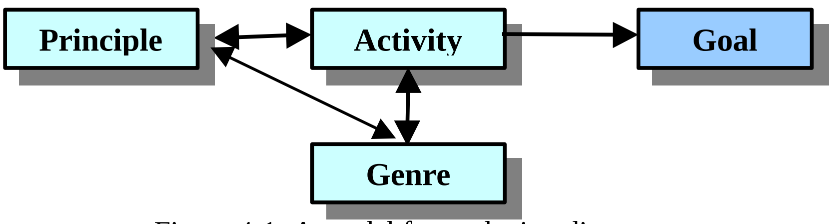

Figure 4-1: A model for analyzing discourse

As depicted in the figure, classroom discourse revolves around a certain learning activity (e.g. correlational problem solving) which is directed towards a goal (learning to solve correlational problems). The activity, actions and operations are most definitely not random. The whole activity has a beginning and an end, so to speak. It involves a lot of sequential steps (especially in the case of correlational problem solving where an algorithm is used for the solution) which fit into a certain rationale and have their own reasoning and meaning. For example, correlational problem solving basically amounts to transforming the representational form of the data, i.e. numerical figures in a table, into another representational form, i.e. a scattergraph, because it is easier and more accurate to see the relationship between any two variables on the scattergraph than it is in the table. The whole activity (algorithm) has a purpose, a rationale, and a meaning: it follows a certain *principle*. This principle, i.e. overall algorithm and how the separate steps fit together, was developed by someone in the history of the human kind who coined certain *terms* and *procedures* for dealing with correlational problems in a generic form. In fact, Pearson was the statistician who developed the concepts of correlation and correlation coefficient, initially using tallies in two dimensional tables instead of graphing and eventually moving to graphing and to the plotting of the dots. The correlation coefficient Pearson developed is actually named after him and is, of course, the well known Pearson product-moment correlation coefficient[4].

On the basis of the model presented above, two main issues should be emphasized. First, the use of the genre is related with scientific concepts in a domain (link between genre and scientific concepts). Second, the genre is connected with the activity (link between the genre and activity, actions, and operations).

In the case of the former, the genre can be studied by: (a) looking at the terms-terminology, special vocabulary and concept names and (b) looking at the syntax and style. According to Bakhtin (1986) both these dimensions are reflected in the genre. Thus, from a genre-based discourse analytic point of view, one needs to identify the genre as expressed in a number of scientific concepts in the area of correlational reasoning: *variable* (also: factor); *independent variable*; *dependent variable*; *correlation* – (also: relationship; relation); *positive correlation*; *negative correlation*; *no correlation* (also zero correlation); *scattergraph* (also: scatterplot); *trendline* (also: best fit line or line of best fit); *correlation coefficient* (sign, magnitude); *partial correlation*; *partial correlation coefficient* (sign, magnitude); *controlling variables* (*control variable, influencing factor)*; *prediction*; *hypothesis*. Of course, the genre is not exhausted in the use of concept names or terms; *it also includes a very special language, unique to the setting*. In correlational problem solving this can be described as a special sort of syntax, that is, a special way of putting certain terms/concepts together, which is drastically deviating from the standard everyday use of these terms. This means that, even though these terms are already present in everyday language, their specific position in certain expressions is not even remotely similar to these expressions. Take for example the term relation (or relationship) which is a common everyday word. It is rather unlikely in everyday language to say that ‘there is a very high

[4] Interestingly enough, naming certain concepts (terms, procedures, etc) after the person who invented or developed them is a standard scientific practice and constitutes an instantiation of genre itself. For

positive relationship (i.e. correlation) between excessive fat consumption and cardiac arrest'. In everyday language it is usually said that 'if you eat a lot of fatty food then you run a higher risk of heart problems'. Both statements express a certain type of association or relationship between two factors but they do that in remarkably different ways. A correlation denotes a relationship of some kind and people intuitively know what a relationship is, i.e. have mastered the meaning of the everyday concept of relationship. A switch from this everyday concept, however, to the scientific concept of relationship (i.e. high positive or negative correlation) blurs the meaning of the word 'relationship' for the uninitiated. Examples of such syntax which are typical of the geography speech genre (both spoken and written) are the following:

- Expressing how the independent variable affects the dependent variable: "as the x variable increases, then y variable increases-decreases-or stays the same" or "the more variable x increases, the more variable y increases". Such an expression is called for during predictions, during the identification of the independent variable and during the process of determining the position of variables in the graph. In everyday language such a ritualistic statement might seem obvious, absurd or too trivial to mention.
- Expressing the meaning of the kinds of correlation: "a positive correlation means that as the x variable increases, the y variable increases". Such an expression is typically required during graph interpretation. In everyday language, we would say 'irrelevant' to indicate no relationship and 'relevant' to indicate a relationship.
- Expressing what the influencing factor, whose effects have to be removed from the relationship observed, is: "when variable z is constant, then, as the variable x increases, variable y increases-decreases-stays the same". Such an expression is required when the students are interpreting what the true relationship is, i.e. having controlled for other factors. In everyday language it is usually said 'other things being equal'.

Regarding the link between genre and activity, as already discussed above, learning to solve correlational problems involves the appropriation of a certain algorithm. This algorithm is comprised of many steps, and sub-steps. All these steps and sub-steps (i.e. actions and operations in terms of activity theory) have specific names. What is important in this sense is that the study of the genre can provide information concerning the activity. More specifically, if certain terms are used very frequently, then this provides information about what specific action (or operation) is talked about and referred to which in turn would suggest a more prominent and central place in the problem solving process.

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instance compare Pearson's product-moment correlation coefficient with Spearman's rho correlation coefficient.

4.2 Activity analysis

As discussed in chapter 2, observation is a way of looking at the process of an instructional intervention itself. In fields like human-computer interaction videotape recording is a standardized method of data collection because it affords the study of the specific steps the user (or problem solver) is taking to achieve a goal (or to solve a problem). The activity of the participants in an instructional intervention may be described in terms of activity theory.

Leont'ev's basic scheme reflecting the structure of human activity was presented above so the main concepts will not be repeated here. Nevertheless, we will look at some contemporary activity theory approaches in a field traditionally dominated by cognitive science: human-computer interaction (see Nardi, 1996a; 1996b; Kaptelinin, 1996a; 1996b; Bodker, 1996; Engestrom & Escalante, 1996). In this field, activity theory is used mostly as a "powerful and clarifying descriptive tool rather than a predictive theory" (Nardi, 1996a, p. 7). This orientation suggests that the theory itself is not tested but merely used as a methodological tool for analyzing human activity with other purposes in mind. One of the major premises of the activity theory approach is that "it is not possible to fully understand how people learn or work if the unit of study is the unaided individual with no access to other people or to artifacts for accomplishing the task at hand" (Nardi, 1996b, p. 69). The application of activity theory in the domain of human-computer interaction mainly involves answering three main questions: why? what? how? The first question refers to the overall activity and helps identify the reasons and motives behind an action or a series of actions. The second question refers to the specific actions taken to materialize the activity and enables one to identify the specific nature of the action, of what exactly it is done. The final question refers to the operations which are used for materializing the activity and helps determine the means used for performing the actions to achieve the specific goal (cf. Bodker, 1996).

Chapter 5

5 Revisiting the research problem

In this chapter we look back at the point of departure and reconsider the research problem. More specifically, the contributions of the theoretical framework presented in chapter 3 and the methodological tools described in chapter 4 are examined with respect to the conceptualization of the research problem. Firstly, the research problem is cast in new terms and two specific research objectives are elaborated. Secondly, a rationale for meeting these objectives is presented and the research design is outlined. Finally, the method and procedure followed in conducting the two studies for the investigation of the problem are described.

5.1 Casting the research problem in a new form

At a *theoretical level* (chapter 3), Distributed Cognitions theory is a rich perspective, the major premise of which is that cognition is distributed over people (social distribution) and artifacts (material distribution). The theory provides us with three main insights regarding the role of the social environment and artifacts on cognition. *First*, it provides us with a comprehensive account of cognition as well as the loci upon which cognition is distributed. *Second*, it furnishes us with theoretical constructs about the influence of the social environment on cognition and learning. More specifically, it outlines the role of social others, like parents, teachers, and peers, in cognitive development. *Finally*, it provides us with theoretical constructs for understanding the impact of artifacts on cognition. In particular, it describes the role of artifacts in cognition in terms of amplification and transformation.

At a *methodological level* (chapter 4), two types of analysis were discussed: frequency, sequential, and genre discourse analysis as well as activity analysis. Sequential analysis allows us to keep track of an instructional process and the succession of various activities as they unfold in time. Frequency, genre, and activity analysis are mostly helpful in studying the structure of an instructional intervention and have plainly descriptive value.

In chapter 1 two goals were set for the present work, i.e. determine the respective roles of teacher and computer in the development of correlational reasoning skills. We will now examine both goals in terms of the theory and the method presented in chapters 3 and 4 respectively. Because of the greater importance of the teacher and, as a consequence, of social factors for learning the role of the teacher will be addressed first.

Regarding the role of the *teacher*, according to the theory presented in chapter 3 the influence of the teacher can be described in the context of the social distribution of cognition. On the one hand, according to the social distribution of cognition and the general genetic law of cultural development, learning to solve a problem is not an individual issue for the student: the teacher is involved as well, coordinating and managing student learning and problem solving actions as long as the student cannot accomplish this independently. The implication is that the contribution of the teacher is not to be judged on the basis of the new information and knowledge to be presented to the students alone: *the study of regulation is equally important*. On the other hand, learning to solve correlational problems involves the acquisition of particular concepts and algorithms which are associated with some special type of language and terminology. This very special type of language constitutes a genre, the study of which can be combined with the study of self-regulation (Karasavvidis, Pieters & Plomp, 1998). Therefore, *the contribution of the teacher to the development of correlational reasoning skills may be conceptualized and investigated in terms of regulation (i.e. transition from teacher regulation to student self-regulation) and genre appropriation (i.e. assimilation of the voice of the teacher into the voice of the student)*.

Regarding the role of the *computer*, as already analyzed in chapter 3, a fundamental property of cognition from a distributed point of view is that it is based on tools. More specifically, human cognition draws on many physical and artificial tools and, as a consequence, one of the fundamental properties of cognition is its mediated character. Therefore, the influence of tools can be conceptualized in terms of the material dimension of distributed cognition.

The impact of artifacts and, consequently, of computers on cognition has been described in two ways: (a) amplification and (b) transformation. According to amplification views, artifacts enhance and amplify mental/cognitive capabilities by speeding up the time it takes to perform a certain task, by improving its accuracy and by allowing humans to do much more in less time and with comparatively less effort. On the other hand, transformation proponents argue that the illusion of amplification stems from the fact that the use of artifacts somehow transforms practice. This transformation of the task entails that some of the cognitive processing is offloaded to the tool, and the mind eventually needs to do less thinking in general. They argue that the notion of amplification results from a sole focus on the outcome (product) of a cognitive or physical activity while, if the process is thoroughly examined, a different picture emerges. To conclude, *the contribution of the computer spreadsheet to the development of correlational reasoning competence can be conceptualized and investigated in terms of amplification and transformation*.

The first goal of this work is to study the influence of the teacher on the development of correlational reasoning skills in terms of (a) the transition from teacher-regulation to student self-regulation and (b) genre appropriation using frequency, sequential, and genre discourse analytic methods.

The second goal is to investigate the impact of the computer spreadsheet on the solution of correlational problems in terms of amplification and transformation using frequency, sequential, and genre discourse analysis as well as activity analysis.

5.2 Design and rationale

To study the influence of both teacher and computer spreadsheet on learning to solve correlational problems, it was decided to conduct two studies. The objective of study 1 is to investigate the influence of the teacher on learning to solve correlational problems. More specifically, in the context of correlational problem solving, *study 1 aims at investigating (a) the transition from teacher-regulation to student self-regulation, and (b) genre appropriation*. The objective of study 2 is to investigate the influence of the computer spreadsheet on correlational reasoning. In particular, *study 2 aims at examining the impact of the computer spreadsheet on learning to solve correlational problems amplification-wise and transformation-wise*.

To determine the contribution of the teacher from a regulatory and genre appropriation perspective a condition where a teacher teaches students how to solve correlational problems is required. Therefore, *in study 1* a *group of ten grade ten students are tutored*[1] *by their geography teacher in how to solve correlational problems using paper and pencil*. The instructional materials (problems and procedures) used in the Cousins & Ross (1993) intervention are used. A set of correlational problems will be selected from the respective module and the students are tutored individually by their teacher in how to solve them.

To determine the impact of the computer spreadsheet amplification-wise and transformation-wise, a condition in which students are taught how to solve correlational problems using a computer spreadsheet is required. Interpreting data from this condition, however, calls for a comparison with another condition where students employ a different tool.

[1] Two points need to be made here. First, we used grade ten students because this is the age of students used in the Cousins & Ross (1993) study. Second, unlike the Cousins & Ross (1993) study where the instruction was delivered in a whole class format, we chose to use small group learning was used, we chose to use one-on-one tutorials for three main reasons. *First*, it is a more tightly controlled setting allowing us to focus on the cognitive process of students at all times. In a whole class approach one cannot focus on and monitor the reasoning processes of individual students. For instance, most of the time in such a setting students are involved in some sort of teacher-specified activity. Even if we focus on such a student with a video camera during an activity, we do not know what they are thinking and what their understanding of the specific operations performed is. We only see the student doing something and the reasoning behind the visual behavior is absent. A *second* reason for using tutorials relates to the unit of analysis. In a whole class situation there is a lot of interaction between: (a) the teacher and the whole class; (b) the teacher and individual students and (c) any two students. The problem with teacher utterances then is that they address both whole class utterances (public) and individual utterances (private). Even though it is possible to identify and separate both types, the unit of analysis is neither the individual student nor the class, or more succinctly put, at times it is the individual and at times it is the class (see Wertsch, 1991; 1998). The *third* reason is basically related to the logistics of using a whole class instruction format. Using the whole class as a unit of analysis, we would need quite a number of

Because of the fact that study 1 provides paper and pencil data, it can be used for comparison purposes. Therefore, *in study 2 another group of ten grade ten students are tutored by the same geography teacher in how to solve correlational problems using a computer spreadsheet*. The same set of teaching materials and exercises as in study 1 are also used for study 2[2].

5.3 Method, procedure, and analysis

5.3.1 Materials and Instruments

5.3.1.1 Subjects

A group of ten grade ten students (school year 1995-96) participated in the paper and pencil condition (i.e. study 1) (8 boys, 2 girls; mean age: 15 years 5 months, s.d.: 10 months) while another group of ten grade ten students (school year of 1996-97) participated in the computer spreadsheet condition[3] (i.e. study 2) (6 boys, 4 girls; mean age: 16 years 2 months, s.d.: 7 months). All students 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.

5.3.1.2 Correlational Reasoning Test

Performance measures were of two types: task specific and general. Task specific performance was directly related to the content of the instruction and was measured with a correlational reasoning test developed by Ross & Cousins (1993a). The test involves a short problem and an accompanying table with an array of data. The students have to find out the relationship between two continuous variables, while controlling for a third categorical variable. More information concerning the test as well as evidence for its reliability and validity may be found in Ross & Cousins (1993a).

Due to the fact that instruction involved all kinds of knowledge of constructing and interpreting graphs, another test was compiled for the purposes of the study, drawing items from

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units (i.e. classes), which essentially requires a large number of subjects, which is a luxury for almost every scientific enterprise.

[2] From this point onwards and for the sake of simplicity, study 1 will be also referred to as PP condition (Paper and Pencil condition) while study 2 will be referred to as CS condition (Computer Spreadsheet condition).

[3] We needed about 20 grade ten students, ten for each condition/study and the research was to be conducted in 1996. At that time, however, there were only 14 grade ten students available at the school, and two of them were used for piloting. Therefore, the only feasible alternative was to use grade 10 students from two successive school years.

TIPS I & TIPS II tests (Dillashaw & Okey, 1980; Burns, Okey & Wise, 1985) as well as from the TOGS test (McKenzie & Padilla, 1986a; 1986b). The composite test aimed at tapping general knowledge of graph interpretation and understanding. The 12 graph-related items from the two TIPS tests were matched, TIPS I items serving as pre test items and TIPS II as their post test equivalents. The 36 items of the TOGS test were carefully screened and 8 functionally equivalent items were selected and matched: 9, 11, 16, 18, 19, 22, 24 and 26. Therefore, the final instrument was comprised of 20 items.

5.3.1.3 Instructional materials

A set of correlational problems, developed by Brash et al. (1991) for the purposes of the Ross & Cousins (1993a; 1993b) studies, was initially selected. The problems were intended to provide stimulation and ground for the introduction and practice of the relevant concepts. Fourteen exercises were initially selected from the module by Brash et al., (1991) as appropriate for use in the study, but after piloting a set of eight exercises was eventually maintained.

The final set of exercises used was comprised of the following exercises from the original Brash et al., (1991) module: 2.1; 2.2; 2.4; 4.2; 4.4; 5.4; 5.5, quiz 1 and they were also presented in this order, hereafter referred to as exercises one to eight. Exercises one, three, and five were designed to present new information to the students, since it was judged that it would be impossible for the students to apprehend all concepts, if they were to be presented during the first exercise. Exercises two and four served simply as drilling exercises, and so was the case for the last three exercises. It should be emphasized, though, that nothing new was presented to the students after exercise five. The exercises were of a problem-based format: every exercise included a fictional short story involving two or more characters, often holding opposite views. Each exercise was accompanied by a table with data on two or more variables, which were directly or indirectly related to the problem. Thus, each exercise presented a problematic situation which could be resolved by using the table data to find out whose character's viewpoint was more 'accurate' or was supported by the data. Other instructional materials included graph paper, the globe and a physical map of Canada. As already mentioned, the same set of exercises were used for both studies.

5.3.1.4 Software

Microsoft Excel v. 6.0 was the software used in the second study for (a) the production of graphs, and (b) the calculation of correlation coefficients. Regarding the former, the software includes the Graph Wizard, a specific tool which facilitates graph production. The Graph Wizard is fairly easy to use and is very powerful in that it allows the user to produce a number of different graphs. Concerning the latter, the calculation of coefficients with MS Excel is not straightforward, even though in principle the Function Wizard, a tool which assists the user with the selection and calculation of a function and is analogous to the Graph Wizard, could be used. For the purposes of the study, however, the Function Wizard was not very practical to use, as it required some extensive familiarization with a number of other procedures which had little bearing on the rest of the spreadsheet activities. For instance, the student had to go through a lot of menus and this required familiarization with the terminology. Moreover, the Function Wizard did not have a built-in function for the direct calculation of partial correlation coefficients. To circumvent these problems two specific macros were created using Microsoft Visual Basic. One of the macros calculated the correlation coefficient between two continuous variables while the other calculated the partial correlation coefficient for two continuous variables controlling for a third dichotomous one. Both macros were interactive in the sense that they guided the student through a series of steps. For example, in calculating the value of a correlation coefficient, the student was asked to enter the range of data for the first variable, and then asked to enter the range of data for the second variable. When these two steps were successfully performed, a pop-up window informed the student about the value of the correlation coefficient. The same procedure was followed for the calculation of the partial correlation coefficient. Examples may be found in the appendix [A].

5.3.2 Procedure

The school was officially contacted and a meeting was held to inquire the possibility of cooperation. Two school teachers expressed interest in the study and the geography teacher was eventually chosen because of the nature and the theme of the module. The teacher had been teaching Geography and English for approximately nine years. She received compensation per hour of participation in both studies.

5.3.2.1 Study 1 - Paper and pencil condition

The teacher was provided with the set of exercises and detailed accompanying information: descriptions of all the concepts as well as the objectives and solutions of all exercises. All teacher questions concerning conceptual aspects of the module (i.e. subject matter knowledge) were answered in detail. The teacher was explicitly informed that no teaching instructions or guidelines could be provided whatsoever, as that would inevitably and inextricably interfere with the research objectives. Whenever an instructional question surfaced in one form or another, it was re-emphasized that she could teach the module anyway she wanted to, if possible, teach it as she normally would, if it were part of the school curriculum. An initial set of exercises was piloted with two subjects, of average and low math ability respectively. On the basis of these two subjects the final set of exercises to be used was selected and information about the range of instructional and regulatory behavior, especially with the low ability student, was gathered. The pilot also served the purpose of providing the teacher with the opportunity to try out a few instructional ideas and strategies.

During the tutorial, the teacher was seated next to the student. The teacher provided the first problem, the student read it, a short discussion followed and the student then was asked to solve the problem. Of course, despite the fact that some students had a few workable ideas, this meant that the students were soon faced with an irresolvable task. In such cases the teacher jumped in and provided instruction and guidance. When the exercise was completed, a new one was assigned. This process went on for about three hours with a short 10-15 minute break after the first one and a half hour. 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; three subjects, however, had covered all seven exercises with almost 20 minutes to go, and so an extra exercise was taken up. Seven exercises was the criterion for all students.

The researcher was present during the tutorials videotaping the interaction and administering pre and post tests. Each student was individually pre-tested before the tutorial and post tested right after. Pre and post testing took approximately half an hour each, with the tests administered in an interview format, requesting the student to provide explanations for every choice made.

5.3.2.2 Study 2 - Computer spreadsheet condition

In the case of the computer spreadsheet condition, no further familiarization of the teacher with the conceptual aspects of the task was necessary, as she had already taught the particular set of exercises a dozen times. Five more exercises from the Brash et al., (1991) correlational reasoning module were also added to the initial set, because it was expected that the students with the help of the spreadsheet will manage to solve more exercises. Hence, the only task-related teacher preparation involved a detailed discussion of the four additional exercises.

The bulk of preparation for this second condition involved extensive familiarization with the computer spreadsheet. The teacher has had a laptop computer for a number of years and was, thus, computer literate. She had some basic operating system knowledge (MS-DOS & MS Windows 3.1) and she had mainly used a word processor (Word Perfect 5.1) for producing short texts. The teacher was introduced to MS Windows 95 and MS Excel 6.0 by the researcher over a period of 10 hours. Main concepts were introduced, examples were given, and supervised as well as autonomous individual practice followed. The main objective of this introduction was to provide the teacher with all the necessary skills for delivering the tutorial with the spreadsheet.

The specific issues covered included: file management and modification; working and editing data; making all kinds of graphs; using the macros to calculate coefficients and correlation coefficients; drawing trendlines both automatically and manually; using the macros specifically created for calculating correlation and partial correlation coefficients; and demonstrating the relationship between the correlation coefficient and the trendline. When the teacher felt confident that she had mastered the requisite skills, we piloted the procedure with one subject. On the basis of the observations, a number of modifications were effected.

During the tutorial, the teacher was seated next to the student. The teacher provided the first problem, the student read it, a short discussion followed and the student was then asked to solve the problem. The students typically proposed a few ideas and the possibility of making a graph was discussed. At that point the teacher introduced the computer and the student was asked to work with it. Eventually, the exercise was solved with the aid of the spreadsheet, i.e. the scattergraph was constructed, a trendline was drawn and the correlation coefficient was calculated. When each exercise was completed, a new one was assigned. This process went on for about three hours. 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; one subject, however, had covered all seven exercises with almost 30 minutes to go, and so two extra exercises were taken up; another subject had finished seven exercises with 10 minutes to time and, thus, an eighth exercise was assigned as well.

The researcher was present during the tutorials, videotaping the interaction and administering pre and post tests. Students were pre-tested before the tutorial and post-tested right after. Pre and post testing took approximately half an hour each, with the tests administered in an interview format, requesting the student to provide explanations for every choice made. It must be emphasized that during the process of solving the correlational task the subjects were allowed to solve the problem *with* the computer. The reasons for this choice are discussed in chapter 8.

5.3.3 Analysis

In this section we will confine the presentation to information related to the development of the coding scheme, which was the initial step in carrying out the discourse analysis for both studies. Specific information about other techniques of analysis will be provided in later chapters.

5.3.3.1 The coding scheme

As already mentioned, all tutorials for both studies (approximately 60 hours of instruction) were videotaped by the researcher and subsequently transcribed verbatim. The discourse analysis procedure to be described below involved about 750 densely typed pages of transcripts. We employed a bottom-up approach in developing a coding scheme. On the basis of teacher and student behavior a number of broad categories of teacher and student behavior were initially constructed. Those categories were related to teacher and student: (a) regulation, (b) task-specific problem solving behavior, and (c) general problem solving behavior. We selected the most average student in terms of skill and started coding the transcript using these categories. As anticipated, it was impossible to meaningfully code all teacher and student behavior using a few rough categories. In response to this problem, further teacher and student categories were developed and a whole transcript was coded. When coding was completed, teacher and student codes were extracted from context and grouped together. This helped us in determining variations within every general category. The approach seemed to be extremely fruitful, as, even out of context, it became evident that the range of behavior initially coded under every category varied considerably. Further classifications and analyses resulted in a radical transformation of the initial categories. This involved the creation of more elaborate and specific codes within each general teacher and student category, which can be described as a process of articulation and fine tuning of the coding scheme. The third step involved distinguishing direct and indirect teacher and student regulatory codes as well as task specific and general problem solving codes. As a first test of the appropriateness of the coding scheme, portions of other transcripts were selected and coded by the researcher. Other researchers with experience in the field of discourse analysis and protocol analysis were consulted resulting in valuable feedback on the structure of the coding scheme and individual codes, collecting construct validity information. As a final step, a native English speaker was asked to check the coding scheme per se, plus to code portions of two transcripts in order to provide information on linguistic and conceptual aspects. Valuable feedback was received and information about the suitability of the coding scheme was collected. Major or minor adjustments were made when necessary.

The final coding scheme included eight general teacher categories and six general student categories. It must be noted that because different tools were used in the two conditions, most of the codes were applicable to both conditions (i.e. both study 1 and study 2 discourse data) while some of the codes were by definition specific to each condition. Teacher categories are presented in table 5-1. More information concerning the definitions of each code, as well as examples can be found in the appendix [B].

Table 5-1: Teacher categories

Category	Code	Description
Task-specific problem solving action	**TR**	Teacher reads
	TM	Teacher marks/takes notes/counts
General Problem solving action	**TPNI**	Teacher provides new information
	TPII[b]	Teacher provides interface information
	TPE	Teacher provides example/explanation
	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 summarizes 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

Student categories are presented in table 5-2. For information concerning the all definitions as well as examples the reader should turn to the appendix [C].

Table 5-2: 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

With respect to segmentation, a number of different possibilities were initially explored, but when the coding scheme was finalized we chose to segment behavior according to *speech functions*: every time the utterance of a speaker served a different purpose a new segment was to be created. It should be stressed, though, that the meaning of the term function, 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 the appendix [D].

For coding the data obtained from study 1, two second year undergraduate students at the Faculty of Educational Science and Technology, received five hours of training in segmentation and coding from the researcher. They were then provided with the opportunity to practice using the two pilot transcripts. Initial levels of agreement for some specific teacher and student codes were very low (around 50%) and, therefore, more training and practice was required. When agreement reached respectable levels (around 80%), after approximately of 40 hours of practice and feedback in total, the students were allowed to begin coding the transcripts. They independently segmented and coded all transcripts, using the segmentation rules and the developed coding scheme. They worked for about one hundred and fifty hours each and were paid per hour of data coding.

Because of the nature of discourse analysis we aimed at performing, segmentation needed to be exact. Segmentation agreement was 97% for all transcripts. The remaining 3% of the segments were removed from any further analysis. Cohen’s Kappa for inter-judge agreement was calculated for teacher and student codes for the remaining 97% of the segments for all transcripts, as part of the reliability examination of the coding scheme. It was found to be very reliable: .77 for student codes and .82 for teacher codes. Disagreements were resolved through discussion between the judges.

Due to the fact that a very thorough and time consuming approach was followed for coding data from study 1, the researcher segmented and coded the data of study 2. The reliability check in the second study involved segmenting and coding about 10% of the data (one transcript). A third year undergraduate student received approximately five hours of instruction in segmentation and coding, followed by fifteen hours of supervised practice. One transcript was then randomly selected and the student segmented and coded it. This process took about ten hours in total and the student was paid per hour of data coding. Segmentation agreement was 98%, while Cohen’s Kappa was .87 for teacher codes and .84 for student codes.

In chapter 6 study 1 is presented and discussed while chapter 7 deals with study 2.

Chapter 6

6 Study 1: The contribution of the teacher to the development of correlational reasoning skills

In this chapter the role of the teacher in the development of correlational reasoning skills is considered. More particularly, the contribution of the teacher is examined in terms of regulation and genre appropriation. Firstly, two specific research questions are stated on the basis of the theory presented in chapter 3. Secondly, the results from frequency, sequential, and genre discourse analysis are presented and discussed in terms of the theory.

6.1 Research questions

The study was aiming at determining whether, to what extent and how decision making in problem solving shifts from teacher to student in the course of the exercises. Additionally, the study was aiming at establishing whether the student is appropriating the genre used by the teacher throughout the exercises. Thus the following research questions were addressed:
(a) Is there a transition from teacher regulation to student self-regulation in the course of the exercises?
(b) Is the voice of the teacher gradually being assimilated in the voice of the student in the course of the exercises?

Based on the theory discussed in chapter 3, it was excepted that teacher regulation would be declining from the first exercise to the last, while student self-regulation would be increasing. On the other hand, it was expected that the voice of the teacher (i.e. certain scientific concepts) would be gradually reflected in the voice of the student.

6.2 Analysis

6.2.1 Discourse analysis

6.2.1.1 Formal discourse analysis: frequency and sequential discourse analysis

Using GSEQ, frequencies for all teacher and student codes were initially tallied per exercise. Subsequently, a series of analyses of variance were then performed for testing whether the frequencies of codes were significantly declining from the first exercise to the last. This procedure has been described elsewhere (Karasavvidis, Pieters & Plomp, 1997).

Subsequently, a number of transformations were performed on teacher and student codes. More specifically, and in accordance with the theory, we chained specific sequences of codes into new codes. The chained categories of codes are presented in table 6-1. One of the implications of chaining events (codes) is that the original number of frequencies for the codes chained is reduced (Bakeman & Gottman, 1986). The frequencies for all these new chained codes were tallied.

Table 6-1: New codes created from chaining theoretically related codes: exchanges

Description	**Old codes**	**New code**
Teacher initiated goal setting	TRPL– SSG	PLANT
Student initiated goal setting	SAGE-TCS	PLANS
Teacher initiated elaboration	TEL-SEL	ELABOT
Student initiated elaboration	SEL-TEL	ELABOS
Teacher initiated explanation	TRE-SPE	EXPLT
Student initiated explanation	SRE-TPE	EXPLS
Teacher initiated provision of task information	TRCI-SPCI	CONCQT
Teacher initiated provision of factual information	TRFI-SPFI	FACTQT
Student initiated understanding exchange	SAEU-TCS	UNDERS
Student initiated articulation, 1st type	SRAI-TPE	ARTICS1
Student initiated articulation, 2nd type	SRAI-TEL	ARTICS2
Teacher initiated articulation, 1st type	TRAI-SEL	ARTICT1
Teacher initiated articulation, 2nd type	TRAI-SPE	ARTICT2

In addition to this theoretically based chaining, practical considerations, stemming mostly from the low occurrence of frequencies for some categories, led us to lump some of the existing codes into new codes. As opposed to chaining, however, lumping codes entails that the initial frequency of occurrence of the lumped codes is maintained (Bakeman & Gottman, 1986). A list of all new codes derived from lumping is presented in table 6-2. Frequencies for these codes were tallied after this recoding procedure.

Table 6-2: New codes created from lumping existing codes

Description	**Old codes**	**New code**
Teacher provision of information	TPNI & TPE	TPI
Teacher request for information	TRCI & TRFI	TRI
Teacher meta-discourse	TRAI & TIN	TMDS
Student provision of information	SPCI & SPFI	SPI
Student request for information	SRCI & SRFI	SRI
Direct teacher regulation	TSST & TSS & TFA	TD
Indirect teacher regulation	TREV & TRIN & TAS	TIND
Teacher knowledge reference	TREF & TESK	TKRF

When these transformations were completed, we proceeded further by dividing each exercise into five distinct phases. In our initial analysis (see Karasavvidis, Pieters & Plomp, 1997) we focused on each exercise as a whole, following previous research. Because of the fact that a whole exercise is a very rough frame of reference, however, we decided to look at specific exercise phases. The rationale for this decision is shortly elaborated.

Firstly, the procedure for solving a correlational problem (i.e. making a scattergraph) was demonstrated and introduced during the first exercise, which meant that, as a rule, nothing new was presented in the remaining exercises. Learning how to make a graph was a constitutive and essential feature of learning how to solve a correlational problem, given that we focused on graphical solutions. Thus, as far as graph construction is concerned, nothing new was presented in the last six exercises. On the other hand, the introduction of new concepts (which were related to graph construction, but at the same time were quite distinct from them – e.g. correlation coefficient) was not completed during the first exercise: new information was presented in exercises three and five as well. Therefore, from the point of view of concepts, only the last two exercises could count as genuine drilling ones.

Secondly, exercises three to seven normally required the construction of two graphs. In these exercises, making two graphs amounted to repeating the same processes required for the construction of the first graph: planning what to do, making the graph, plotting and reaching a conclusion pertaining to the correlation featured in the graph. Generally speaking, less interaction was required when a second graph was being made within the same exercise.

All these features related to the nature of the task and the particular instructional choices made, had one very important implication: if each individual exercise would be our sole frame of reference, then a lot of valuable regulatory information would be lost. To circumvent this problem, each exercise was divided into five different phases: reading, planning, making the graph, plotting and concluding. These phases constituted natural units of the problem solving process, with clearly identifiable boundaries and objectives. More information about phase definitions as well as the problem solving actions these phases included can be found in the appendix [E].

Subsequently, the frequencies for all codes per exercise phase were tallied. On the basis of these raw frequencies, the mean for all subjects for every code per exercise phase was computed. This statistic was correlated with the exercise number to obtain Spearman's rank order correlation coefficients for every code in all five exercise phases (Hays, 1973; Siegel & Castellan, 1988).

6.2.2 Genre analysis

Genre analysis in study 1 was based on the model introduced in chapter 4. More specifically, we only focused on the relationship between genre and principle, that is on the connection of genre (Bakhtinian theory) with specific scientific concepts (Vygotskian theory). The relationship between genre and activity was not explored in this study. For the purposes of this first study, we focused on two of the most important (scientific) concepts: *correlation* and *variable*. The concept of variable is encountered in the following forms: independent variable, dependent variable, and control variable. The concept of correlation is encountered it the following forms: positive correlation, negative correlation, no correlation, partial correlation, correlation coefficient, and partial correlation coefficient.

Following the procedure proposed by Wegerif & Mercer (1997a), all transcripts were thoroughly examined with WinConcord (a Windows concordancer developed by Martinek & Siegrist, 1995), the focus being on the occurrences of each word/term. *For every student use of the terms, it was determined whether the introduction was independent*. An independent introduction meant that the term was not used by the student right after a teacher utterance. Proximity in discourse was thus one of the criteria of independence used. If the student used the term following a teacher introduction of it within ten utterances, then this would be marked as a dependent use. A second criterion we used was *topic continuity*. Of course, topic continuity was most of the time related to discourse proximity, as the teacher would use the term in a question or a statement and then the student would also use the term as part of his response or of another statement. If however, the topic of discussion was different, and the student would use the term, even if the term would be within the ten utterances range, it was marked as an independent student use. As stated already, we focused on the two most important terms (i.e. scientific concepts): correlation and variable. This also included terms like independent variable and positive correlation, and thus all the terms in the various combinations, including the same terms in plural.

A second step included the calculation of two types of proportions. On the one hand, the independent uses of the respective terms by the students were divided with the total student use of the terms. This provided an index of the portion of the student uses of the term which were independent ones. Ideally, it would be expected that the use for the first exercises would be low, increasing with the passing of time, as the voice of the teacher is assimilated into the voice of the student. To examine the relative proportion of teacher and student uses of the terms, the number student uses of the term was divided with the respective number of teacher uses of the term. The average proportion was calculated over all subjects and this statistic was further used to compute Spearman's rank order correlation coefficient (Siegel & Castellan, 1988).

6.3 Results

6.3.1 Performance improvement

Before we turn to the examination of the research questions, the effect of the tutorials on student ability to solve correlational problems should be determined. Pre and post test performance on the correlational reasoning test is presented in table 6-3. The fact that student performance on all four component skills was low on the pre test suggests that students lacked the conceptual knowledge to solve correlational problems. On the other hand, post test performance was significantly higher, which implies that the requisite knowledge and skills were acquired by the students in the course of the tutorials.

Table 6-3: Pre and post test performance on the correlational reasoning test

		Pre-test	Post-test	t-value	df	p
Organizing [0-4][a]	*M(SD)*	1.00 (1.41)	3.80 (0.63)	-6.332	9	0.000
Locating [0-2]		1.00 (0.82)	1.90 (0.32)	-3.857	9	0.004
Synthesizing [0-3]		0.80 (0.92)	2.70 (0.48)	-5.019	9	0.001
Concluding [0-3]		0.90 (0.57)	2.80 (0.42)	-8.143	9	0.000

a: Range of the skill

Table 6-4 features student performance on the composite test which was aimed at tapping general knowledge of understanding and interpreting graphs. As can be seen in the table, student performance was relatively high with the exception of two items, namely item 7 and item 9. Pre test results suggest that students had a fair understanding of graphs, their construction and interpretation. Student performance increased on the post test with the exception of items 1, 5 and 8 where pre test performance was already very high. This achievement improvement was found to be significantly higher than the corresponding pre test scores for items 3,4,7,9,10.

Table 6-4: Pre and post test differences on the composite test

		Pre-test	Post-test	t-value[a]
Item 1[b]	*M (SD)*	0.90 (0.32)	0.90 (0.32)	0.000
Item 2		0.80 (0.42)	1.00 (0.00)	-1.500
Item 3		0.80 (0.42)	1.00 (0.00)	-1.500
Item 4		0.80 (0.42)	0.90 (0.32)	-0.557
Item 5		0.90 (0.32)	0.70 (0.48)	1.000
Item 6		0.90 (0.32)	0.90 (0.32)	0.000
Item 7		0.20 (0.42)	0.90 (0.32)	-3.280*
Item 8		0.80 (0.42)	0.80 (0.42)	0.000
Item 9		0.40 (0.52)	1.00 (0.00)	-3.674**
Item 10		0.50 (0.53)	1.00 (0.00)	-3.000*

a: df=9; b: student responses were scored as correct (1) or incorrect (0);
* $p < 0.05$; ** $p < 0.01$.

What do these performance scores indicate with respect to the conceptual knowledge that is called for solving a correlational problem? Firstly, the results of the task specific correlational reasoning test indicate that the students were unable to solve a correlational problem before the tutorial, whereas they were definitely capable of solving such a problem in the post-test due to the intervening instruction. Secondly, the results of the composite test, which was less likely to be directly affected by the specific correlational reasoning instruction, are indicative of a transfer effect: although students performed reasonably well on the pre-test as a whole, there was still room for improvement as a consequence of the instruction. The tutorials therefore did make a difference in terms of the knowledge required to deal with a correlational problem.

6.3.2 Frequency and sequential analysis

Elsewhere we have described the outcomes of the standard analyses of variance for every code in the course of the exercises (Karasavvidis, Pieters & Plomp, 1997). These analyses showed that, overall, there was little support for the idea of a transition from teacher-regulation to student-regulation, even though students did well on the correlational reasoning task. There was some positive evidence for some of the codes but, overall, there was little support for the general genetic law of cultural development (Karasavvidis, Pieters & Plomp, 1997). The main issue was that even though for most of the codes between two successive exercises a significant decline was found, no overall significant decline was found from the first exercise to the last. The nature of the task was quite complex and, therefore, we proceeded to an examination of specific exercise phases as described above. Instead of analysis of variance, we used a correlational approach, looking for trends instead of looking for a significant decline from exercise 1 to exercise 7. The Results of the correlational analyses are presented next.

Table 6-5 features the Spearman rank order correlation coefficients for direct teacher regulation codes for all five problem solving phases.

Table 6-5: Direct teacher regulation codes

	Read	Plan	Graph	Plot	Conclude
TSG	-0.607	-0.498*	0.084	-0.219	0.102
TCS	-0.250	-0.529*	-0.126	0.000	0.035
TCE	0.299	-0.453	-0.235	0.346	0.360
TD	-0.090	-0.421	-0.593*	-0.137	0.120

* $p < 0.05$

According to the theory, with the exception of teacher step confirmation (TCS), all other direct teacher regulation forms should be declining over the exercises. It is worth noting that the phases of reading, planning and making a graph are characterized by low to moderate negative correlations, a pattern which is suggestive of an overall decline for direct teacher regulation codes for these phases. This decline, however, turned out to be significant for three codes only. The most genuine manifestation of direct regulation is teacher goal setting (TSG), and, as can be seen from the table, teacher goal setting is significantly decreasing over the exercises for the phase of planning, a finding which supports the theory. From a theoretical viewpoint, teacher confirmation (TCS), would be expected to increase in the course of exercises, based on the assumption that the student is performing more correct steps with the passing of time as a consequence of learning. As the table shows, teacher step confirmation was declining over the exercises. An overall significant decrease can be seen for the composite code of direct teacher regulation (TD) in the phase of making the graph. It is also interesting to note that teacher error correction did not seem to be significantly declining over the exercises for any of the problem solving phases. This outcome suggests that errors were being made without decrease throughout course of the exercises.

The Spearman correlation coefficients for the indirect teacher regulation category are presented in table 6-6.

Table 6-6: Indirect teacher regulation codes

	Read	Plan	Graph	Plot	Conclude
TRPL	0.337	-0.117	-0.754**	0.411	-0.004
TRE	0.056	-0.431	-0.400	-0.274	0.151
TIE	0.000	-0.751**	-0.361	-0.035	0.151
TRI	0.111	-0.305	-0.604*	0.120	0.404
TIND	0.699*	-0.426	-0.385	-0.137	-0.076

* $p < 0.05$; ** $p < 0.01$

Theoretically speaking, all indirect forms of teacher regulation were expected to be declining over the exercises. As can be seen from the table, the overwhelming majority of the correlations are moderate to high negative ones, a pattern which indicates decline of the respective forms of teacher regulation in the course of the exercises for the phases of planning, making a graph and plotting. Three of the correlations were significantly declining for two of the phases: teacher planning questions (TRPL) for the phase of making a graph, the correlation being very high. This finding is in full compliance with the theory, as it suggests that the teacher asked relatively more questions in the first few exercises, and in this way provided structure and guidance for the student. The fact that teacher error indication (TIE) was found to be declining over the exercises for the phase of making a graph, is also in agreement with the theory, as it signifies that the number of student errors in the course of exercises were being decreased; this decrease in errors can be taken to be a very important index of learning. The composite code of teacher informational requests (TRI) was also found to be significantly decreasing for the phase of making a graph, a finding which suggests that factual and conceptual information questions were not typical of the last few exercises, which in turn indicates that there was no need on the part of the teacher to raise these types of questions, be it for evaluation or instructional reasons, because the student had mastered the subject matter reasonably well, so that reference to or occurrence of these types of questions was trivial and had nothing to contribute to learning. It should be noted that a finding which was not anticipated by the theory was the fact that the composite code of indirect forms of teacher regulation was significantly increasing over the exercises for the phase of reading.

Spearman correlation coefficients for teacher general problem solving step codes are presented in table 6-7.

Table 6-7: Teacher general problem solving codes

	Read	Plan	Graph	Plot	Conclude
TPI	0.000	-0.470	-0.412	-0.310	-0.539*
TKREF	-0.168	-0.587*	-0.133	0.000	-0.423
TMDS	0.071	-0.691**	-0.595*	-0.548	-0.204
ARTICS1	0.170	-0.641*	0.000	-0.518	0.437
EXPLS	0.158	-0.335	0.224	-0.621*	-0.315
ARTICS2	-0.158	-0.404	-0.526	0.411	-0.078
ELABOS	0.170	-0.690**	-0.405	-0.671*	-0.600*

* $p < 0.05$; ** $p < 0.01$

As far as general teacher intervention in the problem solving is concerned, the theory predicts that it would be reducing in the course of the exercises as a direct consequence of increase student competence. As can be seen in the table, this notion received support from a number of codes for different problem solving phases. It is worth noting that, with the exception of the reading phase, all other phases are characterized by negative correlations ranging from low to moderate, a pattern which suggests an overall decline over these phases in the course of the exercises, even though the cases of significant decline are less. It should be emphasized that the case of teacher general problem solving steps has more significant negative correlations compared to the other two types of teacher intervention, that is direct and indirect teacher regulation. The composite code of teacher information provision (TPI) shows that for the phase of concluding increasingly lower amounts of new information and explanations were required, this fact being an indication of student acquiring more grasp of the subject matter. Teacher knowledge reference (TKREF) was also significantly decreasing for the phase of planning, and this signifies the fact that teacher knowledge references and evaluation of student knowledge were becoming unnecessary in the course of the exercises and this could only be happening as a result of increased understanding on the part of the student. Teacher meta-discourse (TMDS) was also significantly declining in the phases of planning and making a graph, a fact which is indicative of the establishment of more common ground and understanding in the last few exercises compared to the first ones, which again could be attributed to the enhanced student skill towards the last few exercises. Teacher provision of explanation can be attributed to student explanation requests as well as to student additional information requests. The table shows that both these codes were significantly declining, although for different phases. On both occasions, the decline signifies a comparative lower occurrence of teacher explanations due to student requests, of either form: this implies increased student understanding of the task over the last few exercises. Teacher elaboration can be broken down into two types: elaboration which is triggered by a student question and elaboration which is due to explication of a particular topic. As can be seen from the table, while student question-led elaboration (ARTICS1) did not seem to vary over the exercises, teacher elaboration which followed student elaboration (ELABOS) during the exercises was significantly decreasing for the phases of planning, plotting and concluding. When a student provides an elaboration and the teacher responds with a further elaboration, this means that the teacher feels that there should be some sort of explication and further clarification of the idea or topic discussed. A decline of these co-occurrences over the exercises means that, according to teacher's judgement, no such further clarification would be required, since the utterance of the student had covered the issue.

Table 6-8 features Spearman rank order correlation coefficients for the category of direct student regulation.

Table 6-8: Direct student regulation codes

	Read	Plan	Graph	Plot	Conclude
SSG	0.089	-0.585*	-0.093	-0.199	0.312
PLANT	0.134	-0.226	-0.120	0.199	0.516*
SID	-0.056	-0.564*	-0.437	-0.529	0.246
SRE	0.089	-0.389	-0.237	-0.091	-0.344
SPE	0.126	-0.210	-0.281	-0.104	-0.281
EXPLT	-0.243	-0.250	-0.764**	-0.548	0.343
ARTICT2	-0.655	-0.400	-0.890**	0.411	0.382

* $p < 0.05$; ** $p < 0.01$

Regarding direct forms of student regulation, it was expected that, with the exception of student goal setting, all codes should be declining over the exercises. Low to moderate negative correlations for the phases of planning, making a graph and plotting, suggested the presence of a pattern of decline, at least for these three phases and even though the decline was not systematic (i.e. significant). The major indication of direct student regulation is of course goal planning, and it could be distinguished into two parts: independent student planning (SSG) (i.e. goal planning that does not come as a result of a teacher planning question) and teacher elicited-planning (PLANT). Paradoxically enough, independent student goal setting was found to be significantly declining for the phase of planning, whereas teacher-elicited planning was found to be significantly increasing for the phase of concluding. More congruent with the theory was the significant decrease for the phase of planning of student perceived difficulty (SID), a finding which suggests that the task was becoming increasingly easier due to student learning. Student explanations can be divided into three parts: independent student explanation; explanation resulting after teacher explanation request (EXPLT); and explanation following a teacher additional information request (ARTICS2). As can be seen in the table, both types of teacher initiated explanation were found to be significantly declining for the phase of making a graph, while independent student explanation did not seem to vary across the exercises.

In table 6-9 the Spearman correlation coefficients for indirect student regulatory codes are presented.

Table 6-9: Indirect student regulation codes

	Read	Plan	Graph	Plot	Conclude
SAGE	-0.896**	-0.820**	0.134	-0.279	0.582*
PLANS	-	-0.709**	-0.681*	0.040	0.212
SAEU	0.000	-0.229	-0.387	-0.104	0.117
UNSERS	-0.866**	-0.151	0.035	-0.274	0.135
SRAI	0.327	-0.625*	-0.373	0.461	-0.049
ELABOT	0.321	-0.274	-0.361	-0.372	-0.361
ARTICT1	-0.073	-0.594*	-0.621*	0.274	0.270

* $p < 0.05$; ** $p < 0.01$

According to the theory, indirect forms of student regulation should be declining throughout the exercises, which in turn would suggest that the student is mastering the task to an extent that all indirect forms of regulation would be unnecessary. The major index of direct student regulation is student planning question, which can be decomposed into student goal planning question (SAGE) and student goal planning question which is confirmed by the teacher (PLANS). The high significant correlations for the phases of reading and planning suggests that the students tended to ask fewer planning questions over the exercises for these two phases, a fact which is in direct agreement with the theory, since a better understanding of the subject matter would necessarily entail that less planning questions would be made in the course of the last few exercises. Again, one of the paradoxical findings is the direct increase of planning statements for the case of student goal setting. It would also be expected that the student would be stating more appropriate goals across the exercises, but, as can be seen from the table, this was not confirmed: student planning questions which were legitimized by the teacher (i.e. correct student planning questions) were significantly declining over the exercises. The same paradox was observed for the case of student understanding questions (UNDERS) which were confirmed by the teacher: although the occurrence of student understanding questions was not systematically changing throughout the exercises, teacher-legitimized student understanding was significantly declining for the phase of reading. This suggests that the student tended to make less appropriate understanding questions towards the last few exercises, but that would be the case only if the student was lacking in knowledge and understanding of the task. Post test scores leave little doubt that this can be the case. Additional information requests seemed to be declining for the phase of planning, which is in agreement with the theory. Student elaboration could be divided into elaboration following teacher elaboration and elaboration which is elicited by a teacher question (TRAI). It can be seen from the table that the first type of elaboration did not seem to be systematically declining over the exercises, while student elaboration following teacher questions inquiring more information was significantly declining over the exercises for the phases of planning and making a graph.

Table 6-10 presents the Spearman rank order correlation coefficients for the student general problem category.

Table 6-10: Student general problem solving codes

	Read	Plan	Graph	Plot	Conclude
SPI	0.286	-0.476	-0.335	-0.359	0.112
SRI	-0.056	-0.346	-0.532	-0.365	0.141
CONQT	0.177	-0.366	0.184	-0.730*	-0.289
FACTQT	0.630	-0.175	-0.329	-0.100	0.007

* $p < 0.05$; ** $p < 0.01$

With respect to general problem solving steps by the student, an overall decline would be theoretically anticipated. The moderate to high negative correlations tend to support the existence of such a pattern, even though a systematic decline was observed for a single code. More specifically, student provision of conceptual information which was elicited by the teacher was found to be declining over the exercises for the phase of plotting the data. The negative trend suggests that the dependency on the teacher for providing conceptual information was declining over time, which is a further indication that the student was acquiring more understanding of the subject matter taught.

6.3.3 Genre analysis

The term 'correlation' was used 718 times while the term 'variable' 188 times. The difference between the two is due to the fact that the term variable could only be used in conjunction with the terms 'independent' and 'dependent' whereas the term correlation could be used with more terms (i.e. positive, negative, no or zero, coefficient, partial coefficient etc).

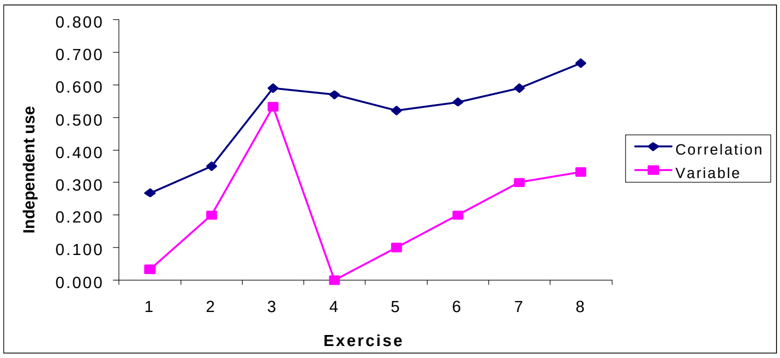

Figure 6-1: Average proportion of independent use of the terms correlation and variable by the student

As is depicted in figure 6-1, the voice of the teacher came to be appropriated as the voice of the student, as far as the use of the term correlation is concerned. The average proportion of independent student utterances was less than 30% for the first exercise, while this rose impressively to more than double for the last one. This increase clearly supports the Bakhtinian notion of the assimilation of the voice of the other into the voice of the self, since it shows that the student is increasingly utilizing this term provided by the teacher in his/her utterances, i.e. is appropriating the particular genre. This increase appears to be significant, when the Spearman rank order correlation coefficient is computed between the average independent proportion of use and the exercise number: r_s = .743, p= .017. Regarding the use of the term variable, a similar pattern in terms of increase was observed, although the increase was not steady and was overall lower compared to the use of the term variable. The average proportion of student independent use of the term variable for the first exercise was very low, below 5%, whereas for the last it was considerably higher, over 30%. In this case though, the increase was not steady and for third exercise the proportion was over 50%, while 0% for the fourth exercise. It should be noted, however, that none of the subjects used the term variable during the fourth exercise and the teacher used it only twice. This suggests that exercise four was a very special case. Although the Spearman rank order correlation coefficient was low and non significant, (r_s = .407, p= .158), the increase in the use is considerable but not uniform: it's six times higher for the last exercise compared to the first.

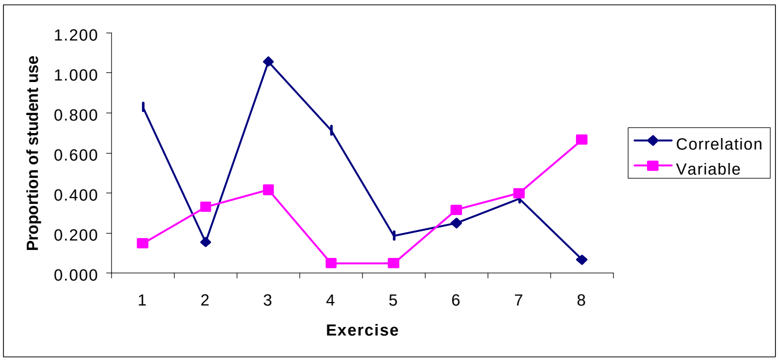

Figure 6-2: Average proportion of use of the terms correlation and variable by the student

To get an impression of the magnitude of the difference between the student uses of the term and the teacher uses of the term, the proportions of student to teacher utterances were computed and then an average over all students was computed. The results are presented in figure 6-2. It can be seen from the table that the proportion of student use of the term correlation is declining, whereas the proportion of student use of the term variable is increasing in the course of the exercises. It is worth noting that the proportion of student uses of the term variable never exceeded 50%, while the proportion of the use of the term correlation was over 70% in three of the exercises. The Spearman rank order correlation coefficient was calculated between the average proportion and the exercise number. With respect to the proportion of student use of the term correlation compared to the teacher, a moderate non significant correlation was found: r_s= -.50, p= .104. A low positive correlation was found for the use of the term variable, but it was not significant: r_s =.37, p=.183. Different patterns of use thus emerge from this examination of student uses of the terms vs. teacher uses of the terms.

Next, we will turn to a typical example of genre appropriation of the term 'independent variable' from the case of a student whom we call Jane. Excerpts are followed by a short commentary highlighting the important aspects for this discussion.

Jane, exercise 1
[student and teacher are in the initial phases of making a graph]
SPCI S: I think the **variable** goes on the x axis
TIE T: but they are both **variables**
….
TPE T: one **variable**, and that's the other **variable**
SCNF S: yeah, that's a **variable**,
SID S: I don't know what it's called
TPNI T: but this **variable**, that affects the other **variable** is called the independent **variable**
SCNF S: oh, yeah…
SRAI S: independent?
TEL T: independent…
TPE T: maybe it's easier if I say if this is the dependent **variable**, cause it depends on that one
SCNF S: ah, ok
TCNF T: yeah
SCNF S: uh hm
TPNI T: and the dependent **variable** goes on the y axis
SSG S: uh….so shall I start?
TCS T: do…

During the construction of the first graph, a number of decisions have to be made and the rationale for making each is very important. In this case, the subject uses the term variable on her own and argues that it goes on the x axis. At this point one might be led to believe that the subject has knowledge of the term variable and knows that the independent variable goes on the x axis. This may not be the case, however, as Edwards and Mercer (1987) have pointed out. It seems that the student is trying to remember something without success, and that she definitely knows something about graph construction. In Bakhtinian terms, the student is trying to speak in terms of a particular genre, without much success on the face of it. What is particularly important though, is how the teacher responds to student's suggestion that 'the variable goes on the x axis'. Teacher's reaction shows that she focused on the linguistic aspect of the statement, largely ignoring the fact that the student seems to know something about graph construction and the positions of the variables. The teacher provides negative feedback in this case, feedback which is not directed at the student' s understanding: rather it's aimed at the particular genre used, and highlighted its inefficiency. This is further supported by the teacher's next comment, which sounds like a truism 'one variable and that's the other variable'. Student's reaction is an indication of the fact that she does not know what the variable is called, in this case this comment is taken to denote a memory failure. Teacher's next utterance provides further support for this type of interpretation: she explicitly says that the influencing variable is usually called an 'independent variable'. It should be heavily emphasized at this point that, this particular teacher utterance could have been the response to the initial student utterance. This was not the case however: the teacher *chose* to discard student's first comment as incorrect (i.e. in functional terms she flagged it as an error), whereas a few utterances later she only used the term 'independent' to denote more or less the same thing the student was trying to. This notable persistence of the teacher upon the use of proper terms (i.e. genre) indicates that a great deal or learning during the tutorial, apart from principles and procedures, involves the appropriation of a particular way of talking about making a graph: the appropriation of the respective genre. At this stage, this also shows that the teacher is not willing to negotiate and accept incorrect student accounts and/or terminology: she decided to give negative feedback by means of focusing on the language used, rather than focusing on the conceptual content of the utterance. It is worth stressing that in the rest of the excerpt the teacher did not really add anything else in terms of constructs, principles or procedures: she stated in a different way what the student had already said in the first utterance. So from a thematic point of view, there was not really any contribution. Seen from the genre viewpoint, the contribution is essential: the teacher used a new term (which, judging from student's reaction, is unknown to the student) to describe an already existing entity: a variable. She used a label to denote its existence. It should be further noted that the use of the term by the student is utterly passive, because she simply repeated it right after the teacher's utterance.

Jane, exercise 2
[student and teacher are in the initial phases of planning]

TESK	T: what did I say the last time while I was explaining?
SDIV	S: the dependent…**variable**
TPE	T: this (pointing to the number of speeding tickets) depends on this
SCNF	S: yeah
TEL	T: yeah
SEL	S: yeah
TCOM	T: so why don't you say that?
SCOM	S: I'm sorry, ok?! (joking)
TCOM	T: ok!

In this passage, the student uses a word that does not belong to her, i.e. variable, for the first time. What should be noted is: (a) the student does use the term without it being used by the teacher (although the student is cued to try to remember what the term was), and (b) the use of the term is appropriate, in the sense that she uses it to describe the influencing variable. From a Bakhtinian viewpoint, this is the first instance of the appropriation of the voice of the other (teacher) into the voice of the self (student), as the student used a term which does not belong to her, was unknown to her and was initially used by the teacher. Teacher's insistence on the proper way of taking about it is manifested in the comment, which is actually task irrelevant: the teacher communicates to the student the fact that she is *expected* to use this kind of terminology (language, genre) in the course of the tutorial. At least this is the ground rule that can be inferred from such a persistence.

All this, seems to be an exercise in remembering, as Edwards (1993a; 1993b) has put it. The teacher has the opportunity to ascertain whether the student knows more about the nature of the independent variable, but does not choose to do so. She seems to be satisfied with the fact that the student can remember the particular term (i.e. genre).

Jane, exercise 3

[student and teacher are in the initial phases of planning]

TRCI T: and which goes on the x axis this time honey?
SDIV S: uh…this (pointing to the variable elevation)
TRE T: why?
SPE S: cause that's the independent **variable**
TCS T: all right

This excerpt is particularly interesting since it shows a number of things concerning the interaction and the use of the genre. Teacher's initial utterance is free of any genre and so is student's. This can be contrasted with the impressive persistence with which the teacher explicitly introduced and requested the use of the appropriate terms in the first two exercises. Instead, the teacher appears to be content with the use of references: 'which' 'this'. The question then arises: why is this the case? It can be hypothesized that the teacher knows or estimates that the student is well aware of the reasons and does not need to address them.

What is also particularly remarkable, is the fact that the teacher asks 'why'. In the second exercise the teacher asked a memory-like question: it was like an exercise in remembering. In this case, it is obvious that the teacher proceeds one step further: she asks the student why the variable of elevation goes to the x axis. This is definitely not a memory exercise alone: in this case, the student has to reason as well: mere knowledge of the term independent variable will not suffice. It should be noted that the student is not just remembering: she is also reasoning. Teacher's response is to confirm student's statement. Again, it should be noted that the teacher could go on further and ask more questions, so that not only the genre knowledge is appraised, but the whole understanding of the underlying principles. At this stage, for whatever reason, the teacher refrains from such further inquiry.

Jane, exercise 6

TRCI T: Which one goes on the x axis?
SDVP S: uh…the price…no…yeah, yeah
TRE T: why?
SPE S: why? Cause that's the independent **variable**
TRE T: why is it the independent **variable**
SPE S: cause we are looking at …like as the price differs, what the difference in the population might be…and not as the population differs what the price does
TCS T: exactly…
TSUS T: that's my girl

In this passage one fact is of primary importance, i.e. that the previous two stages are completed with yet another one: with a third wh- type of question. The teacher had initially tested memory (i.e. the genre) in the first passage. In the second excerpt, the teacher had tested the genre, plus some type of procedure, i.e. that the independent variable goes on the x axis. In the third case, in this exercise, the teacher makes the final move: she considers whether the student has any understanding of the principles involved. The fact that this type of inquisitive teacher behavior is seen in a later exercise, suggests that the teacher wished to provide some sort of room for the student to work with, practice and understand all respective concepts, before she would start questioning the student. The response by the student leaves no doubt that she has understood what the selection of the independent variable is all about: 'as the price differs, what the difference in the population might be'. This is the most complex question the teacher might ask within the context of variable selection.

We now turn to a typical example of genre appropriation of the term 'correlation' from the case of the same subject. Excerpts are again followed by a short commentary.

Jane, exercise 1

[Student has just finished plotting and they are discussing what the graph shows]

TIE	T: can you see any relationship really?
SRG	S: not really
TREF	T: cause at the beginning you were saying maybe it goes like this (showing a positive trend) maybe it goes like that (showing a negative trend) or maybe….
SCNF	S: yeah…
SPCI	S: it's not really something like that actually
TEL	T: it's not really something like that actually
SCNF	S: no
TESK	T: what do you call it when you have a relationship between two things, like this here (pointing to the graph) weekly allowance and number of visits
SAEU	S: you mean like a positive or negative relation, something like that?
TCS	T: yeah,
TRCI	T: it's a positive or negative what?
SEL	S: relation
TPNI	T: **correlation**
SEL	S: **correlation**, yeah that's what I was going to say
TESK	T: yeah, what sort of **correlation** is this then?
SRG	S: no
TCS	T: zero, right

In this excerpt the student has just finished plotting and the teacher asked her what it is on the graph that she can describe. The student had just said that there is some relationship and the teacher flagged it as an error. The student was cued to say that there is no relationship, i.e. 'really'. At this moment the student is complying with the teacher without necessarily agreeing or understanding what a relationship is. Teacher's next utterance refers to a former student suggestion on the kind of correlation. The words the student had used were 'goes like this' and 'goes like that' to denote positive and negative trends respectively. From such a comment, it can be inferred that the student has some knowledge of trends and what a trend looks like, but in this case their use is inappropriate, because the graph shows no correlation whatsoever, as well as the language used by the student to refer to and describe these terms was not appropriate, i.e.

other words were used instead of the genre. In the next few utterances, the teacher and the student come to some agreement on the fact that there is no trend: 'it's not really something like that actually'. Then, the teacher based on the fact that the student has some prior knowledge of the concept of trend, is trying to establish whether the student indeed knows something about it and more precisely what. From the student's response to this question, it can be seen that she knows what a positive and a negative trend looks like (not necessarily though what it means). It should be noted, however, that the student uses the term relationship to describe the trend. The term relationship is an everyday term and is commonly used in everyday life, but the teacher, once again, shows that the use of the term relationship to describe the trend is not really the most appropriate one. Thus, the teacher introduces the term correlation, to describe the relationship, and the student states that she was trying to find this very word. Given the fact that the student appeared to be aware of the some of the concepts introduced, her comment could be credible. It must be borne in mind, however, that in this case we have an instance of an 'exercise in remembering' as Edwards (1993a; 1993b) puts it. The student has some elementary understanding but lacks the genre, and this lack is attributed by the student to a memory failure (the 'it's on the tip of my tongue' feeling).

Jane, exercise 2
[Student has just finished plotting]

TRCI	T: so Jane
	S: uh?
	T: if you look at that graph, how would you describe what's happening in that graph?
SRG	S: as the age increases, the number of speeding tickets decreases
TRCI	T: and what sort of **correlation** is that?
SPCI	S: uh…negative
TCS	T: yeah…

In this excerpt we have a first instance of the use of the term correlation by the student. It's very instructive, though, to see in what context it occurred. The teacher question is rather straightforward: she wants to know 'what's happening on the graph'. Student's response couldn't have been more perfect (she is was a high ability student): she gives an accurate description of 'what's happening on the graph'. What is particularly striking, is teacher's response to this utterance: she further inquired into what type of relationship it is. The student said of course that it was a 'negative' correlation. It is interesting to note that the student had just described a negative correlation in other terms (i.e. in terms of the problem variables) and not in an abstract form, as the teacher requested it. Although the student appears at this point to have a very clear understanding of what a negative correlation looks like, she does not use the term correlation herself. The teacher introduces the term once again in the dialogue and the student of course responds by saying that it's a 'negative' correlation. This type of use is indirect, as the student did not actually use the noun 'correlation', she only used the adjective 'negative' and of course in that context the referent is the term correlation in the preceding teacher utterance.

Jane, exercise 3
[Student has just finished plotting]
TRCI T: and? Jane darling, what can you tell me?
SRG S: negative **correlation**
TREV T: were you correct in your prediction?

In this case, we have the first genuine instance of the independent use of the term correlation by the student. It should also be noted that the teacher question is becoming less specific as well: ‘what can you tell me’ as opposed to ‘what’s happening on the graph’ in the former exercise. The student for the first time refers to the relationship as a ‘negative correlation’. It has already been shown that the student exhibited signs of knowing what a negative relationship is but has never – up to this point – referred to it as a negative correlation. This is the first indication of genre appropriation: the student is using a term which was offered by the teacher in the context of the discussion.

Jane, exercise 4
[the student has just finished plotting]
TRCI T: ok Jane, what about males?
SRAI S: what?
TEL T: and speeding tickets
SRG S: they have a negative **correlation**
TSS T: so as the age increases (waiting for input)
SRG S: the number of speeding tickets decreases
TCS T: yeah

This is a further indication of genre appropriation. The student uses the term ‘negative correlation’ for the second time and this time the use is quite independent and appropriate as well. The teacher asks the student to describe the relationship to her and the student responds appropriately, by stating that there is a negative correlation. This is the third time that the student uses the term independently and correctly. What is interesting is that the teacher does not bother to confirm that (so the underlying ground rule is that the response was correct), but goes further and inquires a description of the relationship in terms of the problem variables. This indicates an emphasis on the understanding of the principle, because the student seems to have appropriated the genre. This episode can be contrasted with the one in exercise two, where the student had described the relationship in terms of the variables of the problem and the teacher had requested a genre-based description.

6.4 Discussion

According to Vygotsky and to the general genetic law of cultural development, the problem solving skills called for in correlational reasoning are primarily manifested on the intermental plane and then on the intramental one, i.e. become internalized. Vygotsky’s contribution, thus, consisted of postulating a transition from other to self-regulation. Additionally, according to Bakhtin, the teacher is using a particular type of speech genre in discussing and describing a problem with the student. This genre includes special types of utterances, as well as terms which are very specific to the particular task used.

Frequency discourse analysis and subsequent analyses of variance *provided little support for the ideas regarding the transition from other to self-regulation* when the problem was used as the frame or reference. Sequential discourse analysis indicated that *the findings of the previous studies were partially supported* when specific problem solving phases were used as a frame of reference. Teacher goal setting, being the main indicator of direct teacher regulation, and teacher planning questions, being the main indicator of indirect teacher regulation, were systematically declining in two of the five problem solving phases. Independent student goal setting, a major indicator of student self-regulation, was found to be declining throughout the exercises for one problem solving phase, and the same holds for the student goal planning questions, which were found to be significantly declining in two problem solving phases. Additionally, the correlational patterns obtained are also in accordance with the theory, especially in the phases of planning, making a graph and plotting the data, and, even though the majority of the correlations were not significant, they manifest a general decline.

On the other hand, there were two specific problems with replicating previous research. Firstly, even in the cases where the codes were in agreement with the theory, this was not uniform for all problem solving phases, and thus the confirmation is not universal (i.e. for all phases). Secondly, in some cases there were clear instances of theory refutation, especially when the codes were in the opposite direction than the one predicted. With respect to the former, different correlational patterns were observed for the same codes in different phases. *This finding suggests that teacher and student behavior was specific per problem solving phase*, hereafter referred to as phase specificity. If we take student planning questions, for example, there is a significant decline for the phases of reading and goal setting, whereas a significant increase is observed for the phase of concluding. The case of the decline is in line with the theoretical framework, as it points in the direction of learning taking place and, thus, less planning checks are needed with the teacher. In sharp contrast, the increase for the phase of concluding indicates that learning is somehow hindered and, thus, the student needs to confirm planning with the teacher. This phase specificity, is largely due to the fact that the problem solving phases are different and place various demands on the students. For instance, the phase of reading is variable over exercises, as new exercise texts are taken up, whereas the phase of concluding was by far the most difficult one, because it involved piecing the separate steps together, making sense of the whole solution and consolidating learning. Therefore, the different correlational patterns constitute no falsification of the theory. Instead, they tend to suggest phase-specific behavior – which, it should be stressed, would have escaped our attention had we employed each separate exercise as our frame of reference.

With respect to the latter, it was hypothesized that student goal setting would be increasing over the exercises, but this prediction was not confirmed by the data and, in fact, the opposite trend was observed for one problem solving phase. Does this finding actually constitute an instance of theory refutation, and if so, in what sense? The simple answer is ‘absolutely’. After all, there is not that much that can be debated once a significant negative correlation has been found. The complex answer is ‘possibly’. Could it be possible that this result is due to other features of the interaction unaccounted for by our analysis? In an attempt to address this question, we examined the first student goal set in the first and the last exercise respectively for each individual subject. Results indicated that the first student goal set in the first exercise usually referred to rearranging the data, calculating the averages, constructing line graphs and bar graphs, and occurred mainly in the phase of planning. In sharp contrast, the first student goal set in the last exercise was markedly different: it referred to some specific aspect of graph construction and it typically occurred in the phases of planning, graph construction, and even plotting (see Appendix [F]). What does this result indicate? It shows that the fact that a graph had to be made to solve the problem was *presupposed*, implicit, had become part of the context, part of the common knowledge reached by the student and teacher in the course of the interaction. To answer the question we initially posed, *it is evident that the negative correlation observed for student goal setting does not constitute a refutation of the theory and the previous research*. It simply highlights the fact that the student, from a certain point onwards, did not have to *explicitly state* that he/she should make a graph, as that would be necessarily trivial and potentially redundant. Had this been the case, it would have been a violation of Grice’s (1975) conversational maxims of quantity (‘make your contribution as informative as is required’) and relevance (‘make your contribution relevant’). Familiarization with the task and the mastery associated with it, coupled with the fact that all the exercises were worked out within a short period of time – which meant that no recapitulation was necessary – rendered explicit goal statements by the student unnecessary. In a word, when the goal has become so conspicuous, it is actually unimportant to state what the goal is. As a consequence, the student gets down to what has to be done without explicitly talking about it, mentioning it or referring to it[1]. Edwards

[1] It should be emphasized that, although we focused on student goal setting only for completeness reasons, the same pattern was observed with the other three teacher and student codes. Regarding the teacher goal setting code, the first teacher goal set for the first exercise was usually in the phase of reading, whereas the first teacher goal set for the last exercise was typically in the phases of planning, graph construction, and even plotting. This fact suggests that the teacher had to intervene in different phases with the passing of time, which in turn shows that student self-regulation was increasing. Turning to teacher planning statements, the first teacher planning question for the first exercise was generally referred to orientation (i.e. what can be done to solve the problem) and occurred in the phase or reading. In sharp contrast, the first teacher planning question for the last exercise, referred to specific aspects of graph construction (and thus the construction of graph was presupposed) and typically occurred in the

& Mercer (1987) have pointed out that "for the participants, the context of an utterance is more a matter of perception and memory – what they think has been said, what they think was meant, what they perceive to be relevant" (p. 66). In this line of reasoning the researchers demonstrated that "having gone through the demonstration together, and having established how to talk about it, teacher and pupils could begin to exchange understandings with words alone. The joint activity and discourse of the past became a shared mental context for the present" (ibid., p. 80).

Turning to genre appropriation, the evidence supported the notion of voice assimilation, with the voice of the teacher being progressively assimilated into the voice of the student. As far as the term 'correlation' is concerned, the independent student use of the term was significantly increasing in the course of the exercises. This is in accordance with the Bakhtinian notion of the voice of the other is being assimilated into the voice of the self. With regards to the use of the term 'variable' the increase was not steady across the exercises, but it nevertheless was considerable, over six times more independent uses for the last exercise compared to the fist.

The thorough examination of the case of one subject, who actually was the highest ability student, illustrated how this appropriation is taking place. It is gradual, straightforward and too obvious to overlook. We have chosen the most competent student to demonstrate how the genre appropriation took place for the two most important concepts of the tutorial. In a sense, thus, the excerpts discussed are not typical of what occurred with the average or low ability students. These students momentarily seemed to have appropriated the genre, while later on seemed to regress to their previous level, i.e. especially when they failed to remember the particular terms and so on. Their understanding of the principles and the procedures involved was deep and, thus, their understanding of the subject matter (combined with their post test performance) cannot be questioned. However, the extent to which they have appropriated the genre (in its various forms) was not as direct and unequivocal as in the case of Jane. What clearly surfaced from this examination was that the teacher, understandably enough, places great emphasis upon genre appropriation, sometimes even 'failing' to build on student's intuitive and incipient understanding.

phases of planning and making a graph. Finally, concerning student planning questions, in most cases the question was about graph construction and occurred in the phase of planning. The first student planning question in the last exercise concerned a specific aspect of graph construction.

Chapter 7

7 Study 2: The contribution of the computer spreadsheet to the development of correlational reasoning skills

In this chapter the role of the computer spreadsheet in the development of correlational reasoning skills is examined. More specifically, the contribution of the computer spreadsheet is investigated in terms of amplification and transformation. Firstly, two specific research questions are presented and a section on operationalization of the main variables used follows. Secondly, the results from the frequency, sequential, genre, and activity analysis are presented and discussed in terms of the theory.

7.1 Research questions

In the second study we examined the impact of the computer spreadsheet on solving correlational problems. In particular, two specific questions were addressed:

(a) Does the use of the computer spreadsheet amplify correlational problem solving compared to paper and pencil in terms of time on task, perceived task difficulty, and total number of exercises solved?

(b) Does the use of the computer transform correlational problem solving compared to paper and pencil in terms of frequency, sequential, genre and activity analysis?

7.2 Operationalization

Based on amplification views, when a task is performed with the aid of a computer spreadsheet three types of changes occur: (a) the task is performed faster, (b) with greater ease, and (c) overall, more work is produced within the same period of time. Three measures were used to operationalize these kinds of effects. We measured perceived task difficulty, time spent on various phases of the task, and the total number of exercises solved.

The instrument used for measuring *perceived task difficulty* was adjusted from Paas (1993) for the purposes of the present study. This instrument is comprised of a rating scale technique where the subjects report their invested mental effort. The instrument is based on a 9-grade point symmetrical category scale ranging from extremely easy (value of 1) to extremely difficult (value of 9). Five such rating scales were used to collect information on the corresponding aspects of the task. More specifically, the subjects rated their mental effort on five distinct dimensions: (a) making a graph; (b) putting information on the graph; (c) deciding on the nature of correlation; (d) drawing a conclusion and (e) overall difficulty. The students reported their perceived task difficulty separately for each exercise. More information concerning the reliability and validity of this subjective scale of invested mental effort can be found in Paas (1993). To determine how much curriculum material was covered in each condition, the *number of exercises solved* by each subject in the two conditions was recorded. Additionally, the overall duration of each exercise as well as the *time* spent on specific exercise phases was recorded. More specifically, for each subject in the two conditions we determined the overall time spent on the exercise as well as the time spent on: reading the exercise, planning a problem solution, making the graph, and finally discussing the findings and drawing conclusions.

Based on transformation views, when a computer is used, not only some physical actions (operations) are abandoned and new ones are introduced, but also the cognitive requirements for performing the physical actions are changed. One way of testing the idea is to look at the activity in the two conditions and thoroughly identify all the actions and operations called for solving the task in each condition. In this way, and based on the physical actions/operations performed, the requisite cognitive requirements for performing these actions/operations can also be identified. Activity theory may be used for such a purpose. Another way of checking transformation between two conditions, is to identify certain patterns (i.e. sequences of actions) which are typical of one condition and then consider whether they also occur in the other condition. These sequences may be specific problem solving actions/operations or may be communicative or general discourse actions. Given that we have segmented and coded the discourse, sequential analysis may be used for that purpose.

7.3 Analysis

First, for each condition (i.e. study) pre and post test performance was compared to establish whether the subjects acquired the skills requisite for solving correlational problems. Secondly, student performance in the two conditions was compared to ascertain whether CS students outperformed PP students. Subsequently, perceived task difficulty was examined in an attempt to test whether the task was easier for the CS students. Additionally, to determine whether there was any differentiation in the time it took to complete the task, the time measures were compared.

To determine differences in activity we analyzed the problem solving activity. To examine differences in terms of behaviors and reasoning, we used frequency and sequential discourse analysis. Subsequently, code frequencies in the two conditions were compared to examine what type of behaviors were more common for each condition. In addition to frequency comparisons, the occurrence of certain patterns of teacher-student behaviors in the two conditions was considered.

When the lengthy process of segmentation and coding of discourse in the second condition was completed, the frequencies of codes in the two conditions were compared. This was intended to be a measure of quantitative behavior differences in the two conditions. Moreover, the underlying structure of the discourse in the two conditions – and, as a consequence, of the activity – was examined through pattern analysis. To achieve this, the most important teacher and student codes were initially selected. We used student behaviors (codes) as our criterion and we looked at what sort of teacher behaviors (codes) preceded and followed these selected student behaviors. We examined teacher behavior immediately before and after each student behavior. Sequential analysis allows one to consider transitions from teacher and student codes. Examination of such transitions reveals information about the existence of patterns in discourse. Once such patterns were identified in both conditions they were compared to determine if they were more typical and likely to occur in the one condition than in the other. This information would also reveal whether there are underlying differences between the two conditions.

7.4 Results

7.5 Performance differences

Firstly, to determine whether the tutorials had any effect on student performance in correlational reasoning, pre-test scores were compared with the post test ones within each condition. The results for the PP condition were presented in chapter 6. It was expected that the tutorial would boost student performance on correlational reasoning on all four component skills, and as can be seen from the table, *students performed significantly better on the post test in all four skills*. It is particularly interesting to note that student performance in the pre-test was very low, since students lacked the knowledge and skill to solve correlational problems.

As far as the CS condition was concerned, the only possible comparison was for the skill of concluding[1]. The comparison indicated that CS students also performed significantly higher on the post test in the skill of concluding (pre-test mean: .60, sd: .51; post test mean: 2.40, sd: .51, t-value: -13.500, $p<.000$).

To examine whether students improved from pre to post test on the composite test, pre and post-test performance scores were compared within each condition. Table 7-1 features the results from this analysis. (Note that results from the PP condition, i.e. study 1, are given again for convenience).

[1] As already noted, students were allowed to use the spreadsheet to solve the post-test exercise. This necessarily made it impossible to compare student performance on the skills of organizing, locating, and

Table 7-1: Performance on the composite test

	PP condition			CS condition		
	Pre-test	Post-test	t-value[a]	Pre-test	Post-test	t-value[a]
Item 1[b] *M (SD)*	0.90 (0.32)	0.90 (0.32)	0.000	0.70 (0.48)	0.80 (0.42)	-0.557
Item 2	0.80 (0.42)	1.00 (0.00)	-1.500	0.50 (0.53)	0.90 (0.32)	-2.449*
Item 3	0.80 (0.42)	1.00 (0.00)	-1.500	0.80 (0.42)	0.90 (0.32)	-1.000
Item 4	0.80 (0.42)	0.90 (0.32)	-0.557	0.90 (0.32)	0.60 (0.52)	1.406
Item 5	0.90 (0.32)	0.70 (0.48)	1.000	0.50 (0.53)	0.60 (0.52)	-0.557
Item 6	0.90 (0.32)	0.90 (0.32)	0.000	0.90 (0.32)	0.90 (0.32)	Na
Item 7	0.20 (0.42)	0.90 (0.32)	-3.280*	0.60 (0.52)	0.70 (0.48)	-0.361
Item 8	0.80 (0.42)	0.80 (0.42)	0.000	0.40 (0.52)	0.50 (0.53)	-1.000
Item 9	0.40 (0.52)	1.00 (0.00)	-3.674**	0.20 (0.42)	0.90 (0.32)	-3.280*
Item 10	0.50 (0.53)	1.00 (0.00)	-3.000*	0.50 (0.53)	0.90 (0.32)	-1.809

* $p<.05$; ** $p<.01$; a: df=9; b: student answers were scored as correct (1) or incorrect (0).

As can be seen from table 7-1, the composite test was rather easy for the students in both conditions, as indicated by the case of many items where student performance was quite high in the pre-test already. Because of the range of the test, only considerable differences between pre and post test scores were likely to be significant. *PP students performed significantly better in three items on the post test, while CS students performed significantly better in two items*. It is worth noting that in some items in both conditions pre-test performance was higher than the respective post-test one, even though not significantly so.

Secondly, to determine whether students in the CS condition performed better than students in the PP one, a number of comparisons were carried out. On the correlational reasoning level, the pre test performance on the skill of concluding was compared between the two conditions; the same procedure was followed for the post-test performance. *Student performance in the two conditions differed neither in the pre-test nor in the post for the skill of concluding*.

On the composite test level, pre-test performances were compared between the two conditions, to determine whether the students had a different entry skill level. The same procedure was repeated for the post test performance on the composite test for all the items. *Results indicated that student performance was not significantly different in the pre or the post test in either condition.*

synthesizing, simply because the student did not use any such skills when solving the problem with the spreadsheet.

7.6 Amplification effects

7.6.1 Perceived task difficulty

Table 7-2: Mean overall perceived difficulty of solving the problem

	PP		CS		Mann – Whitney U	p
Exercise 1 *M (SD)*	4.10	(1.73)	4.00	(2.05)	47.50	0.430
Exercise 2	2.70	(1.64)	3.60	(1.51)	31.50	0.087
Exercise 3	5.80	(1.81)	4.00	(1.63)	24.50	0.026
Exercise 4	2.10	(0.99)	2.50	(1.84)	49.50	0.499
Exercise 5	3.40	(1.78)	3.10	(2.18)	42.50	0.292
Exercise 6	2.90	(0.74)	3.20	(2.15)	46.50	0.393
Exercise 7	2.90	(1.37)	2.56	(1.42)	39.50	0.338

Perceived difficulty scale: 1 = very easy; 9= very difficult

It was hypothesized that, due to the use of the computer spreadsheet, CS students would report lower perceived difficulty per exercise. As can be seen from table 7-2, *this hypothesis received very little support*: CS subjects found exercise three to be significantly easier overall. It must be stressed that the difference in units is 1.80 and that the exercise three is by far the most difficult exercise.

Table 7-3: Mean perceived difficulty of making a graph

	PP		CS		Mann – Whitney U	p
Exercise 1 *M (SD)*	2.80	(1.75)	3.60	(2.27)	38.00	0.188
Exercise 2	2.20	(1.93)	2.80	(1.32)	29.50	0.059
Exercise 3	2.30	(1.64)	2.60	(1.58)	42.50	0.300
Exercise 4	1.40	(0.52)	1.80	(1.03)	41.00	0.272
Exercise 5	2.20	(1.87)	2.40	(1.71)	46.50	0.393
Exercise 6	2.00	(1.25)	2.00	(1.15)	50.00	0.527
Exercise 7	1.90	(0.88)	1.67	(0.87)	38.00	0.340

Perceived difficulty scale: 1 = very easy; 9= very difficult

With respect to making a graph, it was also expected that the CS students would report lower difficulty. *This hypothesis was not supported by the data*, as can be seen from table 7-3. No significant differences whatsoever were found between the perceived difficulty of each exercise for the two groups. The low means for both conditions indicate that students thought that making a graph was not difficult at all, despite the fact that they had to spent significantly more time making the graph by paper and pencil and they had to think during that process as well. This finding suggests that it is quite possible that the subjects did not necessarily associate time and mental labor with task difficulty. It may be the case that their judgement was influenced by other task parameters as well.

Table 7-4: Mean perceived difficulty of deciding on the nature of correlation

	PP	CS	Mann - Whitney U	p
Exercise 1 *M(SD)*	3.30 (2.41)	3.80 (2.57)	44.50	0.349
Exercise 2	1.80 (1.23)	3.50 (2.22)	25.00	0.024
Exercise 3	3.30 (2.87)	3.30 (2.21)	44.50	0.344
Exercise 4	2.10 (0.99)	2.10 (1.20)	49.00	0.455
Exercise 5	3.10 (1.85)	3.20 (2.04)	49.50	0.492
Exercise 6	2.10 (0.57)	2.60 (1.35)	38.00	0.180
Exercise 7	2.20 (1.14)	2.22 (1.30)	44.00	0.490

Perceived difficulty scale: 1 = very easy; 9= very difficult

It was hypothesized that students in the CS condition would report lower difficulty in finding the correlation. *This hypothesis was not supported by the data*, as can be seen in table 7-4. Students in the two groups did not substantially differ in how difficult they thought finding the correlation was. The only significant difference found was for exercise two and, contrary to expectations, CS students reported that finding the nature of the correlation was almost twice as difficult compared to the PP students.

Table 7-5: Mean perceived difficulty of reporting the relationship

	PP	CS	Mann - Whitney U	p
Exercise 1 *M (SD)*	3.50 (1.90)	3.70 (1.89)	47.50	0.425
Exercise 2	2.00 (0.94)	2.10 (1.10)	48.50	0.414
Exercise 3	6.40 (1.35)	4.30 (1.42)	15.00	0.003
Exercise 4	2.00 (0.94)	2.10 (1.20)	49.00	0.485
Exercise 5	3.00 (2.00)	3.70 (1.95)	38.50	0.197
Exercise 6	2.90 (1.20)	3.10 (2.08)	50.00	0.502
Exercise 7	2.60 (1.35)	2.56 (1.51)	43.50	0.469

Perceived difficulty scale: 1 = very easy; 9= very difficult

As far as the difficulty of reporting the relationship was concerned, it was hypothesized that students in the computer condition would find it easier to report the conclusion, i.e. describe the nature of the relationship. *The hypothesis was only partially supported*: CS subjects reported that stating a conclusion was relatively easier for exercise three.

7.6.2 Time on task

Students in the computer spreadsheet condition worked for 24.56 hours while students in the paper & pencil condition worked for 24.20 hours. This difference was not statistically significant: CS mean=8849.9, sd=511.17, PP mean=8714.2, sd=435.14, t=.063 (df=18), p=.531. Even though the two groups did not differ in terms of how much time the worked on the task, it is very instructive to examine the distribution of time within each group. The distributions are given in table 7-6.

Table 7-6: Distribution of time in the two conditions

Phase	PP	CS
Reading	11%	10%
Planning	17%	18%
Graphing	39%	13%
Discussing	33%	59%

As can be seen from the table, the total time spent on reading the problem and planning a solution was not different in the two conditions. On the other hand, marked differences can be seen for the phases of making a graph and discussing the solution. In the PP condition most of the time was devoted to making graphs (39%) as opposed to the CS condition where graph construction was an activity which occupied about one eight of the time (13%). Almost twice as much time was spent discussing the problem and its various aspects in the CS condition compared to the PP condition. Therefore, it can be concluded that the central activity in the PP condition was making the graph while the central activity in the CS condition was discussing and interpreting the graph. *This finding supports the hypothesis that the use of the computer spreadsheet would result in a faster execution of the task.*

We have just examined the global time differences per problem solving phase for the two conditions but without considering the situation within the exercises. Our next step involves a more thorough examination of the time differences between the two conditions per exercise.

Table 7-7: Average time (sec) spent on the phase of reading

		PP		CS		t-value	df	p
Exercise 1	*M (SD)*	105.70	(16.04)	137.10	(39.46)	2.331	18	0.032
Exercise 2		88.30	(27.74)	88.50	(24.24)	0.017	18	0.986
Exercise 3		230.90	(42.36)	230.50	(93.43)	-0.012	18	0.990
Exercise 4		88.20	(38.94)	76.30	(21.90)	-0.842	18	0.411
Exercise 5		83.80	(39.12)	107.00	(50.40)	1.150	18	0.265
Exercise 6		280.60	(159.60)	132.20	(70.40)	-2.690	18	0.015
Exercise 7		90.70	(29.64)	74.80	(38.33)	-1.037	18	0.313

Table 7-7 features descriptive statistics for the phase of reading for the two conditions. On logical grounds alone, the use of the computer spreadsheet was not expected to impact on this phase of solving the problem. On the whole, *this hypothesis was partly supported by the data*, as significant differences were found for two exercises. As can be seen from the table, CS students spent significantly more time reading the first exercise, while PP students spent more time reading the sixth exercise. It is quite probable that these differences reflect the specific nature of the exercises.

Table 7-8: Average time (sec) spent on the phase of planning

	PP		CS		t-value	df	p
Exercise 1 *M (SD)*	346.80	(95.73)	535.20	(154.43)	3.279	18	0.004
Exercise 2	77.60	(55.12)	75.10	(53.58)	-0.103	18	0.919
Exercise 3	281.30	(203.86)	177.10	(78.37)	-1.509	18	0.149
Exercise 4	95.10	(48.94)	59.10	(37.04)	-1.855	18	0.080
Exercise 5	243.10	(140.20)	324.10	(117.64)	1.400	18	0.179
Exercise 6	219.60	(113.72)	296.30	(81.15)	1.736	18	0.100
Exercise 7	206.20	(96.24)	114.60	(68.30)	-2.455	18	0.025

The time differences between the two conditions for the phase of planning are presented in table 7-8. On logical grounds alone, we expected no differences between the two conditions in terms of total time spent on planning a solution. *This expectation was partly supported by the data,* because significant differences were found for two exercises. More specifically, students in the CS condition spent more time on planning during the solution of the first exercise, while PP students spent more time planning during the last exercise. As far as the first exercise is concerned, in the CS condition the teacher allowed the students to explore different types of graphs and discussed with them which of these was most appropriate to do. In sharp contrast, the making of various graphs was not encouraged in the PP condition, as that would inevitably take a lot of time. The time differences for the first exercise can, therefore, be attributed to the fact that the teacher allowed more exploratory behavior in the phase of planning and orientation.

Table 7-9: Average time (sec) spent on the phase of making the graph

	PP		CS		t-value	df	p
Exercise 1 *M (SD)*	383.80	(103.93)	118.50	(78.27)	-6.448	18	0.000
Exercise 2	295.70	(82.55)	109.80	(61.72)	-5.703	18	0.000
Exercise 3	871.90	(152.08)	170.60	(60.92)	-13.537	18	0.000
Exercise 4	343.90	(62.01)	124.90	(32.57)	-9.888	18	0.000
Exercise 5	398.70	(90.02)	170.70	(31.55)	-7.558	18	0.000
Exercise 6	545.10	(105.09)	168.80	(47.42)	-10.321	18	0.000
Exercise 7	399.90	(123.11)	194.20	(102.85)	-4.055	18	0.001

With respect to making the graph, the use of the computer spreadsheet was expected to lead to making the graph much faster. *This hypothesis was fully supported by the data*, as can be seen from table 7-9. All means differed significantly, and the magnitude of differences is worth considering. The smallest time difference was observed for exercise seven where it took the PP students twice as much time to make the graph. On the other hand, the largest difference was observed for exercise three, where it took more than five times as much time for the PP students to make the graph.

Table 7-10: Average time (sec) spent on the phase of discussion

	PP		CS		t-value	df	p
Exercise 1 *M (SD*	159.30	(88.89)	277.50	(113.04)	2.599	18	0.018
Exercise 2	200.00	(49.87)	1116.60	(459.82)	6.267	18	0.000
Exercise 3	1095.90	(264.93)	1079.60	(273.70)	-0.135	18	0.894
Exercise 4	242.90	(119.89)	446.20	(158.32)	3.237	18	0.005
Exercise 5	401.80	(186.30)	959.00	(204.71)	6.366	18	0.000
Exercise 6	301.00	(218.34)	658.70	(214.59)	3.695	18	0.002
Exercise 7	338.20	(225.90)	592.40	(229.81)	2.495	18	0.023

For the phase of discussion it was expected that the use of the computer spreadsheet would allow for more discussion and reflection. *This prediction was supported by the data*, as can be seen from table 7-10. With the exception of exercise three to which comparable amounts of time were devoted in both groups, all other mean differences were statistically significant in favor of the CS group.

7.7 Transformation effects

7.7.1 Comparing the genre

Firstly, we used WinConcord (a windows concordancer developed by Martinek & Siegrist, 1995) to examine the frequency of all words which were common in the two conditions. Subsequently, the terms which were unique to each condition were examined. The frequencies reported in the tables below are the total frequencies in each condition. These frequencies represent both teacher and student uses of the terms as well as implicit uses. For example, we took into account the use of pronouns when they were referring to those terms and nouns (in singular and plural) and verbs in all tenses (e.g. plot, plots, plotted) were included.

7.7.1.1 Terms common in both conditions

In this paragraph we will more closely examine a number of terms (which constitute the genre of solving correlational problems) which were common to both conditions. How the teacher and student talk about certain aspects of graph construction can be seen in table 7-11.

Table 7-11: Total number of word occurrences related to the construction of the graph

Graph construction	PP	CS	CS/PP
Label	42	27	0.64
Scale	247	23	0.09
Range	29	164	5.66
Axis	830	497	0.60
Dot	378	272	0.72
Plot	24	6	0.25
Draw	354	384	1.08

Because the occurrence of the terms: ‘label’ ‘scale’ ‘axis’ ‘dot’ ‘plot’ was higher in the PP condition compared to the CS condition, we may conclude that in the PP condition these activities occupied a central part in learning and solving the problem. These specific activities reflected the object of consciousness and deliberate action. For example, the fact that the term ‘scale’ was used ten times more in the PP condition compared to the CS one, suggests that the specific activity which is associated with the term (genre), i.e. putting in scale in the axes, occupied a very prominent place in the PP condition. This is because it is talked about and referred to much more in the one condition while it is remarkably absent in the other. This finding is due to the fact that the PP students have to use paper and pencil to make a graph, and the use of these tools requires the consideration of a number of issues like e.g. ‘scale’. In sharp contrast, in the CS condition, the term ‘scale’ is referred to a number of times, but the crucial point is that the students are using a different tool in constructing the graph and one of the consequences of using this tool is that conscious attention to issues like scale is uncalled for.

On the other hand, there is one term which occurs approximately five times more in the CS condition: ‘range’. This is the case because students in that condition use a tool which forces them explicitly or implicitly to take into account the range of the data. Data ranges are required cause this is how the student inputs the data into the chart wizard and eventually constructs the graph. In the PP condition, the activity of using ranges is mentioned and referred to as well, but it is only consulted when the students want to put in scale and want to know what the unit of the scale is going to be; in this case it is quite handy to make a decision after considering the range of the variable values. It should also be noted that the difference between the two uses of the term ‘range’ in the two conditions. In the PP condition it is the object of attention and it is something used in another procedure: the unit. In the CS condition, the term is used implicitly for the most part, when the student selects the variable data; it is, thus, the object of conscious attention again, *but* it has simple procedural and mechanical nature; it is an actual object as it is manipulated by the user in the context of the program.

Table 7-12: Total number of word occurrences related to the concept of variable

Variable	**PP**	**CS**	**CS/PP**
Variable	302	248	0.82
Independent variable	65	52	0.80
Dependent variable	11	15	1.36
Control variable	29	38	1.31
Influences/Affects	132	156	1.18

Table 7-12 shows the intensity of how teacher and students talk about the variable(s) of the problem. In this case the differences do not seem to be considerable.

Table 7-13: Total number of word occurrences related to different types of graphs

Types of graphs	**PP**	**CS**	**CS/PP**
Chart	5	192	38.40
Graph	901	1396	1.55
Scattergraph	66	187	2.83

Table 7-13 presents the intensity of how teacher and students talk about the different types of graphs. The term ‘chart’ occurs considerably more in the CS condition and this is because the students make many more graphs in the CS condition. The same holds for the terms ‘graph’ and ‘scattergraph’, even though the differences in frequency between the two conditions are not as impressive. The graph is referred to and talked about by teacher and student more in the CS condition. This suggests that in that condition a lot of conscious thinking and a great deal of the activity was devoted to it.

Table 7-14: Total number of word occurrences related to the concept of correlation

Correlation	**PP**	**CS**	**CS/PP**
Relationship	219	428	1.95
Correlation	327	230	0.70
Positive correlation	83	148	1.78
Negative correlation	111	172	1.55
Non correlation	108	126	1.17
Correlation Coefficient	132	617	4.67
Partial correlation coefficient	53	134	2.53

Table 7-14 shows how often the correlation in its various dimensions is referred to in the two groups. As can be seen from the table, with the exception of the term ‘correlation’, all criterion terms were more frequent in the CS condition. The most conspicuous difference was observed for the case of the term ‘correlation coefficient’ which occurred four times more in the CS condition. The fact that these terms are more talked about in the CS condition can be accounted for by the fact that students make many more graphs in that condition and for each they have to specify whether there is any correlation and what sort of correlation it is. On the other hand, the term ‘correlation’ was less frequent in the CS condition. This finding is rather difficult to account for, cause due to the fact that more graphs were made in the CS condition we would expect more frequent usage of the term as well.

Table 7-15: Total number of word occurrences related to the concept of trend

Pattern & trend	**PP**	**CS**	**CS/PP**
Spread	29	69	2.38
Pattern	36	93	2.58
Trendline	136	579	4.26

Table 7-15 depicts how frequently teacher and students refer to the existence of trends and patterns in the data. In all three cases the frequency of occurrence is much higher in the CS condition, and this can be explained by the fact that CS students made more graphs in the course of the tutorials.

Table 7-16: Total number of word occurrences related to the concept of data

Data	PP	CS	CS/PP
Data	36	580	16.11
Figures	11	6	0.55
Values	92	38	0.41

Table 7-16 shows how numerical values are referred to and their respective frequencies in the two conditions. It is very instructive to note that the term ‘data’ is much more frequent in the CS condition. This finding is in accordance with the computer metaphor: the computer processes *data*, and data is the raw material. In sharp contrast, in the PP condition the students have to pay more conscious attention to the actual data cause they both have to put in scale and plot. Therefore, the actual values are important and received a lot of attention in the course of making the graph. In the CS condition the actual values are unimportant and escape conscious attention *unless* the scale of the graphs has to be corrected.

7.7.1.2 Terms unique to each condition

In this paragraph we will thoroughly examine a number of terms which were unique to each condition.

Table 7-17: Total number of unique words in the PP condition

Tools	f	Graph construction	f
Ruler	51	Unit	59
Graph paper	61	Erase	24
Pencil/Pen	50		
Eraser/rubber	11		

Table 7-17 presents the total number of words unique to the PP condition. Table 7-17 indicates explicit and implicit references to the tools of the trade: the student uses graph paper, a ruler, a pencil and an eraser. These are the main tools that are available to the student in his attempt to solve the problem. These tools do not have specific names, names that are different from their common everyday ones. Contrast this, however, with the names/terms in the table below.

Table 7-18: Total number of unique words in the CS condition

Tools	f	Graph construction	f
Computer/Excel	232	Legend	83
Mouse	46	Title	70
Button	46	Choose/select	503
Icon	13	Insert/Enter	216
Cell	30	Click/Press	409
Tool/Toolbar	274	Delete	28
Function Wizard	16	Edit	45
Chart Wizard	390	Type	323
		Move	198
		"Finish"/"Next"/"Cancel"[1]	321
		Calculate	69

1. Microsoft Excel button labels

Concepts like ‘cell’, ‘spreadsheet’, ‘mouse’, ‘button’, ‘icon’, ‘tool’, ‘toolbar’, ‘chart wizard’ and ‘function wizard’ are terms which are associated with the specific tool the student is using to solve the problem: the computer spreadsheet. As a consequence, the teacher-student discourse is filled with explicit or implicit references to these terms.

The new properties of the tool afford new actions as well: ‘clicking’ would be inconceivable for the PP students; it would be impossible and yield no results. Thus, a new series of activities are introduced: ‘selecting’ the data, ‘entering’ ranges; ‘clicking’ on buttons and activating menu tools; drawing a trendline with a ruler is not used anymore.

7.7.2 Comparing the activity

Two students of average ability, one from each condition, were selected and their problem solving activity during the last exercise they solved was analyzed from an Activity theory viewpoint. The last exercise was chosen as an appropriate one because by that time the students have appropriated both the tools and the particular algorithms required for solving the problems. By the last exercise the students have been taught all there is to know concerning correlational problem solving – at least at the algorithm level – and about the use of the tool. The two excerpts are presented in table 7-19.

Table 7-19: Making a graph in the two conditions

PP condition, exercise 7, Beth	CS condition, exercise 7, Susan
S: ok…let me see….uh…**70**…(draws the y axis) (divides y axis into units) …yes? T: what are you going to **put here**?…you are amazing! (laughing while student is erasing the axis), you are truly amazing, you always say yes, this must **go on the x axis** and then immediately **draw the scale** of the **y axis**, it's stunning … S: (draws x axis) ok…**10, 20, 30, 40, 50, 60**…(divides x axis into units) T: you've done it again! S: why? T: cause this one **goes up to 70** (referring to the total number of drivers variable), and that one **goes up to 60** (referring to the percentage of killed drivers variable) S: ok…**10, 20, 30, 40, 60, 50, 70** (divides the x axis into units again) …**5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60** (draws the y axis and divides it into units) T: Elizabeth? S: yeah T: why does this **scale go up in 5s** and this one **in 10s?** (referring to the y axis scale) S: isn't that possible? T: well really, the **x axis** should be a little bit **longer** than the **y axis** S: ok…**go up in 5** T: but I was just wondering, why do you **go up in 5s on one scale** and **in 10s** on the other?…when they are both more or less the same **range** uh? S: I don't know, I've just **started by 10** so I just continued (draws the x axis again), ….**5, 10**, (divides it into units) (and puts in scale) …**percentage of total drivers** (labels the x axis) …**percentage of drivers killed** (labels the y axis) …uh…**50 - 51** (puts the dot)…**51 -58** (puts the dot) ……uh…**51 - 58** (puts the dot), **45 – 56** (puts the dot), **56 – 48** (puts the dot), **51 - 54** (puts the dot), **49 - 47** (puts the dot), **57 - 47** (puts the dot), **47 – 52** (puts the dot), **63 – 42** (puts the dot), **49 - 49** (puts the dot), **65 - 40** (puts the dot), **66 - 36** (puts the dot), **51 – 58** (puts the dot), **68 - 31** (puts the dot)	S: (student **selects** the data) (student goes through the first four chart wizard windows) T: ….do we need a **legend**? S: no we don't T: do we need a **title**? S: yes we do, no we don't! thank you (laughing) T: total number just total number otherwise you might be typing for the next three hours S: **total number** (student **types** it in as a label for the x axis) yes… T: and **percentage** S: ok (student **types** it in as a label for the y axis) …ok (student **clicks** 'finish' on the fifth chart wizard window) (the graph appears on the screen)

From a pragmatic point of view, it is worth commenting that what enters the conscious sphere of thought in the two conditions. In the PP condition, students worry about determining the unit, putting in scale, labeling the axes, and plotting the data. In sharp contrast, in the CS condition, the first thing to be concerned about is labeling the two axes. Note that PP students cannot get around the construction of the scales upon which the whole graph is dependent, while CS students do not even realize how the scale is constructed or that it is being constructed. If the utterances related to graph construction in the two transcripts are counted, it can be concluded that more interaction and thinking is involved in getting the scale right in the PP condition, especially in the case of an absent-minded student or a student who fails to concentrate throughout the process. Also note that even though plotting is mechanical it requires continuous attention, an undetected mistake can be very costly, in terms of time and effort it would take to repair.

At a local level in the discourse one main point is of primary significance: the fact that PP students had to pay active attention to the construction of the scale and, thus, to issues related to range, scale, axes, and data values. In sharp contrast, students in the CS condition lacked conscious awareness of these issues. For instance, as can be seen from the excerpt, a lot of data values are referred to in the PP condition, while they are conspicuously absent in the CS condition; moreover, terms like ‘x axis’, ‘y axis’, ‘scale’ and ‘range’ were mentioned in the PP condition, whereas they did not occur in the CS condition; finally, phrases like ‘go up in’ ‘goes up to’ ‘started by’ which are related to graph construction are occurring in the PP condition but not in the CS condition.

To analyze the problem solving activity in both conditions, three specific questions were asked: (a) what is done? (b) how is it done? (c) why is it done? In both cases students are involved in the *construction of a graph* under the close supervision and guidance of the teacher (i.e. what). In the PP condition the students use graph *paper and pencil* in solving the problem; in the CS condition students use a *computer spreadsheet* (i.e. how). A graph is, of course, not an end in itself. In the particular context, the graph serves the purpose of a problem solving tool and the whole activity is centered around the solution to the problem (i.e. why).

Thus, the same correlational problem is solved using two different types of tools. The presence of the tool entails that there exist new possibilities for solving the problem.

Activity level – (motive)

PP group	**CS group**
The motive of the *activity* in the PP group is to *solve the problem*.	The motive of the *activity* in the CS group is to *solve the problem*.

Action level – (goal)

PP group	**CS group**
In the PP group there are three main *actions* which need to be performed: ✓ Making a graph ✓ Plotting the information ✓ Deciding on the nature of the correlation	In the CS group there are two main *actions* which need to be performed: ✓ Making a graph ✓ Deciding on the nature of the correlation

Operation level – (conditions, method)

PP group	**CS group**
To make a graph:	
✓ **Determine** the independent variable	✓ **Determine** the independent variable
✓ **Draw** x axis	✓ **Select** the independent variable
✓ **Give** the x axis the name of the independent variable	✓ **Select** the dependent variable
✓ **Draw** y axis	✓ **Double click** on Chart Wizard
✓ **Give** the y axis the name of the dependent variable	✓ **Click** on the ‘next’ button on the first Chart Wizard window
✓ **Find** the lowest value of the independent variable	✓ **Double click** on scattergraph on the second Chart Wizard window
✓ **Find** the highest value of the independent variable	✓ **Double click** on a scattergraph type on the third Chart Wizard window
✓ **Begin** with the lowest score on the x axis and **end** with the highest	✓ **Click** on the ‘next’ button on the fourth Chart Wizard window
✓ **Determine** the unit for the x axis	✓ **Type** the x axis label in the appropriate field on the fifth Chart Wizard window
✓ **Divide** x axis into units	✓ **Type** the y axis label on in the appropriate field on the fifth Chart Wizard window
✓ **Find** the lowest value of the dependent variable	✓ **Click** on the ‘finish’ button on the fifth Chart Wizard window
✓ **Find** the highest value of the dependent variable	
✓ **Begin** with the lowest score on the y axis and **end** with the highest	
✓ **Determine** the unit for the y axis	
✓ **Divide** y axis into units	
To plot the data:	
✓ **Plot** the first data case	(plotting is automatically carried out by the spreadsheet)
✓ **Repeat** for the rest of the cases	
To determine the nature of the relationship:	
✓ **Draw** a trendline	✓ **Click** on the drawing tool bar
✓ **Decide** the kind of correlation	✓ **Select** straight line
	✓ **Draw** a trendline on the graph
	✓ **Decide** on the nature of the correlation

As can be seen from this comparison, there are no differences between the two conditions as far as the goal of the activity is concerned. After all, students in both conditions were aiming at solving the problems. Differences, however, arise at the level of actions, where one of the actions, i.e. plotting, is not a conscious and deliberate goal anymore in the CS condition. More importantly, however, a large number of significant differences emerge at the level of operations, i.e. specific steps to be taken to materialize the goals.

The specific verbs indicating the nature of the operations are stressed. Even though most of the operations in the PP condition are of an algorithmic nature, all operations require students’ *conscious attention*, and *thinking*. For instance, a number of decisions have to be made by PP students in order to make a graph; these decisions are not automatic and the students need to consult the actual data values, and make smart decisions and shortcuts regarding the operations. In sharp contrast, CS students pay conscious attention only to aspects like selecting the data and clicking. Note that a few decisions need to be made in that condition and most of what the student does requires his attention only; no decision making or thinking is required! Thus, conscious decision making is transformed into some sort of mechanical activity, where the computer takes over. As Leont'ev put it "even when an operation is carried out by a machine, it still realizes the actions of the agent. When one uses a calculator to solve a problem, the action is not broken by this extra-cerebral link: as with other links, it finds its realization in it" (1981, p. 64). Thus, the action (in the form of specific operations) is materialized by the computer and, thus, there is no specific role for that for the human agent.

7.7.3 Frequency analysis

7.7.3.1 Procedure

As a first step, *the frequencies of all codes over exercises and subjects were aggregated* using GSEQ. This manipulation meant that each subject had only one frequency per code instead of the initial seven (or more depending on how many exercises were solved). Comparing all codes available in the two conditions was not possible for a certain number of codes which were unique to each condition. Comparing frequencies was, therefore, only possible for the common codes in the two treatments. At this stage, all codes unique to either condition were removed from further analyses.

The first step in comparing the frequencies involved an examination of the comparability of the PP and CS conditions. To ascertain whether the conditions were comparable, the total number of events was initially compared. There were 13553 events for the paper and pencil condition, whereas the corresponding number for the computer spreadsheet condition was 14203. This difference was not statistically significant: PP mean = 1353.3; S.D. = 185.43; CS mean = 1420.3, S.D. = 246.265; Mann-Whitney U= 44; p=.684. Having established the comparability of the two groups we proceeded further with the comparison of the frequencies. The mean frequencies per code are given in tables 7-20 and 7-21 respectively.

Table 7-20: Mean frequencies of teacher codes for the two conditions

		TFA	TSG	TSST	TCE	TCS	TSS	TRPL	TREV	TRIN	TRFI	TRCI	TRE	TIE	TAS	TR	TM	TPNI	TPE	TREF	TESK	TRAI	TIN	TEL	TCSF	TCNF	TSUS	TCOM
PP	**m**	11.4	31.1	18.4	17.8	84.1	13.5	28.0	44.0	14.7	27.3	71.6	33.8	20.2	2.9	18.2	17.4	22.2	65.5	12.9	11.1	31.8	11.6	113.2	11.6	25.3	3.8	29.6
	sd	4.0	6.0	8.6	5.4	19.6	7.1	6.7	2.5	4.5	12.1	18.7	9.1	6.5	2.7	3.2	8.7	5.5	29.1	5.1	4.3	14.8	4.9	23.4	4.6	14.2	1.6	12.9
CS	**m**	13.7	49.4	12.4	11.1	194.9	18.0	31.2	58.0	9.2	40.9	113.8	25.7	32.1	0.9	6.6	22.4	21.2	52.6	14.2	5.0	11.7	17.5	77.6	22.5	7.8	2.4	21.7
	sd	6.3	9.9	4.7	8.9	34.4	5.7	8.0	2.6	3.4	13.1	21.2	11.9	9.8	1.6	2.8	6.5	7.3	21.3	5.6	2.3	5.9	6.1	23.7	8.7	3.9	3.1	11.5
	M-W[a]	42	2	29	18.5	0	29.5	40	34.5	14.5	22	6	30	18	24	0.5	31	47.5	39	40.5	11	8.5	21.5	10.5	10.5	5.5	23.5	29.5
	p	.565	.000	.117	.015	.000	.127	.466	.252	.006	.033	.000	.135	.014	.042	.000	.159	.867	.423	.490	.002	.001	.030	.002	.001	.000	.043	.127

a. Mann-Whitney U test

Table 7-21: Mean frequencies of student codes for the two conditions

		SSG	SPE	SID	SRE	SRAI	SRCI	SRFI	SAGE	SAEU	SR	SP	SDIV	SDVP	SDCV	SLA	SDT	SRG	SSC	SEL	SPFI	SPCI	SCNF	SCOM
PP	**m**	25	38.6	29.4	6.8	25.8	5	3.8	16.4	12.4	3.8	9	7.5	6.2	1.7	2.8	6	31.2	16.2	132	38.3	62.6	96.2	23.3
	sd	7.3	8.8	7.6	3.6	13.5	1.9	3.8	8.3	7.6	5.1	2.2	2.2	2.3	1.7	2.6	1.9	5.7	7.1	28.9	15.5	7.9	29.2	11.8
CS	**m**	47.8	24.50	19.2	4.1	10.4	1.2	3.3	10.6	11.8	10.6	11.1	12.4	8	1.9	23.1	11.5	17	27.9	68.3	46.1	91.8	112	10.9
	sd	13.4	10.5	10.6	2.1	4.8	0.8	2.3	3.9	6.4	3.9	2.0	3.5	5.8	1.3	3.5	4.3	3.1	5.5	42.6	15.5	18.2	31.2	8.4
	M-W[a]	5.5	17	16	25	7.5	2.5	49	32.5	48	16.5	21.5	10	47	42.5	0	8	0.5	9.5	9	35	7.5	35.5	23
	p	.000	.011	.008	.057	.001	.000	.957	.194	.897	.009	.027	.001	.840	.572	.000	.001	.000	.001	.001	.271	.001	.287	.041

a. Mann-Whitney U test

7.7.3.2 Findings

Overall, the frequency differences suggest that certain teacher and student behaviors were differentiated as a result of the introduction of the computer spreadsheet.

As far as *teacher behavior* is concerned, the differences between the two conditions can be grouped in three categories. The *first category* involves teacher feedback in the two conditions: error correction, error indication, error warning, step confirmation and supportive statements were significantly different between the two conditions. The observed pattern seems to suggest that the feedback the teacher is providing to the students is different in the two conditions. More specifically, *the teacher corrected significantly more errors in the PP condition, whereas she indicated more errors in the CS condition*. This finding indicates the different significance attributed to error making in the two conditions. An error in making the graph in the CS condition does not require much time or effort to correct and, thus, has no important implications. On the other hand, an unnoticed error in the PP condition during graph construction can have devastating effects in terms of the time required to correct it and the conscious effort which is called for for its correction. Error indication is an indirect form of error feedback, whereby the teacher is simply informing the student that an error has occurred or is likely to occur. On the other hand, error correction is a direct form of error feedback. The implication for student learning is different with each form of error feedback: in the first case the student is expected to figure out what is or has gone wrong while in the second the teacher explicitly informs the student about what is wrong. Some errors may be left unnoticed or addressing them can be postponed for some time, depending on how important the teacher perceives them to be. These errors are mostly conceptual ones, stemming from incorrect student ideas and concepts about some problem solving part. On the basis of observations made during the tutorials, it can be argued that the teacher was very quick in pointing out to the student that an error has been committed during graph construction, or whenever the student would engage in an activity which would require sometime to complete and upon which further steps were dependent. Whenever the teacher did not flag an error for instructional reasons, the students seemed to be devastated and expressed their disappointment (e.g. ‘you should have told me’ ‘this is mean’ etc).

This line of reasoning seems to be supported by some further differences between the two conditions. *The teacher alerted the students to the fact that a mistake was about to be made, evaluated their knowledge, requested additional information, and provided them with supportive statements significantly more in the PP condition*. This behavior 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 in the CS condition we have significantly more teacher confirmatory feedback 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 *second category* is task-related and involves factual and conceptual information as well as interpretation. *The teacher requested conceptual and factual information, interpreted student utterances and checked student's understanding significantly more in the CS condition*. These differences are mostly due to the fact that many more graphs were made in the CS condition and, therefore, many more conceptual and factual information questions could be asked by the teacher. From a learning point of view, the fact that a lot of conceptual questions are raised by the teacher is very encouraging. It means that there is more time spent on task and that the student is involved with many task elements/dimensions. It is expected that the student would have to think and make use of his subject matter knowledge in order to answer all these questions. Direct involvement with the subject matter is also greatly facilitated.

The fact that more factual information questions were asked in the CS condition is probably related to the interface itself. There were a lot of features (items/objects) on the interface and, thus, to establish common ground and a common referential perspective a lot of these questions were asked at least in the initial stages of exploration. Additionally, the visual element was more dominant in the CS condition and, thus, there was a bulk of visual information available to the teacher-student dyad. It could well be that these questions were raised by the teacher with the objective of focusing student's attention to some particular feature object/item of the interface and not on others.

The *third category* involves teacher goal setting and the management of the environment. The fact that the mistakes in the computer environment did not cost much time to repair was expected to lead to a more free and exploratory learning. The teacher was expected to interfere less on the direct level (goal setting) and be more involved on the indirect level (planning questions). This expectation, however, was not confirmed by the data, as *the teacher set significantly more goals in the CS condition whereas there was no significant difference was found concerning planning questions*. This finding suggests that the teacher dominated the CS condition much more than the PP condition, although it should be borne in mind that, because of the tutorial format of the instruction, the teacher was the person with all knowledge and power to make decisions.

As far as *student behavior* is concerned, the differences can be grouped in two main categories: general problem solving behavior and task specific problem solving behavior. With respect to the *first category,* 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 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. The students requested significantly more conceptual information in the PP condition and this finding indicates that the students were more actively involved in their own self-regulation. Moreover, the students asked significantly more additional information in the PP condition, a result suggesting that the students were more actively monitoring their own understanding and when in doubt or in need for information, they requested this sort of information from the teacher.

On the other hand *the fact that the students provided significantly more explanations in the PP condition, suggests that the students reasoned more in that condition* (in the sense that they gave more reasons/explanations). This finding is especially important, in the light of the fact that the difference in teacher explanations was not significantly different.

Finally, *students indicated difficulty significantly more in the PP condition*. This finding is in line with our previous conclusions about the error treatments in the two conditions. The student indicates lack of understanding more often because if he/she does not, errors might occur and they can be very devastating and effort consuming in the long run.

In regard to the *second category,* i.e. task specific problem solving behavior, the mean frequency for student behavior in the CS condition was significantly higher than the corresponding frequency for the PP condition in most of the cases. This was due to the fact that more graphs were made and, thus, it is only natural that the mean frequencies are higher. On the other hand, reading the graph was found to be occurring significantly more in the PP condition compared to the CS condition. This finding is difficult to account for, provided that more graphs were made in the CS condition and, thus, many more possibilities for reading them were available.

To conclude, the fact that the student provided more conceptual information (i.e. answered more task related questions) in the CS condition is to be expected, given that the teacher requested many more conceptual information questions for the CS condition.

In addition to looking at how the two conditions differed in terms of frequencies of teacher and student behavior, it is also worth noting how much alike they were. For example, summarization of steps did not differ; the teacher provided the same support (i.e. the number of sentences started in the two conditions did not significantly differ); explanations and new information provided by the teacher were not significantly different, and the same holds for teacher explanations as well. Therefore, on the basis of mean frequencies of occurrence for each code, teacher instruction did not seem to be differentiated between the two conditions: providing new information, providing explanation, referring to information previously presented, summarizing a step, focusing attention, starting a sentence, asking for explanation, asking for evaluation, and asking for goal setting.

7.7.4 Sequential analysis

7.7.4.1 Procedure

The second step involved the examination of the most frequent transitions of events in the two conditions. This served the purpose of identifying different patterns in the two conditions worthy of further investigation. Given that 62 codes were used for the two conditions– some of which were unique for each condition for reasons explained above – a 62x62 table would be less appealing from a theoretical point of view. More specifically, a 62x62 table would make use of all teacher and student codes as given and target behaviors. However, the probability that a teacher code is followed by another teacher code is very low; this probability is even lower for student codes. Therefore, any teacher code was much more likely to be followed by a student code and vice versa. As already demonstrated in the literature, learning discourse is mainly characterized by three steps: teacher initiation-student response-teacher evaluation. This pattern of course was also typical of our own data, given that the teacher had absolute control over the interaction. *It is for these reasons that we chose to use the student behavior as given and the teacher behavior as target*. This meant that student behavior constitutes the focus of attention for further analyses. Using student events as our focal point, we examined what sort of teacher events *both preceded and followed* each student event. This approach allows us great flexibility in examining what sort of teacher behavior is likely before every student behavior as well as in determining how likely a certain teacher reaction is to a given student behavior. We selected 20 teacher and 20 student codes, the ones which presented the greatest theoretical interest. These 20 student and 20 teacher codes can be used to define one 20x20 table, where the rows indicate given behavior and columns indicate target behavior. It must be noted that *for this type of analysis we pooled the data over all subjects and exercises*. We followed such an approach because we were interested in the transitions which are more common in general and not in which specific subjects are characterized by which transitions.

Firstly, joint frequencies for both conditions (PP & CS) were calculated for lags –1 and +1. These joint frequencies are presented in tables 7-22, 7-23, 7-24, and 7-25. It must be noted that in all cases we used the residual code (&) because we were interested in the total number of events. Secondly, and due to the fact that absolute frequencies are difficult to interpret directly, the conditional probabilities for each cell in all four 20x20 tables were computed. Subsequently, the adjusted residuals (z values) for each cell in the four 20x20 tables were computed as well, in an attempt to determine which transitions within each table exceeded chance level.

Table 7-22: Joint frequencies of events in the PP condition, Lag –1

Lag -1	TFA	TSG	TSST	TCE	TCS	TRPL	TREV	TRIN	TRFI	TRCI	TRE	TIE	TAS	TPNI	TPE	TREF	TESK	TRAI	TIN	TEL	&	Totals
SR	1	6	0	2	2	0	0	1	0	1	0	0	1	1	2	0	0	0	0	4	14	35
SP	0	3	2	1	2	1	0	0	0	19	1	1	0	1	6	0	0	0	1	6	47	91
SDIV	0	1	0	2	8	6	0	1	0	23	3	1	1	1	2	2	0	0	0	8	19	78
SDVP	0	2	0	1	7	9	0	1	0	18	3	0	0	0	1	0	0	1	0	5	15	63
SLA	0	1	1	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	20	30
SDT	0	22	0	0	6	7	0	0	0	0	0	0	0	0	2	0	0	1	0	8	19	65
SRG	2	5	2	2	13	2	3	32	11	145	7	1	2	1	13	1	3	9	0	27	42	323
SSC	0	4	2	8	5	4	0	46	2	26	1	2	1	1	2	1	0	4	0	7	53	169
SSG	4	19	2	3	14	80	0	0	1	12	6	6	0	1	13	0	2	6	0	33	52	254
SPE	1	6	2	4	3	10	1	0	2	6	152	5	1	1	24	4	6	53	6	46	62	395
SID	2	6	3	4	10	22	2	13	12	27	33	9	1	2	10	2	15	20	5	36	68	302
SRE	0	4	1	4	3	4	1	1	0	2	4	5	0	5	5	1	1	2	0	7	19	69
SRAI	1	13	0	9	6	11	2	9	15	31	26	15	1	23	25	7	10	4	1	19	40	268
SRCI	1	2	2	3	3	1	0	0	1	1	0	0	1	4	6	0	0	1	0	5	19	50
SRFI	0	3	0	0	1	1	0	0	1	0	1	2	0	0	4	0	0	0	0	6	22	41
SAGE	0	19	2	0	12	10	0	0	2	5	2	2	2	2	9	2	1	1	0	22	77	170
SAEU	1	1	2	1	6	1	1	0	5	12	5	2	0	6	12	3	4	2	1	16	48	129
SEL	20	36	26	51	110	25	6	13	21	44	30	44	10	48	101	29	14	53	22	384	260	1347
SPFI	6	10	3	8	17	5	5	2	171	21	4	5	0	2	24	1	1	14	3	28	62	392
SPCI	3	7	3	7	22	27	12	17	4	240	16	11	0	17	46	8	29	35	4	48	94	650
&	76	153	131	73	610	65	11	16	39	104	45	99	8	107	366	71	28	116	74	417	6972	9581
Totals	118	323	184	184	866	291	44	152	287	737	339	210	29	223	673	132	114	322	117	1133	8024	14502

Table 7-23: Joint frequencies of events in the CS condition; Lag –1

Lag -1	**TFA**	**TSG**	**TSST**	**TCE**	**TCS**	**TRPL**	**TREV**	**TRIN**	**TRFI**	**TRCI**	**TRE**	**TIE**	**TAS**	**TPNI**	**TPE**	**TREF**	**TESK**	**TRAI**	**TIN**	**TEL**	**&**	**Totals**
SR	1	28	0	0	11	0	0	0	2	2	0	0	0	0	2	0	0	0	0	8	32	86
SP	0	1	0	0	1	0	0	0	2	58	1	3	0	0	13	0	0	0	5	1	28	113
SDIV	1	1	0	0	16	6	0	0	0	55	1	1	0	1	2	1	1	1	1	5	35	128
SDVP	0	1	1	1	7	0	0	0	0	39	0	1	0	0	0	0	0	0	0	1	27	78
SLA	0	3	0	3	58	0	0	0	0	12	0	2	0	0	1	0	0	0	0	21	140	240
SDT	3	31	0	2	20	0	0	0	1	2	1	3	1	0	0	1	0	0	0	5	50	120
SRG	1	0	0	0	6	0	0	3	0	122	2	2	0	0	5	2	0	3	0	3	31	180
SSC	5	4	0	9	8	0	0	2	1	115	1	16	0	1	4	2	0	1	0	9	105	283
SSG	2	136	1	2	29	216	0	1	1	7	5	8	0	0	9	5	0	0	0	17	50	489
SPE	2	2	1	1	12	0	1	0	0	0	151	8	0	0	3	3	4	24	3	6	26	247
SID	2	5	0	1	8	14	5	3	19	39	22	7	1	0	9	6	4	3	2	12	30	192
SRE	0	1	0	1	0	1	0	0	1	5	1	1	0	0	6	0	0	1	0	2	21	41
SRAI	1	3	0	1	4	10	1	0	15	29	8	2	0	2	2	3	3	2	1	6	12	105
SRCI	0	1	0	0	2	0	0	0	0	0	0	1	0	2	0	0	0	0	0	1	5	12
SRFI	0	1	0	1	4	2	0	0	2	1	0	1	0	0	5	0	0	0	0	5	11	33
SAGE	0	15	1	1	18	12	0	0	1	6	0	2	0	4	4	0	1	1	0	12	37	115
SAEU	3	4	1	1	17	0	0	2	4	13	1	3	0	14	10	4	1	2	1	10	27	118
SEL	11	12	2	4	68	12	10	1	25	72	25	36	1	7	30	12	9	31	17	195	115	695
SPFI	9	2	0	1	15	1	0	3	302	6	3	3	0	0	10	3	0	16	4	21	68	467
SPCI	10	8	5	5	39	3	33	73	7	486	8	17	0	6	16	10	21	14	8	31	140	940
&	87	246	107	77	1627	41	9	7	31	95	28	208	6	173	394	95	6	20	133	414	8057	11861
Totals	138	505	119	111	1970	318	59	95	414	1164	258	325	9	210	525	147	50	119	175	785	9047	16543

Table 7-24: Joint frequencies of events in the PP condition, lag 1

Lag 1	TFA	TSG	TSST	TCE	TCS	TRPL	TREV	TRIN	TRFI	TRCI	TRE	TIE	TAS	TPNI	TPE	TREF	TESK	TRAI	TIN	TEL	&	Totals
SR	0	0	0	2	0	1	0	1	0	2	1	0	0	0	1	0	0	0	0	2	29	39
SP	0	3	5	0	38	1	0	0	0	2	5	1	1	0	2	0	0	8	4	7	14	91
SDIV	1	0	0	1	23	0	0	0	0	3	15	2	0	1	0	0	0	3	3	8	18	78
SDVP	0	0	0	2	16	0	0	0	1	5	17	0	0	0	2	0	0	0	3	3	14	63
SLA	0	1	0	1	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0	1	23	30
SDT	0	3	0	0	14	3	0	0	1	11	7	1	0	3	0	2	2	0	1	4	13	65
SRG	4	4	10	5	90	3	6	26	7	35	13	6	0	3	5	5	8	26	3	29	35	323
SSC	1	3	2	9	66	2	2	7	4	10	2	11	1	0	3	0	1	11	8	10	16	169
SSG	1	8	3	3	87	14	0	0	2	10	12	16	1	0	4	0	1	27	1	15	49	254
SPE	6	7	8	14	55	14	4	1	11	33	29	23	1	1	19	3	2	42	11	48	63	395
SID	14	17	4	1	2	7	0	1	15	22	17	3	2	16	29	6	3	23	3	72	45	302
SRE	0	1	0	2	0	2	0	0	1	2	4	2	0	4	25	1	0	1	0	16	8	69
SRAI	2	5	3	4	10	1	2	2	2	11	8	5	0	8	39	9	2	4	0	60	91	268
SRCI	1	2	0	0	1	1	0	0	0	5	0	1	1	4	15	0	1	1	0	14	3	50
SRFI	1	0	0	2	6	0	0	0	1	0	1	0	0	0	16	1	0	2	0	3	8	41
SAGE	0	10	0	2	63	8	0	1	3	8	9	14	0	1	11	0	0	8	1	18	13	170
SAEU	0	2	0	11	36	2	0	2	2	6	2	12	0	1	5	1	1	4	0	14	28	129
SEL	16	52	20	36	54	52	11	33	30	93	43	30	4	25	87	17	13	65	15	390	255	1341
SPFI	2	15	3	18	75	7	1	1	44	17	14	15	0	3	22	4	1	25	9	45	71	392
SPCI	5	10	13	45	160	12	2	12	8	56	38	30	0	16	24	6	10	51	18	61	72	649
&	64	180	115	26	78	161	16	65	154	404	102	38	18	141	366	77	69	21	37	336	7116	9584
Totals	118	323	186	184	875	291	44	152	287	737	339	210	29	227	675	132	114	322	117	1156	7984	14502

Table 7-25: Joint frequencies of events in the CS conditions, lag 1

lag 1	TFA	TSG	TSST	TCE	TCS	TRPL	TREV	TRIN	TRFI	TRCI	TRE	TIE	TAS	TPNI	TPE	TREF	TESK	TRAI	TIN	TEL	&	Totals
SR	0	2	0	0	5	11	0	0	6	23	3	0	0	0	3	1	0	0	0	6	49	109
SP	0	3	0	0	41	3	0	0	1	3	9	4	0	0	1	1	0	4	25	9	9	113
SDIV	0	0	0	2	57	0	0	0	3	5	16	3	0	0	2	0	0	4	4	3	29	128
SDVP	0	0	0	1	33	0	0	0	0	2	1	1	0	0	0	0	0	0	3	0	37	78
SLA	0	1	0	0	26	0	0	0	0	29	0	0	0	0	1	0	2	1	0	7	173	240
SDT	1	3	1	0	57	0	0	0	2	6	4	9	1	0	1	0	0	1	0	3	31	120
SRG	0	9	0	1	89	0	0	3	2	20	5	8	0	0	1	1	0	6	2	5	28	180
SSC	5	2	0	22	136	0	3	1	1	26	4	44	0	0	3	0	0	3	4	12	17	283
SSG	4	8	0	8	171	29	1	2	11	22	25	40	2	1	7	1	1	11	4	21	120	489
SPE	3	7	1	7	72	5	0	0	4	17	25	21	0	3	5	3	2	5	20	22	25	247
SID	14	12	2	0	0	4	0	0	6	9	8	2	1	6	28	13	0	7	9	32	39	192
SRE	1	0	0	0	0	0	0	0	0	0	0	1	0	0	28	0	0	0	0	6	5	41
SRAI	1	2	1	0	7	2	0	0	4	5	0	1	0	0	35	6	0	1	0	31	9	105
SRCI	0	0	0	0	0	0	0	0	0	1	0	0	0	0	2	1	0	1	1	5	1	12
SRFI	0	0	0	0	0	0	0	0	0	2	0	0	0	1	4	0	0	2	0	18	6	33
SAGE	0	5	0	0	66	5	0	0	0	4	2	24	0	0	0	0	0	1	1	3	4	115
SAEU	1	2	1	5	64	0	0	0	2	6	0	18	0	0	5	1	0	2	1	6	4	118
SEL	9	20	8	12	77	20	4	4	30	75	34	29	0	10	35	12	5	22	19	138	132	695
SPFI	7	3	2	10	128	4	0	13	51	23	17	16	0	8	8	5	1	17	15	40	99	467
SPCI	3	33	5	28	399	11	4	9	15	95	40	46	0	8	19	2	7	22	33	64	97	940
&	89	365	104	15	567	224	47	63	276	791	65	58	5	175	341	100	32	9	34	350	8128	11838
Totals	138	477	125	111	1995	318	59	95	414	1164	258	325	9	212	529	147	50	119	175	781	9042	16543

As can be seen from these four tables, there are considerable differences as far as joint frequencies are concerned. As already discussed in chapter 4, to determine which of these joint frequencies exceed chance two steps are required: (a) the calculation of Pearson's chi-square test and (b) the calculation of z-values for each cell. Looking at conditional probabilities instead of joint frequencies is more meaningful and we, therefore, focused on conditional probabilities. The conditional probabilities for each cell in all four tables were computed. The Pearson Chi-square was statistically significant in all four cases, and this warrants further consideration of which joint frequencies exceeded chance level (*PP condition, lag -1*: Chi-square=16427,04, df=400, p = .000000; *CS condition, lag -1*: Chi square = 30817,22, df = 400, p = .000000. *PP condition, lag +1:* Chi-square = 9314.40, df=400, p= .000000; *CS condition, lag +1*: Chi-square =10280.46, df=400, p=.000000). We then proceeded to the calculation of adjusted residuals for each cell (z-values). However, the direct interpretation of adjusted residuals cannot be straightforward, as discussed in chapter 4. Two conditions have to be met: (a) sufficient number of tallies, and (b) distributional normality.

Firstly, for such a 20x20 table, we generally need five times more events than cells. This means that, given that we have 400 individual cells, a fair number of events (tallies) required is about 6000. As can be seen from the tables and the total number of events, this requirement is definitely met. A bit of caution, however, is necessary at this point as far as the number of tallies is concerned. If for every 20x20 table we exclude the residual codes and sum the tallies for the cells of the 40 teacher and student codes, then it becomes obvious that the total number of events is considerably lower. More specifically, for lag –1, the total number of events tallied is 3869 for the PP condition and 3692 for the CS condition; for lag +1, the number of tallies was 4050 for the PP condition and 3791 for the CS condition respectively. It can be easily seen that these figures are not very good approximations, given that about 6000 events were required.

Secondly, we used GSEQ for the calculation of adjusted residuals for each cell in all four tables, and the program also affords the possibility of examining whether the adjusted residuals are normally distributed. In the overwhelming majority of the cases, the adjusted residuals were *not* normally distributed, which in turn means that the joint frequencies were not normally distributed. More specifically, for lag –1 only about 35% of the cells in the PP condition and 33% of the cells in the CS condition had expected frequencies higher than five; the corresponding figures for lag +1 were 36% in the PP condition and 33% in the CS condition. On the basis of this consideration, it can be argued that the value of the chi-square as well as the values of the adjusted residuals calculated should be interpreted with extreme caution, because the normality requirement is not met. To conclude, granted that the number of tallies in all four tables was insufficient and the normality requirement was not met, *the significance of the corresponding adjusted residual values only has face value or, better, simple informative one*.

Bearing in mind the two problems associated with the statistical significance of the adjusted residuals, *our next step involved the examination of the conditional probabilities (transitions) which exceeded chance level*. At this stage a grave problem surfaced: sometimes the value of the adjusted residual was higher than 1.96 while the associated conditional probability was extremely low, e.g. 0.01. A conditional probability of 0.01, even though statistically significant, presents little theoretical interest: it simply conveys that, given a particular event x, an event y is bound to follow 1% of the time, the transition being greater than chance. Because of the fact that our approach was mostly data-driven and, thus, exploratory in nature, the significant values of adjusted residuals had only informative value and not absolute one. We perceived of them as indicators of transitions which stand more chances of being quite unlikely.

To solve the problem of having to look at conditional probabilities of 0.01, we needed to consider the size of the conditional probabilities in conjunction with the size of the adjusted residual. From a theoretical viewpoint, a conditional probability worth looking at is at least 0.10, or simply put, given two events A and B, any transition AB occurring 10% of the time. For confirmatory studies it may be more interesting to look at conditional probabilities of .25 (i.e. 1 out of four times that event A occurs event B follows) or even .33 (i.e. 1 out of 3 times that event A occurs, event B follows). In our case, though, we kept the conditional probability level at 0.10 and this, of course, was an arbitrary decision. It simply served the purpose of a tool for data screening. At the same time, we considered the size of the adjusted residuals. After a careful examination, it turned out that the lower the value of the residual, the lower the conditional probability tended to be. For this reason, we decided to take into consideration only the adjusted residuals with values greater than 5.00. To summarize the procedure, *we examined conditional probabilities if and only if the value of the conditional probability was greater than .10 and the value of the corresponding adjusted residual was greater than 5.0*. All conditional probabilities meeting these two requirements are presented in table 7-26.

As can be seen in table 7-26, for the PP condition and for lag –1, 20 out of the 400 transitions – or 5% of all transitions – had a probability of occurring greater than .10 and this probability of occurrence was greater than chance (i.e. the probability of occurrence was statistically significant). For the same lag in the CS condition, 24 out of all 400 possible transitions – or 6% – had a probability of occurrence greater than .10 and the probability of this occurrence was greater than chance level. For lag +1 in the PP condition, 26 out of all 400 possible transitions – or 6,5% – had a probability of occurring greater than .10 and this probability was greater than chance. The figure for the CS condition for lag +1 was 7% (28 out of all 400 possible transitions). Two further pieces of information presented in table 7-26 are worth commenting on. On the one hand it can be seen that some conditional probabilities (transitions) are unique to each condition. On the other hand, it can be seen that even quite a number of transitions is common to both conditions, even though the magnitude of the respective conditional probabilities is not the same. Some similarities in transitions were to be expected because the same teacher was teaching the same task, using the same materials to students of the same age.

The final problem we are presented with at this point is: *are these transitions – which are statistically significant within each condition – different in the two conditions?* It must be noted that there are 46 transitions for lags –1 and +1 for (within) the PP condition and 52 transitions for (within) the CS condition. To confirm or reject our hypothesis, we need to consider whether these transitions are different *between* the two conditions. To deal with this problem we followed a procedure developed by Bakeman et al., (1996) which was thoroughly introduced in chapter 4.

Firstly, *we switched from a pooled data level* (which was required for producing the tables above) *to an individual data level, using individual subjects as the unit of analysis*. Secondly, Yule's Q coefficient for every 2x2 table for all statistically significant transitions for every subject in the two conditions was calculated as the most appropriate statistic (Bakeman, personal communication). Finally, permutation tests (i.e. randomization tests) instead of parametric tests were used, using the procedure described in chapter 4. Provided that the total number of permutations for two independent groups is N!/r!(N-r)!, in our case where 20 subjects are divided into two groups of 10, the total number of permutations is 184756, which is certainly not large and, thus, we used exact probabilities instead of estimations. When all 184756 permutations were performed, the exact probability was computed, by taking the *proportion of the t statistics greater than or equal to the magnitude of the observed t value.* A permutation program PGD specifically developed for these purposes was used for carrying out these permutation tests, as discussed in chapter 4. The results of this analyses are presented in table 7-27.

Table 7-26: Transitions exceeding probabilities of .10 and having adjusted residual values higher than 5.00

	TSG	TRPL	TRFI	TRCI	TRE	TEL	TRAI	TRIN	TPNI	TPE	TCS		TCS	TRFI	TRE	TPE	TEL	TRAI	TRPL	TRCI	TIE
PP																					
	.17											**SR**									
				.21								**SP**	.41								
				.29								**SDIV**	.29		.19						
		.14		.29								**SDVP**	.25		.27						
	.34	.11										**SDT**	.21								
				.45				.10				**SRG**	.27								
				.15				.27				**SSC**	.39								
		.32										**SSG**	.34					.10			
					.38		.13					**SPE**	.13					.10			
					.11							**SID**					.23				
												SRE				.36					
					.10							**SRAI**				.14	.22				
												SRCI				.30	.28				
												SRFI				.39					
	.11											**SAGE**	.37								
												SAEU	.27								
						.29						**SEL**					.29				
			.44									**SPFI**	.19	.11			.11				
				.37								**SPCI**	.24								
CS																					
	.33											**SR**							.10	.21	
				.51						.12		**SP**	.36								
				.43								**SDIV**	.44		.12						
				.50								**SDVP**	.42								
	.26											**SDT**	.47								
				.68								**SRG**	.49								
				.41								**SSC**	.48								.15
	.28	.44										**SSG**	.35								
					.61							**SPE**	.29		.10						
			.10	.20	.11							**SID**				.14	.16				
												SRE				.68					
		.10	.14	.28								**SRAI**				.33	.29				
												SRCI					.41				
												SRFI					.54				
	.13	.10										**SAGE**	.57								.20
									.12			**SAEU**	.54								.15
						.28						**SEL**					.19				
			.65									**SPFI**	.27	.10							
				.52								**SPCI**	.42								

Table 7-27: Transition means in between the two conditions

Lag -1	Condition			Lag +1	Condition		
	PP	CS			PP	CS	
Transition	Mean	Mean	p[a]	Transition	Mean	Mean	p[a]
TSG-SR	-0.45	0.82	0.00134	SP-TCS	0.82	0.58	0.00238
TSG-SDT	0.34	0.75	0.20745	SDIV-TCS	0.54	0.64	0.73085
TSG-SSG	0.41	0.84	0.00532	SDVP-TCS	0.27	0.48	0.56466
TSG-SAGE	0.51	0.37	0.71158	SDT-TCS	-0.09	0.70	0.02988
TRPL-SDVP	0.29	-1.00	0.00306	SRG-TCS	0.70	0.70	0.98631
TRPL-SDT	-0.26	-1.00	0.03196	SSC-TCS	0.80	0.75	0.29819
TRPL-SSG	0.93	0.98	0.00002	SSG-TCS	0.78	0.60	0.00766
TRPL-SRAI	-0.11	0.04	0.66168	SPE-TCS	0.39	0.44	0.72564
TRPL-SAGE	0.26	0.24	0.99599	SAGE-TCS	0.78	0.61	0.55896
TRFI-SID	0.11	0.29	0.55608	SAEU-TCS	0.33	0.78	0.01651
TRFI-SRAI	-0.06	0.26	0.37914	SPFI-TCS	0.33	0.43	0.65097
TRFI-SPFI	0.98	0.99	0.00109	SPCI-TCS	0.70	0.73	0.4112
TRCI-SP	0.35	0.83	0.03599	SPFI-TRFI	0.24	0.47	0.55566
TRCI-SDIV	0.59	0.70	0.69652	SDIV-TRE	0.47	0.45	0.86908
TRCI-SDVP	0.41	0.27	0.81193	SDVP-TRE	0.48	-0.83	0.00123
TRCI-SRG	0.88	0.93	0.07426	SPE-TRE	0.48	0.41	0.74352
TRCI-SSC	0.40	0.81	0.00182	SID-TPE	0.21	0.51	0.23893
TRCI-SID	0.13	0.53	0.00366	SRE-TPE	0.28	0.56	0.30814
TRCI-SRAI	0.38	0.51	0.57368	SRAI-TPE	0.47	0.89	0.00001
TRCI-SPCI	0.87	0.92	0.00782	SRCI-TPE	0.11	-0.81	0.0496
TRE-SPE	0.95	0.99	0.00009	SRFI-TPE	-0.23	-0.29	0.65922
TRE-SID	0.63	0.43	0.46385	SID-TEL	0.45	0.37	0.73792
TRE-SRAI	0.43	-0.27	0.05783	SRAI-TEL	0.55	0.53	0.95105
TEL-SEL	0.72	0.81	0.01794	SRCI-TEL	0.30	-0.82	0.00364
TRAI-SPE	0.76	0.15	0.08642	SRFI-TEL	-0.58	0.15	0.07666
TRIN-SRG	0.82	-0.64	0.00016	SEL-TEL	0.72	0.65	0.18986
TRIN-SSC	0.76	-0.67	0.00013	SPFI-TEL	0.09	0.23	0.46546
TPE-SP	-0.54	0.30	0.0236	SSG-TRAI	0.33	-0.13	0.27375
TPNI-SAEU	-0.46	0.11	0.16484	SPE-TRAI	0.70	-0.32	0.00598
				SR-TRPL	-0.83	0.39	0.00239
				SR-TRCI	-0.73	0.41	0.00044
				SSC-TIE	0.20	0.75	0.05864
				SAGE-TIE	0.07	0.67	0.0513
				SAEU-TIE	-0.07	0.62	0.1266

a. Fisher’s exact probability; computation based on all possible permutations

As can be seen from table 7-27, 15 out of the 30 transitions for lag –1 differed significantly between the two conditions. On the other hand, for lag +1, 11 out of the 34 transitions were found to be significantly different. In light of these outcomes, table 7-26 needs to be updated with only those transitions which were significantly different *between* the two conditions. These statistically significant transitions are given in table 7-28.

Table 7-28: Patterns significantly different between the two conditions

	TSG	TRPL	TRFI	TRCI	TRE	TEL	TRIN	TPE		TCS	TRE	TPE	TEL	TRAI	TRPL	TRCI
PP																
	.17								**SR**							
				.21					**SP**	.41[5]						
		.14[2]							**SDVP**		.27[2]					
		.11[2]							**SDT**	.21						
							.10[2]		**SRG**							
				.15			.27[2]		**SSC**							
		.32							**SSG**	.34[5]						
					.38				**SPE**					.10[2]		
									SID							
									SRAI			.14				
									SRCI			.30[2]	.28[5]			
									SAEU	.27						
						.29			**SEL**							
			.44						**SPFI**							
				.37					**SPCI**							
CS																
	.33[4]								**SR**						.10[3]	.21[3]
				.51[4]				.12[3]	**SP**	.36						
									SDVP							
									SDT	.47[4]						
									SRG							
				.41[4]					**SSC**							
	.28[3]	.44[4]							**SSG**	.35						
					.61[4]				**SPE**							
				.20[3]					**SID**							
									SRAI			.33[4]				
									SRCI				.41			
									SAEU	.54[4]						
						.28[4]			**SEL**							
			.65[4]						**SPFI**							
				.52[4]					**SPCI**							

2. Transition unique to PP condition; 3. Transition unique to CS condition; 4. CS mean higher than the PP mean; 5. PP mean higher than the CS mean

7.7.4.2 Findings

The question emerging at this point is: what do these significant differences featuring in table 7-28 mean? In the next few paragraphs we will attempt to interpret the findings.

Before we turn to the interpretation process we must take notice of one particular issue. There are four different possible combinations of frequencies and patterns and our interpretation is largely based upon them: (a) neither significant frequency differences nor significant pattern differences are found; (b) no significant frequency differences but significant pattern differences are found; (c) significant frequency differences but not significant pattern differences are found, and (d) both significant frequency differences and significant pattern differences are found. The reader should note that if a certain pattern (consisting of a sequence of one teacher behavior followed by one student behavior) occurs significantly more in one of the conditions and both the component teacher and student behaviors also occur significantly more in the same condition, the pattern differences are more likely due to the sheer number of frequencies. Therefore, patterns of the last category (d) were the least interesting ones, theoretically speaking. On the other hand, patterns belonging to the second and third categories present the most theoretical interest.

In table 7-29 both unique PP patterns and PP patterns more frequent than the corresponding CS patterns are presented.

Table 7-29: Patterns in the PP condition

Unique	More frequent than CS
TRPL-SDVP	SP-TCS
TRPL-SDT	SSG-TCS
TRIN-SRG	SRCI-TEL
TRIN-SSC	
SDVP-TRE	
SPE-TRAI	
SRCI-TPE	

7.7.4.2.1 Unique patterns in the PP condition

Deciding on which axis the independent variable goes after a teacher planning question was unique in the PP condition (and, thus, by definition significantly more frequent too). As can be seen from tables 7-20 and 7-21, there were significant differences between the two conditions neither in terms of frequency of occurrence of decisions concerning the position of the independent variable nor in terms of the frequency of teacher planning questions asked. Therefore, the observed pattern suggests that *PP students were more likely to determine the axis on which the independent variable goes in response to a teacher planning question*.

Drawing the trendline in response to a teacher planning question was unique to the PP condition as well. As can be seen from tables 7-20 and 7-21, no significant differences between the two conditions were found in terms of teacher planning questions, while students drew significantly more trendlines in the CS condition. Thus, *even though PP students drew less trendlines, the teacher was more likely to intervene by asking them to draw those trendlines*.

Another pattern which was unique to the PP condition was the following: the student determined the nature of the correlation after being asked an interpretation question by the teacher. Tables 7-20 and 7-21 show that more interpretation questions were asked by the teacher in the PP condition and that the students read the graph more often in the PP condition as well. This is an interesting finding because the students made many more graphs in the CS condition and, thus, were expected to report the nature of the relationships more often. The observed pattern suggests that *PP students were more likely to be asked to make sense of the data when reporting the nature of the correlation* compared to the CS students.

According to table 7-29, students stated the conclusion (i.e. reported the nature of the relationship in the form: as variable x increases, variable y increases, decreases or stays the same) in response to a teacher interpretation question, a pattern unique to the PP condition. As can be seen from tables 7-20 and 7-21, the teacher requested more interpretation questions in the

PP condition while more conclusions were stated for the CS condition. It must be emphasized that the teacher asked conceptual questions in both conditions (in the CS with higher frequency as will be discussed later on) before the student stated a conclusion. The fact that the student stated a conclusion in response to teacher interpretation questions suggests that *PP students were more likely to go beyond the information given in stating the conclusion than the CS students*.

The PP condition was also characterized by another unique pattern: when the student determined the position of the a variable, the teacher was more likely to request an explanation. As can be seen from tables 7-20 and 7-21, frequency differences were found neither for determining the position of a variable nor for explanation requests. Therefore, *the observed pattern shows that PP students were more likely to account for their selection of the axis on which the independent variable goes*.

As table 7-29 shows, another unique pattern to the PP condition was the teacher request for additional information when the student had already provided an explanation. Tables 7-20 and 7-21 indicate that the students gave more explanations in the PP condition as well as the teacher requested more additional information. Therefore, it is quite probable that the observed pattern is due to the higher frequencies of both constituent codes in the PP condition. This fact makes it difficult to draw any conclusions from the pattern.

The last unique pattern in the PP condition involved a teacher reaction when the student requested conceptual information: the teacher provided an explanation when the student had just requested conceptual (task related) information. Tables 7-20 and 7-21 show that students requested more conceptual information in the PP condition while the teacher did not give more explanations in either condition. Therefore, this pattern indicates that *PP students requested more examples and explanations with their conceptual questions than did CS students*.

7.7.4.2.2 Patterns more frequent in the PP condition

Firstly, the teacher seemed to be more likely to confirm a student prediction in the PP condition than in the CS one. It must be noted that, according to tables 7-20 and 7-21, the students made more predictions in the CS condition and that the teacher confirmed student behavior in the CS condition more often than in the PP one. Therefore, even though more predictions were made in the CS condition and the teacher confirmed student behavior in the same condition more often, the pattern analysis shows that *the students were more likely to make an accurate prediction in the PP condition*.

Secondly, the teacher confirmed more student goals in the PP condition than in the CS one. This pattern is particularly interesting because, as tables 7-20 and 7-21 show, the teacher approved of student actions and the students set more goals in the CS condition. Assuming that a teacher confirmation of a goal essentially amounts to the goal being ‘correct’ or ‘appropriate’, this pattern indicates that, *despite the fact that students set less goals in the PP condition, they were more likely to set correct ones compared to the CS students*.

Finally, in the PP condition the teacher was more likely to respond to a student conceptual question with an elaboration. According to tables 7-20 and 7-21, the student requested more conceptual information in the PP condition and the teacher elaborated more for the same condition. Therefore, the observed pattern is quite probably due to the fact both constituent pattern codes are more frequent in the PP condition. This makes it difficult for drawing any conclusions on the basis of this pattern.

In table 7-30 unique patterns in the CS condition are given in the left column, while patterns occurring significantly more in the CS condition compared to the PP one are presented in the right column.

Table 7-30: Patterns in the CS condition

Unique	**More frequent than PP**
SR-TRPL	TSG-SR
SR-TRCI	TRCI-SP
TPE-SP	TRCI-SSC
TSG-SSG	TRPL-SSG
TRCI-SID	TRE-SPE
	TEL-SEL
	TRFI-SPFI
	TRCI-SPCI
	SDT-TCS
	SRAI-TPE
	SAEU-TCS

7.7.4.2.3 Unique patterns in the CS condition

As can be seen in table 7-30, the teacher asked planning questions in response to student reading events. Tables 7-20 and 7-21 indicate that students read more often in the CS condition, while teacher planning questions were not different in any condition. *This pattern suggests that the transition from the phase or reading to the phase of planning was more direct for the CS condition*.

A second pattern unique to the CS condition was the teacher request for conceptual information after student reading events. According to tables 7-20 and 7-21, the teacher asked more conceptual information as well as the student read more often in the CS condition compared to the PP one. Therefore, it is very probable that the observed pattern is due to the significantly higher frequencies of the two constituent pattern codes in the CS condition and this fact does not allow us to draw any conclusions from the pattern.

The CS condition was also characterized by a third unique pattern: the student made a prediction after the teacher had provided an explanation. Tables 7-20 and 7-21 indicate that students made more predictions in the CS condition while the teacher did not provide more explanations in either one. Therefore, assuming that the code following the explanation indicates what it was about, the observed pattern suggests that *CS students needed more elucidation with respect to the exercise contents before they were able to make a prediction*.

Another pattern unique to the CS condition was the student goal setting in response to teacher goal setting. As tables 7-20 and 7-21 show, the teacher set more goals in the CS condition and so did the student. Therefore, it is very likely that the obtained pattern is due to the fact that both constituent pattern codes occur significantly more in the CS condition and this makes it difficult to conclude anything from the pattern.

The last unique pattern to the CS condition involves the indication of difficulty by the student as a reaction to a teacher conceptual question. According to tables 7-20 and 7-21, the teacher asked more conceptual questions in the CS condition while the student indicated more difficulty in the PP condition. Therefore, assuming that the sequence of the two events provides information concerning what prompted the difficulty, it may be argued that *CS students are likely to have more conceptual related difficulties than PP students*.

7.7.4.2.4 Patterns more frequent in the CS condition

A first pattern more frequent in the CS condition than the PP one, was that the student read the exercise in response to a teacher goal. As tables 7-23 and 7-24 show, students read more often and the teacher set more goals in the CS condition. Hence, it is very probable that the pattern is due to the fact that both constituent codes occur significantly more in the CS condition and, thus, it is not possible to reach any conclusions on the basis of this pattern.

A second pattern more likely to occur in the CS condition compared to the PP one, was that the students made a prediction as a reaction to a teacher conceptual information question. As can be seen from tables 7-23 and 7-24, students made more predictions and the teacher requested more conceptual information in the CS condition. Therefore, this pattern is possibly due to the fact that both constituent codes occur significantly more in the CS condition, which makes it quite problematic to draw any conclusions.

A third pattern more likely to occur in the CS condition was the following: the student stated a conclusion after being asked a conceptual question by the teacher. As indicated in tables 7-23 and 7-24, students stated more conclusions and the teacher asked more conceptual questions in the CS condition. Thus, it is probable that this pattern is attributed to the fact that both constituent pattern codes occur significantly more in the CS condition, and, as a result, it is difficult to reach any valid conclusion for this pattern.

Another pattern more frequently encountered in the CS condition was the setting of goals by the student followed by teacher planning questions. According to tables 7-23 and 7-24, the student set more goals in the CS condition, whereas the teacher did not ask more planning questions in either condition. *The observed pattern indicates that CS students were more likely to set goals in response to a teacher initiation*.

A fifth pattern more frequently occurring in the CS condition was teacher explanation requests followed by student explanations. As can be seen from tables 7-23 and 7-24, the teacher did not request more explanations in either condition, while the students provided more explanations in the PP condition. This finding indicates that *CS students were more likely to answer a teacher explanation request,* even though PP students provided more explanations in total. Therefore, the explanations/examples given by CS students were restricted to teacher questions alone, while PP students seemed to have provided reasons and explanations in more instances.

The CS condition was characterized by yet another pattern: teacher elaborations were followed by student elaborations significantly more. As can be seen from tables 7-23 and 7-24, both teacher and student elaborations were more frequent in the PP condition. Thus, even though teacher and student elaborations were more likely to occur in the PP condition, the pattern obtained from sequential analysis shows that a teacher elaboration was more likely to be followed by a student one in the CS condition compared to the PP condition. This suggests that *the elaborations of CS students were somehow patterned and followed teacher ones* in contrast with the elaborations of PP students which were probably occurring more freely.

Another pattern more frequently encountered in the CS condition was the provision of factual information by the student in response to factual information questions by the teacher. Tables 7-23 and 7-24 show that students did not provide more factual information in either condition, while the teacher requested more factual information in the CS condition. Therefore, even though there was no difference in terms factual information in one of the conditions, *CS students were more likely to respond to a factual information question* than the PP students.

The eighth pattern more likely to occur in the CS condition was the following: the student would respond to a teacher conceptual question by providing conceptual information. According to tables 7-23 and 7-24, in the CS condition the students provided conceptual information more often and the teacher requested conceptual information more often as well. This finding indicates that this pattern is most likely due to the fact that more conceptual questions are asked and more such answers are provided in the CS condition, and, therefore, no reasonable conclusion can be drawn from this pattern.

A ninth pattern more likely to be encountered in the CS condition was the following: the teacher confirming the trendline drawn by the student. As tables 7-23 and 7-24 show, more trendlines were drawn by the student and more teacher confirmations of student actions occurred in the CS condition. Therefore, it is quite likely that this pattern is attributable to the fact that both constituent pattern codes occur significantly more in the CS condition.

Another pattern more likely to occur in the CS condition involved the teacher response to student additional information questions: the teacher provided explanations. As can be seen from tables 7-23 and 7-24, the teacher did not provide more explanations in either condition, while the students asked more additional information questions in the PP condition. Therefore, even though more additional information questions were asked by PP students, the sequential analysis revealed that it is in the CS condition that such questions are answered through explanations. Therefore, *in the CS condition the teacher was more likely to give explanations and examples in response to student inquiries*.

The last pattern more likely to occur in the CS condition was the teacher confirmation of student questions addressing their own understanding. Tables 7-23 and 7-24 show that there were no frequency differences in terms of students asking about their own understanding, while teacher confirmation was more frequent for the CS condition. Assuming that the confirmation communicates enough information about the appropriateness of student questions, this finding suggests that *CS students tended to be more 'accurate' in their intuitive understandings*.

7.8 Discussion

In this section the main findings will be discussed. Firstly, the issue of student performance in the two conditions will be addressed. Secondly, we will consider the perceived difficulty and time findings and discuss whether the computer spreadsheet amplifies what students can do. Finally the case of transformation will be discussed along three dimensions: genre, activity and discourse.

7.8.1 Test performance

The results indicated that student performance in both conditions significantly increased from pre to post test. While both PP and CS students had very little knowledge of how to solve correlational problems, as indicated by their pre test scores, the tutorials had an impact on student performance, significantly boosting it from the pre to the post test. *This finding is in line with the findings of previous studies in the area of correlational reasoning which showed that a few hours of instruction, with or without computers, is sufficient in making students competent correlational problem solvers* (Ross & Cousins, 1993a; 1993b; Cousins & Ross, 1993). It must be stressed that the correlational reasoning test developed by Ross & Cousins (1993a) is exclusively related to correlational problem solving. It does not measure or reflect general graph competence or understanding.

Performance on the composite test was quite high in some items in the pre-test for both conditions and, thus, PP students only improved in three items on the post test while CS students improved in two items respectively. What the pre test scores of both groups suggest is that students' general understanding of graphs was above average before the tutorial took place, and, therefore, no spectacular gains in performance could be found. The composite test essentially constitutes an index of students' general understanding of graphs and, therefore, is less likely to be influenced by the correlational reasoning instruction. *Results indicated, however, that there was some small gain in both conditions, in cases of items where the pre-test performance was low*.

7.8.2 The case of amplification

Firstly, regarding perceived task difficulty, the effect of the computer spreadsheet can be described in two interrelated ways. One the one hand, the effect is expected to be *direct*: the computer spreadsheet makes it *easier* to produce a scattergraph given that a few mouse clicks suffice. On the other hand, the effect is *indirect*: because no mental resources need to be devoted to the business of making a graph, there are more intellectual resources available overall. This is expected to facilitate working on and understanding of the task as a whole.

The results indicated *no direct influence of the computer spreadsheet on the perceived difficulty of the task*. Students in both conditions perceived of graph construction as being very easy – despite the fact that PP students had to think hard during the construction of a graph and make a lot of decisions about issues which never really puzzled CS students. This finding casts doubt on the commonly held belief that the use of the computer makes a task easier and potentially facilitates its understanding[2]. As far as the indirect influence is concerned, *the evidence was positive in one exercise, while negative in another.* Students in the computer condition reported considerably lower perceived difficulty for stating a conclusion for the third exercise. This is in line with our hypothesis, although it must be noted that exercise three was the most difficult one. On the other hand, contrary to expectations, students in the paper/pencil condition reported that the second exercise was easier compared to what the students in the computer spreadsheet condition reported. This finding was not anticipated but it probably reflects the specific conditions of the treatment[3]. Finally, it was hypothesized that CS students, due to both direct and indirect influences of the computer spreadsheet, would report that, overall, the task would be easier compared to PP students. *This hypothesis was confirmed for*

[2] One possible reason for failing to find such differences could be the nature of the treatment itself: the students were taught how to use Excel during the tutorial and to some of them this was quite a complex task in the beginning although it took them very little time to fully master the procedures. Therefore, due to the specific contents of the treatment, it is quite likely that the perceived difficulty measures reflected not only task difficulty but complexity of the interface as well.

[3] For instance, in the second CS exercise a great number of concepts were introduced and the correspondence between the correlation coefficient and the trendline was demonstrated.

exercise three only. As already stated this is an interesting finding, bearing in mind that this exercise is by far the most difficult, both conceptually and technically.

Secondly, regarding time spent on task, even though students in the two conditions spent the same time on the task, some impressive time differences were found for the phases of making the graph and discussing the problem. On the aggregate, approximately one third of the total time was spent making a graph in the PP condition, while a little over one tenth was spent on making the graph in the CS condition. Additionally, all time differences between the two groups were statistically significant for the phase of making a graph.

In terms of the direct effects of the use of the computer tool, *the computer spreadsheet clearly had an influence*: the time required to perform the task was drastically decreased. This seems to confirm the common sense view that the use of a computer tool accelerates the process of solving the problem. The data gathered consistently support this view. In terms of the indirect computer effects and as far as time is concerned, it can be argued with a degree of certainty that the computer also has had some impact on the solution of the problem. With one exception, *significantly more time was spent discussing the problem in the CS condition*.

Speeding up the graph construction process should naturally lead to the solution of more problems in the CS condition. The results of the present study, however, showed that *CS students did finish making the graph in less time but the time gained with the automatic production of the graph was devoted to discussing the problem solution than to solving more problems*.

7.8.3 The case of transformation

The results from genre analysis indicated that some of the activities performed by the students in the two conditions were markedly different. More specifically, considerable differences between the two conditions concerning the terms common to both were detected. This reflects the specific nature of the tools used in solving the problem in the two conditions. The presence of paper and pencil entailed that a lot of discussion should be devoted to aspects of graph construction and this was indeed suggested by the data. On the other hand, the use of the computer spreadsheet resulted in more discussion with respect to graph interpretation. The activity of graph construction was also present and referred to but not in the exactly the same way. Additionally, certain terms were specific to each condition. This finding suggests that the use of the specific tool was associated with more activities of a certain kind. The very fact that some frequencies were unique to each condition also shows that the use of the tool brought about some unique dimension in the solution of the problem.

One of the major issues of transformation is related to the actual physical activity during problem solving when a different tool is employed. Activity theory provides us with a broad three-level framework for the describing the activity: activity, action and operation. The examination of two short transcripts and a subsequent analysis showed that the incorporation of the computer spreadsheet in the problem solving activity basically changed it only at the level of operations. The motive remained the same in both conditions: solving the problem. Solving the correlational problem can be accomplished by achieving three distinct goals: (a) make a graph; (b) plot the data and (c) read the graph. Two of these goals (making a graph and reading it) were common in the two conditions, at the level of actions. To materialize each of these goals the problem solver has to perform a number of specific operations which, as expected, were very different in the two conditions. Thus, at the level of operations a lot of changes can be described and analyzed. As already described, the most important difference with respect to the actual physical operations performed is the following: the introduction of the computer spreadsheet created new conditions for the solution of the problem and, thus, a number of conscious mental operations which required a lot of thinking and decision making were taken over and automatically carried out by the spreadsheet. These operations mainly involved deciding the unit, putting in scale and plotting the data. These operations were visible in the PP condition but conspicuously absent in the CS condition. In a word, *a number of mental operations (i.e. decision making during the construction of the scale) were transformed into mechanical ones (i.e. mouse-clicking)*.

7.8.4 On frequencies and patterns

The findings may be distinguished into two main categories: (a) patterns related to specific problem solving operations and, thus, indicate a direct impact of the computer on the problem solving process, and (b) more general patterns related to the indirect impact of the computer on the problem solving phases.

7.8.4.1 Transformation of problem solving activities

In the first category, determining the position of each variable was a very important step in the PP condition and that’s why the teacher was actively involved in it (i.e. the teacher was asking planning questions). This is because deciding which variable goes where is a very important and conscious decision in the PP condition: quite a lot is at stake with that particular decision. A possible error might have many negative effects which may be carried on to the latter stages of the work. It is a very conscious decision and the step is very specific: the students draw the two axes, decide which variable goes to each axis and then start working on the scale. Thus, it is a whole step in itself. In sharp contrast, determining the position of variables in the CS condition is a process embedded in another process: it is not a central but a peripheral activity. The students do not actively have to worry about the position of the variables and they only have to deal with that when they are labeling the axis at the end of the graph making process. The teacher is always asking them about the labels and this is how the issue of the position of the variables came into the active consciousness. Therefore, *a pattern typical of the PP condition is no longer typical when the computer spreadsheet is introduced*.

In connection to this first point, PP students had to account for their choices every time they selected the position of a variable. Thus, the teacher was the one who on the one hand initiated the discussion related to the positions of the variables on the axes and on the other was quite likely to ask the students to explain their choices. As already pointed out above, the making of a graph was a very conscious and active process in the PP condition, while some of these processes became background or secondary – or even utterly faded – in the CS condition. *This pattern also suggests that the reality of making a graph was altered after the introduction of the computer spreadsheet*.

A second point which has to be made is that PP students drew trendlines after some direct teacher intervention (i.e. planning question). In both conditions drawing a trendline was a very important and conscious activity and, thus, on the surface, we would not expect different patterns. Two important features of the CS processes, though, might help account for the observed pattern. On the one hand, the process of making the graph took longer in the PP condition and, thus, by the time students had finished making it and plotting the data they had forgotten all about the trendline. Thus, the teacher had to explicitly or implicitly ask the student to try and draw a trendline to summarize the trend, an action performed with a planning question. On the other hand, CS students were informed about the automatic drawing of trendlines by the computer spreadsheet and seemed to like that feature quite considerably. For example, they were told that Excel could draw a perfect or 'ideal' mathematically calculated trendline to fit the data. Most of the students would first draw a trendline all by themselves, then they would also have Excel draw a trendline, and eventually they would compare the two to see how accurate their trendline was. This feature of Excel was used in the first few exercises as an instructional tool, in order to provide an extra measure of how well students' trendlines were drawn. Later on, however, it served no special functionality to compare two trendlines since the subjects already knew what a trendline was. Nevertheless, some of the students went on to compare their trendline with the 'ideal' trendline drawn by the computer – in a man vs. machine completion – and at times even ignored teacher's suggestion to the opposite. What this behavior shows is that *the incorporation of the spreadsheet led to some changes in how trendlines were drawn, why they were drawn and what purpose they served*. Hence, the observed pattern seems to support the idea of a transformation of the problem solving processes due to the introduction of a computer tool.

A third important issue relates to the fact that PP students were asked to go beyond the information given in reporting the nature of the correlation and stating how the variables were related (i.e. they were asked interpretation questions by the teacher and not simply factual ones). At this stage we need to be explicit with respect to what an interpretation question is and what it demands of the students. Normally, a teacher would ask students a conceptual question like ‘what sort of correlation is this?’. To respond to such a purely conceptual question the student would have to mention that the correlation depicted on the graph is positive (or negative or there is no correlation). An interpretation question would require the student to go beyond the information given in the sense that reporting the nature of the relationship would not suffice, e.g. ‘what does this graph show you/tell you?’. To deal with such a question the student would have to go beyond what is visible on the graph (i.e. positive/negative/non correlation) and describe how the particular correlation is related to the problem itself and to the initial problem variables. In a way, the student was asked not only to report the nature of the correlation but also to make sense of it. The same holds for the interpretation questions preceding stating a conclusion, i.e. describing how the two variables are exactly related. What these patterns show is that the incorporation of the spreadsheet led to the construction of many more graphs in the CS condition but not necessarily to higher levels of thinking. What *these patterns suggest is that the use of the spreadsheet transformed the problem solving activities*.

The final issue is related to the fact that while CS students needed more teacher intervention in terms of explanations to make a prediction, PP students were generally speaking more accurate in their predictions, i.e. their predictions were confirmed more by the teacher even though more predictions were made in the PP condition.

7.8.4.2 Transformation of teacher-student communication

The second category involves all other changes on teaching, interaction, and communication levels. It is very important to notice that according to the theoretical framework it is very possible that the integration of a computer tool in the process of solving a problem is going to have an effect not only on the actual physical operations performed, but also on communication patterns in general. The patterns belonging to this type of transformation may be distinguished as follows: (a) cognitive-conceptual issues; (b) regulation, and (c) other.

Regarding cognitive-conceptual issues, sequential analysis showed that PP students tended to ask conceptual questions which were answered by teacher explanations. It must be emphasized that whenever a conceptual question is asked by the student the teacher has three main possibilities to respond: (a) provide new information if it is needed, (b) give an example or explanation, and (c) elaborate. In the first case, the teacher response implies that the conceptual-task related information is new to the student and has not been mentioned before. Thus, a new concept is introduced by the teacher (or a new procedure or a new term). The teacher responds by providing new information when it is called for. In the second case, the definition or new information has been provided already but the topic/issue idea seems to require some sort of example/explanation to clarify it. In the third case, both new information and explanations of it have been provided and, thus, the teacher may only elucidate a bit more. *The observed pattern suggests that PP students required more examples/explanations related to conceptual issues*. This also suggests that more examples were available or could be given in the CS condition, because the graphical properties of the computer spreadsheet made it possible.

A second issue concerns teacher confirmations of student questions about the evaluation of their understanding. Results from sequential analysis showed that when the CS students asked the teacher to evaluate their understanding the teacher was more likely to confirm it. *This suggests that CS students were accurate in terms of their understandings compared to PP students*. It may be argued that this is due to the fact that more instructional and other information were presented to the CS students due to the affordances of Excel.

A third issue relates to the fact that the difficulties CS students expressed were related to conceptual issues, even though PP students indicated more difficulties overall. At this point it must be emphasized that the students express difficulty when they cannot follow what the teacher is saying or when they do not know how to preceded. Indications of difficulty essentially constitute points where the communication between teacher the student in breaking down, with the student explicitly informing the teacher that he/she cannot follow or understand what is happening. The fact that CS students indicated more difficulty after conceptual related questions, suggests that either the level of coverage of the subject matter was very high and abstract for that condition or that teacher questions were more complex. This pattern suggests that *the CS condition was more conducive to thinking and more demanding overall*, given that, as discussed above, CS students had a better understanding of the subject matter.

A fourth pattern related issue concerns how the students responded to teacher explanation requests in the two conditions. According to sequential analysis, CS students were more likely to provide explanations to teacher questions than PP students. This finding suggests that the CS students reasoned more in conjunction with teacher questions, even though PP students actually provided more explanations overall. If we assume that examples and explanations are indicative of reasoning, then *this pattern shows that PP students actually reasoned more independently than the CS students*.

Another observed pattern is related to students’ responses to factual information. As the results of sequential analysis showed, CS students were more likely to provide factual information when such information was requested by the teacher, even though the students provided the same amount of factual information in the two conditions. *This pattern suggests that PP students provided more factual information independently than the CS students.*

In the CS condition the teacher was more likely to respond to additional information requests by the students by providing an explanation. It must be noted that, on the whole, PP students requested more additional information. Therefore, *this pattern indicates that even though PP students had more difficulties understanding a concept or implementing a procedure or responding to a question/request, the teacher estimated that explanations were required*.

In the second group of pattern differences (i.e. regulation) two patterns are basically included: (a) PP students were more likely to set correct goals and (b) CS students set more goals in response to teacher initiations. Regarding the former, it must be noted that the students set more goals in the CS condition but eventually it was the PP students' goals which were confirmed more often by the teacher. *This pattern suggests that in the PP condition the students were more accurate in the goals they set, compared to CS students*. This is most probably due to the fact that the students in the PP condition had to set very specific and concise goals, otherwise the implications could have been devastating in the sense that the students could have had to repeat some processes all over again, a very time consuming procedure. On the other hand, CS students relatively speaking were more free to embark on a 'wild goose' chase as Schoenfeld (1983) put it. At least not all of the goals they set were likely to be appropriate or confirmed by the teacher.

On the other hand, CS students were more likely to set goals in response to teacher initiations (i.e. teacher planning questions) even though the teacher asked approximately the same number of those questions in the two conditions. This finding suggests that *CS students needed more explicit teacher input in order to set a goal*.

Finally, in the third group two patterns are typical which are somewhat difficult to account for. On the one hand, the sequential analysis showed that the transition from the reading phase to the planning phase was more direct in the CS condition. On the other hand, in the CS condition teacher elaborations were more likely to be followed by student elaborations. Given that elaboration was a default category in our coding scheme, it is rather difficult to explain these patterns.

Chapter 8

8 Synthesis

In this final chapter the findings of the two studies are discussed and their contribution to theory, method, and teaching and learning practice is appraised. Firstly, the respective roles of teacher and computer spreadsheet in learning to solve correlational problems are discussed. Secondly, a number of issues related to regulation, genre appropriation, amplification, and transformation as well as their implications for theory and practice are further explored.

8.1 An overview

In the field of computers and learning hundreds of studies have been conducted since the launch of the personal computer into the market in the early 1980s. The availability of cheap computers and their potential for learning led many countries to introduce them in the curriculum, first as a separate curricular subject and then, using a more integrated approach, as a learning aid. The results of meta-analyses show that, whenever computers are incorporated in the teaching and learning process, their contribution to student learning is considerable. In spite of the positive findings, however, there has been a lot of skepticism about the potential of new technologies to enhance learning.

Firstly, the need to integrate research findings with theory has been stressed. The early days of computers and learning research were characterized by an emphasis on instructional effectiveness and technocentric approaches. On the one hand, ideas and theories related to how computers influence learning and impact on problem solving have been discussed quite often in the literature and have been invoked to account for the typically positive learning results from the use of computers. In fact, there is an inverse relationship between the number of studies theorizing about how certain computer properties contribute to learning and the number of studies actually investigating such properties. Therefore, *how the computer contributes to and impacts on learning has not been systematically investigated*. On the other hand, mostly due to the fact that the computer has been perceived of as merely another ‘variable’ to be manipulated, the role the teacher plays in the effectiveness of computerized instructional interventions has not been systematically explored. Whenever teacher’s role is taken into account, the focus is either on the teaching method (e.g. group work, expository instruction, advance organizers, reciprocal teaching etc) or on the form of representation of the information to be presented (as it affects the encoding of the presented information in long term memory). As is often the case with most educational innovations, the research approaches in the field of computers and learning have been fragmentary, mostly focusing on separate aspects of the whole situation. As a consequence, *teacher's role and contribution to learning in the context of computerized interventions has largely been unexplored*.

Secondly, the need for the development of new methods more appropriate for studying the effects of computers on learning has also been stressed. More particularly, research in the field typically focuses on the learned product rather than the learning process itself. The information acquired from studying the product is, under certain conditions, sufficient in answering certain types of questions about the instructional effectiveness of computers compared to other teaching methods and tools. Nevertheless, this type of information is insufficient for determining *how* computers contribute to learning. The main problem with the product-oriented approaches is that whatever transpires in the course of the process of an intervention is usually beyond the reach of the investigator. Therefore, *there is a need to change the emphasis from product to process and develop as well as apply methodological tools for studying the very process of a computerized instructional intervention*.

In this dissertation we have attempted to fill in the existing theoretical and methodological knowledge gap in the field of computers and learning regarding the respective roles of teacher and computer. Their contribution to learning was investigated in the context of correlational problem solving. On the one hand, the present dissertation primarily aimed at determining how the teacher contributes to the development of correlational reasoning skills. After an elaborate examination of a theoretical framework in chapter 3, it was decided in chapter 5 to explore the role of the teacher in the process of acquiring correlational reasoning skills in terms of regulation and genre. In particular, study 1 dealt with two specific research questions: (a) Is there a transition from teacher regulation to student self-regulation? (b) Is the voice of the teacher gradually being assimilated in the voice of the student? On the other hand, this dissertation was also aimed at determining how the computer spreadsheet contributes to and impacts on the development of correlational reasoning skills. More specifically and with respect to this goal, study 2 addressed two research questions: (c) Does the use of the computer spreadsheet amplify correlational problem solving compared to paper and pencil? (d) Does the use of the computer spreadsheet transform correlational problem solving compared to paper and pencil? Below we will examine the findings and consider how they provide answers to these questions.

8.2 The contribution of the teacher

8.2.1 The transition from teacher-regulation to student self-regulation

> *"No Nirvana is possible for a single consciousness. A single consciousness is a contradiction in terms. Consciousness is essentially multiple"*
>
> Bakhtin (cited by Emerson, 1986)

The transition from other to self-regulation in the context of acquiring a cognitive skill (or learning how to solve a task) has been well documented in the literature (Rogoff, 1990; Wertsch et. al., 1980; Rogoff & Gardner, 1984; Rogoff, Malkin, Gilbride, 1984). Contrary to what is typically reported in such studies, however, *the initial results from the analyses of variance did not support the expected transition from teacher to student self-regulation.* This may be the case for a number of reasons. Study 1 is different from other studies in the field of self-regulation in that relatively older subjects, a formal academic task with multiple versions (exercises), and discourse analytic methods were used. Firstly, research on regulation, as described in chapter 3, typically uses children whose age ranges from 2.5 to 10 years. In the present study we used relatively older subjects who have more developed self-regulatory skills. Secondly, regulation has only being investigated using puzzle-assembly or sorting tasks but not with formal academic tasks, while for the purposes of the present research such a task was used (i.e. correlational reasoning). Subsequently, in the overwhelming majority of cases of previous research regulation has been examined within tasks rather than across tasks. In study 1 regulation was basically examined across tasks. Finally, the discourse analytic methods used in previous research are incomplete in some respects, e.g., the sequential nature of teacher-student interaction is ignored, direct and indirect forms of regulation are not distinguished, either content of discourse or function constitute the focus of attention, and the units of analysis vary considerably (for a more detailed discussion see Karasavvidis, Pieters & Plomp, 1997; Karasavvidis, 1998), while the discourse analytic approach used in this study has definite advantages especially over segmentation and coding.

In view of these differences, we looked closer into the task and used exercise phases as the frame of reference. Moreover, correlational analysis was deemed to be more appropriate for the study of code trends in time. *The outcomes of the correlational analysis supported the theory to a larger extent*. When the exercise phases were used as a frame of reference, sequential analysis partially supported the notion of a transition from other (teacher) to self-regulation, for the most important teacher and student codes. Nevertheless, there were some occasions where the theory was clearly refuted, e.g., student goal setting was expected to be increasing in the course of the exercises. A further examination, however, revealed that the problem was that *the coding scheme is not sensitive to the subtle issue of context or common ground*. More specifically, the examination of the first goal set in the course of the exercises by all subjects indicated that, while for the first few exercises the goal was very concrete, in the last exercises it was not talked about or addressed: it had become implicit and was largely assumed. Once it was not mentioned or talked about, it was impossible to be coded. It was, therefore, due to the very specific quantitative nature of the discourse approach used that some codes were not in the direction predicted by the theory. Context continuity cannot be reflected in a coding scheme: it can only be perceived of and understood by following the course of discourse in time. Coding deals with utterances at a local level and cannot take into account the fact that with the passing of time the context (i.e. whatever has already been talked about) plays a very important role. Typical discourse coding procedures cannot adequately deal with the problem of common ground, especially in cases like student goal setting. No quantitative method of discourse analysis can circumvent this problem without really coding what is implied in the transcript. But this seems to be no easy or reliable task. In fact, it is downright impossible because it can never be accurately determined what is and what is not known for any given utterance. Quantitative ways of discourse analysis will be incomplete unless new techniques for dealing with the issue of common ground are developed.

8.2.2 Genre appropriation

> *"Each word contains voices that are sometimes infinitely distant, unnamed, almost impersonal (voices of lexical shadings, of styles, and so forth), almost undetectable, and voices resounding nearby and simultaneously"*
>
> Bakhtin (1986, p. 124)

As far as genre appropriation is concerned, *study 1 showed that the voice of the teacher is being gradually reflected in the voice of the student*, in terms of how the student talks about aspects of the problem. According to correlational analysis, the proportion of independent use of the terms 'variable' and 'correlation' by the student is increasing in the course of the exercises, even though the increase is not significant in the case of the term 'variable'. Additionally, the thorough examination of the case of one subject illustrated how the this genre appropriation is taking place. In particular, it was demonstrated how the student is gradually using certain terms (i.e. correlation, variable) which did not belong to her but were provided by the teacher during the instruction. In this sense, the student was describing the problem in an alien 'voice', a voice which had eventually assimilated the 'voice' of the teacher. Moreover, it was examined how, with the passing of time, the teacher demands that student uses the terms provided, at times even providing negative feedback because the language (genre) used by the student was not appropriate. A few other studies which have been conducted in this area also report similar findings in terms of genre appropriation (Wertsch, 1991; Wertsch & Toma, 1995; Wertsch & Rupert, 1993; Wertsch, 1998).

8.3 The contribution of the computer spreadsheet
8.3.1 Amplification

> *"Whenever logical processes of thought are employed – that is, whenever thought for a time runs along an accepted groove – there is an opportunity for the machine"*
>
> Bush (1945)

Overall, *the use of computers in learning may be characterized as a success story*: meta-analyses typically show moderate but significant achievement gains favoring CAI students (e.g. Niemiec & Walberg, 1985; Niemiec & Walberg, 1987; Niemiec, Sikorksi & Walberg, 1989; Niemiec & Walberg, 1992; Kulik & Kulik, 1991; Khalili & Shashaani, 1994; Kulik, 1994; Fletcher-Flinn & Gravat, 1995; Christmann, Badget & Lucking, 1997). Nevertheless, when performance for the pre and post tests was compared between the two conditions, no significant differences emerged as far as correlational reasoning performance is concerned. *This finding is not in agreement with meta-analytic results*. However, it is not uncommon for studies to report no performance differences whatsoever (cf. Savelsbergh, 1998).

Nevertheless, caution should be exercised in interpreting this finding for two main reasons. On the one hand, according to meta-analyses, the higher performance of CAI students disappears when (a) the same instructor teaches both experimental and control groups (see Khalili & Shashaani, 1994), and (b) identical instructional materials are used in both experimental and control groups (see Fletcher-Flinn & Gravat, 1995). In both studies (i.e. study 1 and study 2) the same teacher and instructional materials were used and this is one possible reason for failing to find such differences. On the other hand, traditional testing procedures were used to assess performance achievement of both conditions. These types of measures are static and do not necessarily reflect all types of understanding that can be acquired by working with computers. One of the issues often addressed in the literature is that the use of computers leads to qualitatively different types of learning (e.g. Scardamalia & Bereiter, 1996). In this dissertation we only focused on test performance. Nevertheless, from informal observations made during the tutorials and from viewing the tapes we have come to the conclusion that PP students had basically acquired a lot of skill in making graphs (e.g. using all kinds of shortcuts to make the process simpler and faster), since that's what they simply spend most of their time on. On the other hand, CS students seemed to have acquired more prediction-related skills (e.g. estimating the value of the correlation coefficient on the basis of the spread of the dots on the graph), and interpretation skills (e.g. what the graph shows), because these two were central and frequent activities in the CS condition.

One of the ideas frequently encountered in the literature is that the use of computers makes computation, graphing and other tedious mathematical operations easier. Contrary to what is discussed in the literature (e.g. Lajoie, 1993) and to logical expectations, *this study did not provide evidence supporting the sharing-of-cognitive-load argument*. More specifically, substantial evidence for the supposed alleviation of cognitive burden of the point-by-point graph construction - which is explicitly evoked in some studies to account for the positive effects of computers on the understanding of graphs (e.g. Morkos & Tinker, 1987) - was not obtained. It is quite possible that no cognitive load differences were found because the measure used required students to accurately rate how difficult each problem solving aspect was. On the other hand, the perceived task-difficulty measure used in this study was administered at the end of each exercise, which might have affected the accuracy of student’s ratings. Moreover, although PP students often strove to construct the scale and the graph and, therefore, the mental effort they had to invest was considerable, they didn’t report a high cognitive load. This might be an indication of the fact that students do not necessarily consider an activity which is tedious and time consuming as difficult, even though they eventually spend a lot of mental effort carrying it out. Similar findings have been reported in other studies, e.g. Savelsbergh (1998) found that subjects did not find Mathematica visualizations difficult, but nevertheless spent too much time figuring out the details of how to work with them. Patterns like these tend to suggest that it is perhaps only when the activity is conceptually intricate that subjects consider the cognitive load to be high, while in all other cases where they are in a position to elaborately work out all the details they think the activity to be manageable. Finally, it must be noted that the task is not very difficult, conceptually speaking, and that students are in principle able to solve it without the help of the computer. Thus, the contribution of the computer is not unique or irreplaceable and students can definitely cope with the problem without it. Therefore, it is quite probable that the solution of the task did not place considerable computational or mental demands on students, so that a the computer would be the difference that makes the difference.

Another belief commonly encountered in the literature is that *the use of computers entails that more work is done in less time*. For example it has been argued that “in most situations in which computers enhance learning, they do so because they increase effective academic learning time” (i.e. the time students are actively engaged in the task) (Vockell & van Deusen, 1989; p. 23). On the other hand, CBI students have been found to learn their lessons in less time (e.g., Kulik, 1994), and this opens up the possibility for covering more curriculum units within the same time period. *The findings of the present study tend to support the time argument, especially as far as graph construction is concerned*, since CS students produced graphs faster. Despite the fact that this speeding up of the construction of the graph was anticipated to lead to the solution of more problems, *study 2 indicated that the same number of problems were solved in the two conditions*. CS students did not solve more exercises than PP students for the following reasons: (a) they made more graphs per exercise; (b) they drew and calculated more trendlines for each graph made; (c) they computed more correlation and partial correlation coefficients and (d) the instructional time included familiarization with the spreadsheet interface and procedures. Therefore the computer spreadsheet accelerated the performance of some actions, but at the same time it brought new features (i.e. affordances) to bear which were exploited in various ways. As a consequence, *the time saved by making the graph in seconds was devoted anew to other instructional activities, e.g. computation of correlation and partial correlation coefficients as well as trendlines*. However, generalizing on the basis of the data gathered, it is beyond doubt that in the long run CS students will manage to solve more correlational problems. Of course, whether they will solve significantly more problems or what the implication of solving more problems is going to be for the quality of learning, needs to be determined.

8.3.2 Transformation

> *"'Is dis Miss Mandy Johnsing?' asked the voice on the telephone.*
> *'Yas, dis is Miss Johnsing'.*
> *'Well, Miss Johnsing, I done called you to de telephone to inquire if you would marry me?'*
> *'Marry you? Marry you? Ob course I'll marry you. What made you all think I wouldn't marry you? Ob course I'll marry you. Who is dis talkin', please?'"*
>
> Excerpt from *Telephony*, 1908 (cited by Marvin, 1988, p. 63).

Firstly, the study of the genre in exploring the effects of computers on learning has been rather uncommon in the field of computers and learning, although some studies have looked at the discourse in general, its structure, and the use of specific words-terms (Fisher, 1997; Kollias, 1997; Wegerif, 1997a; 1997b; Wegerif & Dawes, 1997). Even though there is no conclusive evidence and the debate is far from over, it appears that some types of computer software are more conducive to certain types of discourse. By means of extending these arguments, we would add that these differences in discourse essentially reflect differences in activity. *The results obtained from study 2 point to a set of specific actions and operations depending on the technology-artifacts used in each condition*. The comparison of the genre used in the two studies indicated that some terms were unique to each condition as a result of the use of a different set of tools, which in turn provide different affordances.

Secondly, we will shortly discuss how mediation can be combined with activity theory in explaining the impact the computer spreadsheet had on the solution of correlational problems. The fact that some of the actions and most of the operations were different in making a graph in the two conditions was pointed out in chapter 7. At this point we will examine how these different operations are effected and how they relate to the making of the graph. In chapter 3 we described the role of mediation and its importance for psychological processing as well as for transforming practice. The classical mediational model (subject, tool, object) is depicted in figure 8-1.

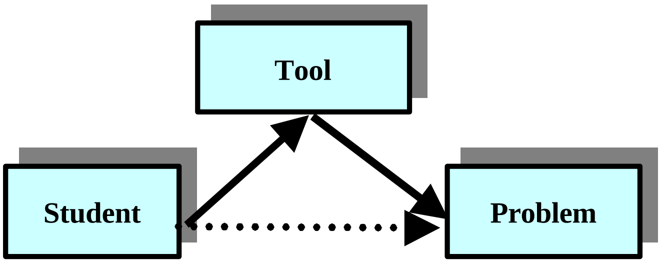

Figure 8-1: The relationship between student and problem

According to this model the student (subject) solves a problem (object) indirectly, through tool use[1]. In the case of correlational problem solving with the aid of graph paper and pencil, figure 8-1 may be graphically represented as follows:

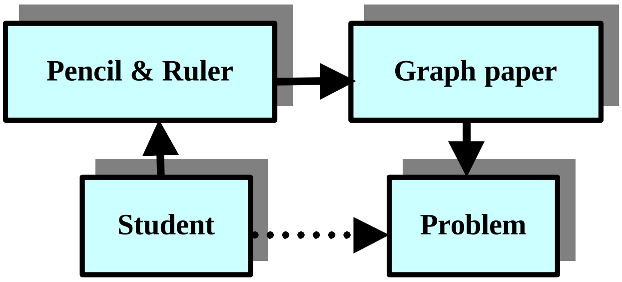

Figure 8-2: The relationship between student and problem in the PP condition

As can be seen from figure 8-2, the student uses graph paper, pencil and a ruler to solve the problem. In a sense, the student uses these tools to change the representational format of data (i.e. put the numbers on a graph) so that the relationship between the two variables of the problem can be easily discerned. Two issues are of crucial importance. First, *the relationship between the student and the problem is indirect*, i.e. the student does not manipulate or work on the raw data directly but makes use of the tools provided. Second, *the tools used have some special affordances*: it is on the graph paper that the student represents the data in another form and, thus, is able to make sense of them. Therefore, *the graph paper functions as a medium, as some sort of general platform upon which the data is manipulated (i.e. represented) with the help of the pencil and ruler.*

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[1] The reader should note that this is an over-simplified model and is only used here for the sake of simplicity. A host of other parameters must simultaneously be taken into account. For instance, the user is not usually working on a problem alone: he's part of a community or a whole network of other people with whom he has to cooperate to achieve the common goal (i.e. the solution to the problem). Moreover, the problem solver hardly uses one and only tool: it is usually the case that a large number of artifacts - both material and psychological - are employed at the same time. Finally, the problem solving activity never takes place in a cultural vacuum, and in every context there are a number of rules and conditions which shape the activity and have to be met. Such a model connecting the concept of mediation with Leont'ev's activity theory has been put forward by Engestrom (1991). Given our study objectives, in our

In the case of the computer spreadsheet, the relationship between student, spreadsheet and problem may be represented as follows:

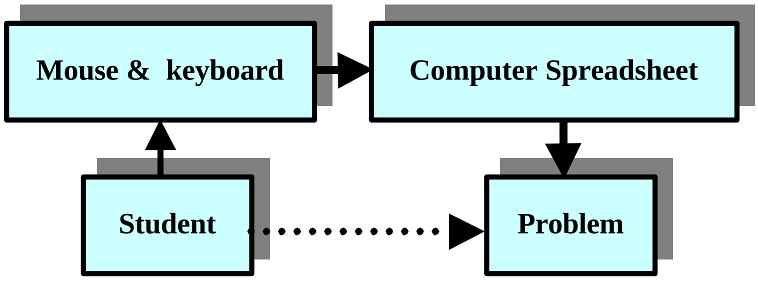

Figure 8-3: The relationship between student and problem in the CS condition

Again, two issues deserve special consideration. First, *the relationship between the student and the problem is mediated*, i.e. indirect. Second, the tools used have special affordances: in this case *the spreadsheet functions as the medium, or platform, upon which the data is manipulated (i.e. represented and acted upon) with the help of the mouse and the keyboard*. On the surface, there is no basic difference between figures 2 and 3. In both cases a certain representational medium having certain affordances was used. Moreover, on both occasions certain tools are used for manipulating the raw data on the representational medium, be it graph paper or computer spreadsheet. The fundamental difference between the two conditions however, is that PP students still operate on the actual data on the paper because the affordances of the tools and the representational medium are different. On the other hand, CS students use the mouse and the keyboard to operate on the data. Bodker (1989; 1996) distinguished five types of interaction of users with the object of their activity and argued that the interface basically determines the conditions for how certain actions and operations are done. One of the typologies of a user handling a problem through the interface, includes the computer spreadsheet. She points out that in the case of a computer spreadsheet the object of activity (i.e. the problem data) is present *only* in the spreadsheet itself. Therefore, at the lowest level of the analysis of activity, *the operations performed are not the same*. On the one hand, students in the PP condition have to use the pencil and work with the actual data on the graph paper, rearranging them, drawing axes, thinking about the unit, putting in scale and plotting the data. All these are observable operations. On the other hand, the only possible observable operations of CS students are those involving mouse moves and the keyboard strikes. As a consequence, *not only different operations are afforded in the two conditions but different thinking processes come into play as well due to the different operations involved.*

Finally, *there is a lot of discussion about transformation in the literature but up to the moment there is very little solid evidence of any transformation occurring*. As already argued in chapter 1, it is perhaps our tendency to avoid investigating something pretty much obvious and

discussion we will solely focus on the two most prominent tools: paper & pencil and computer spreadsheet.

commonly accepted. For instance, today hardly anyone can ignore the impact of computers on everyday life or even on scientific practice itself (e.g., Kaufmann & Smarr, 1993). However, the dimensions of this transformation are largely unknown, not only at a practical activity level (e.g., when a calculator is used to compute a sum only the numbers are keyed in while the actual computations are not performed) but also at a cognitive level (e.g., what does it mean to compute a sum using a calculator? Does it count as a legitimate computation? cf. Wertsch, 1998). Frequency and sequential discourse analysis indicated that *when the computer spreadsheet is used in solving correlational problems a transformation occurs* – compared to how these problems are solved with paper and pencil – which is twofold: *transformation of the specific problem solving activities and transformation of the structure of discourse and, consequently, of activity.*

Regarding the former, *certain sequences (and therefore structuring) of specific problem solving activities were observed for the solution of correlational problems using paper and pencil through sequential analysis. When the same sequences were examined for the CS condition, a number of sequences (and therefore structures) of specific and concrete problem solving activities were markedly differentiated* (either unique or more frequent in one of the conditions). Therefore, this finding provides evidence for a certain change in the succession (sequencing, structuring) of problem solving actions in the two conditions.

Regarding the latter, *certain sequences (and therefore structuring) of general communicative activities were observed for the solution of correlational problems using paper and pencil*[2]*. When the same sequences were examined for the solution of correlational problems using the computer spreadsheet, a number of sequences (and therefore structures) related to communication were considerably differentiated between the two conditions*, being either unique or more frequent in one of the conditions. Therefore, a certain change in the succession (sequencing, structuring) of communication between teacher and students was effected upon the introduction of the computer spreadsheet.

To conclude, when the computer spreadsheet is introduced into the solution of correlational problems, the sequence (succession, pattern, structure) of the problem solving activities required to solve it *changes*. Additionally, communication sequence (succession, pattern, structure) change as well.

[2] Note that by 'communicative' we refer to both teacher and student the categories of the coding scheme which do not fall under the category of task-specific problem solving actions. Communication as used here involves basically aspects of teacher-student interaction regarding regulation, instructional activities, explanations, provision of new information etc.

8.4 General discussion

8.4.1 Regulation and phase specificity

According to study 1, a noteworthy issue is the one of exercise phases. More specifically, whereas little evidence supporting the notion of the transition from other to self-regulation was obtained when the whole exercise was used a frame of reference, the theory received more support when separate exercise phases were used as the frame of reference. Five distinct problem solving phases were identified: reading the problem, making a graph, plotting the data, drawing a trendline, and concluding. It must be noted, of course, that these exercise phases are nothing but constructions of convenience. It is not known whether at a conscious level the teacher or the student actually understood each exercise in terms of phases. It is more probable that the phases were construed as general problem solving steps. These phases constitute decisions of convenience for analyzing the problem, because it was realized that using the whole exercise as a frame of reference was a very rough approach. On the other hand, on conceptual grounds alone, it can be easily demonstrated that these five phases are also, to some extent, autonomous and require the activation of many different cognitive skills. Setting the issue of whether these problem solving phases are actual or conceptual aside, what is remarkable is that *the patterns of interaction among the phases differed*, while usually short math problems are perceived of as forming an undifferentiated whole. As the correlational analysis showed, *different patterns emerge for each exercise phase, which in turn suggests that different aspects of the task place different engagement and thinking demands on the student*. Correspondingly, teacher intervention is tuned to these task demands and, therefore, teacher regulation varies depending on how much help is needed by the student at any point in time. In a way, teacher regulation appears to be sensitive to task variations and student needs.

8.4.2 Analyzing instructional discourse with the developed model

The model of discourse used provides certain insights into analyzing instructional discourse and studying learning, as well as the role of the teacher in such an environment. *Combining the three components of the model, one can examine discourse from seven different perspectives*, depending on student proficiency in each dimension/component. For instance, a student may be adept at learning the genre, but fail to reach any understanding of the principle(s). The implication in this case is that the student will be proficient in discussing it on the discourse plane, but when it comes to activity and/or rationale, he will be in the dark. Another student may understand the principle but fail to appreciate the importance of genre or fail to appropriate it:

the implication is that, due to the fact that problems and questions are cast in the form of a special language – i.e. genre, this student will seem to be lacking understanding, even though he/she may be simply lacking genre knowledge. These examples suggest that definitional questions or tests favor students who have appropriated the genre. Procedural questions or isomorphic problems favor those students who have learned the activity components: what to do (actions) and how (operations). Finally, medium and far transfer tests favor students who have appropriated the principle(s).

We will now examine the case of a student who had in the course of the tutorial appropriated the genre and the activity but had failed to understand the principle.

Jim, exercise one
[teacher and student are discussing the details of the construction of a scattergraph]
T: on the x axis you should always put the independent variable…do you know what an independent variable is?
S: no
T: do you know what a variable is?
S: uh…uh…I think so]
T: what's a variable?
S: I can't explain it
T: it's this basically (pointing to the graph), so here the weekly allowance is one variable, and the annual number of visits to the movies is the other variable
S: ok
T: and the independent variable is the one that isn't affected by the other one

In this excerpt the teacher introduced the term independent variable, in the first utterance, and went on to define its meaning. In a way, the teacher provides instruction on the scientific concept of variable, a term the student ignores. Apart from providing a definition, the teacher at the same time introduces and uses a special type of language for talking about and describing variables, a certain type of geography speech genre. The teacher provides a particular way of 'seeing and interpreting' particular problem aspects, i.e. 'weekly allowance' and 'number of visits to the movies' and referring to them as variables.

Jim, exercise 2
[student is about to start making the graph]
T: but what are you going to put on what axis?
S: I am going to put the age on the y axis and the total number of speeding tickets on the x axis
T: why?!
S: cause it's more…I don't know, because this one is on the left (referring to the age variable on the table) and this one on the right (referring to the number of tickets variable which is on the right of the other variable), If I am going to draw a line graph I mean, no it was the age did something that is given already
T: what do you mean?
S: it's not to be measured
T: what do you mean it's not to be measured?
S: it's not to be measured, you can't measure how old you are
T: of course you can, I'm thirty four, you can look at my birth certificate and subtract sixty one from ninety six
S: yeah, I can…it's not measurement…it's…

T: T: do you remember what I told you about the last graph?
S: yes
T: about variables, and independent variables?
S: uh, this one (age) is the independent variable and this one the dependent
T: yes, so where does the independent variable go?
S: the independent variable goes on the y axis

In terms of activity theory, the student determines the operations (putting age on the y axis and speeding tickets on the x axis) which have to be performed to materialize an action (making a graph). Although this operation is not correct in itself (age should go on the x axis), the student appears to have appropriated some part of the activity from solving exercise 1, that is, he knows that the variables should be assigned to the axes. The last student comment is also indicative of the fact that the appropriation of the activity is not working out all right: for the second time the student argues that the independent variable goes on the y axis. What is remarkable is that, despite the teacher's negative response 'why!', the student did not realize the cue, and went on in an attempt to justify his argument. His position reflects a lot of confusion as to what the rationale is, and from what he is saying it is clear that he is trying to refer to the independent variable but without much success: 'something that is given', 'it's not to be measured'. It also is very interesting to note that the teacher, instead of choosing to build on student's incipient understanding of what an independent variable is, e.g. 'given', responded to the linguistic part of the student's utterances, and not to the conceptual part. The student, conceptually speaking, seems to be quite close to conveying what an independent variable is. In doing this, however, he uses inappropriate language. The intervention of the teacher at this point shows a persistence upon genre appropriation: the student has to learn how to talk about it in scientific terms. The teacher refutes student's argument linguistically, and her contribution is linguistic: 'variables and independent variables'.

Jim, exercise four
[student is about to start making the graph]
S: uh…so….I have to put….uh…the age on the….x axis
T: yes!

Jim, exercise five
[student is about to start making the graph]
S: …ok I am going to…uh…this one is on the x axis
T: yes! That's my boy!

In these two exercises from an activity theory viewpoint, the student seems to have appropriated the action and the operations to realize it: he knows what has to be done (i.e. operation) and can describe it on the discourse plane. It should be noted, however, that the teacher checks neither this understanding of the activity, nor the genre and the requisite principle. The teacher simply seems to be content with the fact that the student has learned what has to be done (i.e. knowledge of algorithm and the order of the steps to be performed).

Jim, exercise six
[student is about to start making the graph]
S: uh…it's gonna be…uh…this one is gonna be on the axis
T: cause it's the (waiting for student input)
S: independent
T: independent variable, precisely

From an activity theory point of view, the student clearly shows once more that he is able to identify the operations to realize a particular action. From a Bakhtinian viewpoint, the present excerpt has some special significance because the student used the term 'independent variable' autonomously. In fact, the student was cued to used the term, and, therefore, the term was elicited by the teacher. In this sense, the student has appropriated the genre but is probably not capable of using it freely and independently. From a Vygotskian point of view, the appropriation of genre does not signify the acquisition of the concept. The word is a carrier of the concept and the path to it, but the knowledge of the word does not coincide with knowledge of the concept. Therefore, on the basis of this excerpt it cannot be judged whether the student has also appropriated the principle.

Jim, exercise seven
[student is about to start making the graph]
S: it's this one…this one goes on the x axis (meaning the variable of the total number of drivers killed in car accidents)
T: yes! Because it's the (waiting for student input)
S: left one (meaning the variable on the left)
T: the left one? (laughing)
S: It's always the left one (laughing)… no it's because it's the independent
T: thank you! That was a very intelligent comment uh? It's the left one. Ok.
[dialogue goes on – the issue is not discussed again]

From an activity theory viewpoint, the student exhibits once again that he knows what needs to be done and identifies the variable positions correctly. As far as the operations for realizing a particular action are concerned, there is nothing more the student could learn. From a Bakhtinian viewpoint, the student is able to use the genre, but only at an explicit teacher request. The genre has been appropriated but the student is probably still incapable of using it independently. From a Vygotskian point of view and in regards to concept understanding, *this episode reveals that the student has notoriously failed to grasp the essential principle concerning variable positions*. The student has made an ingenious observation, however, which allowed him to successfully cope with the requirements of the task: he noticed that the independent variable was the first variable to be reported in the data-table (this is remarkable because nine other students who participated in the study did not notice or report it). The student had mentioned earlier in exercise two that it is the variable on the left which goes to the x axis, but at that time the teacher did not respond to this comment, because it was unintelligible. In this case, however, the student is being very explicit about it, in fact, so open that the teacher thinks of it as a joke, commends the student for a ‘very intelligent comment’ and the solution goes on! With respect to the principle(s), this particular student has probably failed to grasp what the independent variable is all about, even though he was able to perform an action/operations with it and talk about it using the proper genre. The student reached no deep understanding of what an independent variable is or why it is independent: in fact, he missed all the conceptual modeling (rationale) behind the problem solution.

As far as the particular student is concerned, the analysis of the excerpts shows that the student progressively appropriated the *activity* in its entirety. Even though in the first exercise he knew very little about correlational problems and graph construction in particular, by the last exercise solved the student unequivocally exhibited knowledge of the activity. Thus, as a result of the instruction and the interaction with the teacher, the student had acquired the requisite knowledge of the actions needed to be carried out, and the specific operations to be drawn on to realize these actions. From an activity viewpoint, all activity components were appropriated. The same pattern occurred with the appropriation of *genre*. In the first exercise the teacher had to introduce some concepts which would have to be used later on in solving the problems. In the first exercise the student had no knowledge and understanding of the genre, of the particular language used to describe these terms. This, however, changed over the exercises, although the student did not reach the maximum of his potential: he did not seem to associate the variable positions with the terms independent and dependent variable independently. In the case of genre appropriation, therefore, more work could have been done. As far as the appropriation of the *principle* is concerned, the student progressed throughout the exercises, but this progress was not optimal. His understanding of the rationale of the problem solution was very poor, and in this sense will not take him very far, when he is confronted with another problem. In a sense, he failed to acquire the meaning of the actions and operations taken, and see why and how they fit together in achieving the overall goal.

8.4.3 Putting the mind in gears before putting the mouse in motion

> *“There no longer exist relations between us. Some time ago I lost my sense of the border between us…the cello is my tool no more”*
>
> M. Rostropovich (cited by Zinchenko, 1996, p. 295-96).

A typical feature of the CS treatment was that the students right after the reading of the exercise grabbed the mouse and started producing a scattergraph without really thinking about it very well - if at all. A recurrent pattern we observed was the teacher ‘fighting’ the students over the possession of the mouse: at times the teacher even had to remove the mouse from the reach of the students to force them into thinking and planning before producing the graph. In analogy to the trigger-happy metaphor, the teacher developed the *mouse-happy* metaphor, referring to students who basically liked to click the mouse without first thinking about what needs to be done and, more importantly, why.

According to the literature the computer is expected to lead to the activation of planning and hypothesis skills (e.g. Tikhomirov, 1974) as well as higher order thinking skills (Vockell & van Deusen, 1989). The use of the computer is expected to make the implementation of plans easier, thus, saving a lot of time and effort, making it possible to devote most of the time and mental energy to devising plans and generating hypotheses. According to the code frequency analysis CS students were both asked more conceptual questions and provided more conceptual answers compared to the PP students. This fact, coupled with their improved post test performance, attests to their understanding of correlational reasoning and suggests that they acquired the knowledge and skills required to solve correlational problems. Hence, CS students could not really get away with less thinking effort in solving correlational problems. What is important to note, however, is that, contrary to these theoretical expectations, CS students deliberately and consistently failed to exhibit such patterns of higher thought (e.g. more exploratory, planning, hypothesis, what-if behavior). *They simply perceived of the spreadsheet as a great opportunity to reduce the amount of the time and the mental effort they would have to put into solving the problem*. In fact, observations made during the tutorials suggest that CS students were routinely not involved into any higher order thinking or at times any thinking at all! Students considerably appreciated the affordances of the computer in terms of avoiding tedious and recurrent problem solving activities and, thus, they treated the whole task as a routine one without really engaging any higher order thinking. This type of thinking behavior might be considered ‘sinful’ as it leads to ‘mindless’ learning – as opposed to ‘mindful’ (Salomon & Globerson, 1987).

One of the reasons for failing to find such a pattern of behavior is the well established fact of opportunities afforded by the tools vs. opportunities taken (Salomon 1985; Salomon & Perkins, 1996). It has been repeatedly stressed in the literature that the fact that computers offer so many wonderful opportunities to enhancing learning is no guarantee that these opportunities will be exploited to any extent. Whether or not these opportunities are taken is utterly dependent upon a host of factors (Salomon & Perkins, 1996).

‘Mindless’ learning is considered to be rather unproductive because students simply don’t sufficiently activate their thinking operations. The paradox is that had a computer tool been introduced in the workplace saving physical and mental energy, the improvement would have been more than welcome. In the school environment, however, this would have been an undesirable situation, definitely not contributive to higher learning. If we follow and extend Norman’s (1993; in press) line of reasoning to classroom contexts, then *it is only natural that the introduction of the tool in the problem solving process entails that students have to spend less mental energy on the task*. As a matter of fact, this is the ultimate criterion of tool effectiveness, since the tool takes over some of the mental processing involved in the execution of the task. In education, therefore, we use the computer to enhance higher order thinking skills but at the same time its use de facto ensures that less thinking opportunities are likely (provided that the use of the computer tool is indeed efficient). If nothing changes in the current teaching and pedagogical conceptions, then chances are that learners will not take the mindful road to learning. And why should they? We are constantly searching for new ways to improve whatever we're doing and make it easier. We use hundreds of artifacts to reduce the physical and mental effort of performing our everyday tasks. Why should this not be legitimate school practice? Why is it that this is considered to be heretic thinking in a school environment? Perhaps the time has come to seriously reconsider the implicit assumptions upon which this field is based. Moreover, a change in the orientation of the teaching and learning curriculum seems to be imperative. As Salomon, Perkins & Globerson (1991) put it, the introduction and use of a new technology like the computer should be accompanied by the use of 'new' tasks, since the activity is restructured (cf. COMMITT, 1996; President's committee of advisors on science and technology, Panel on Educational Technology, 1997; Plomp & Brummelhuis, 1998).

8.4.4 Effects *of*, *with*, and *without* tools

"To determine the proper place of computers in the classroom, a theory of learning is required"
Dreyfus & Dreyfus (1997, p. 715).

Salomon (1992a) distinguished between effects *of* the tool and effects *with* the tool. Effects 'with' technology represent cases where the technology is actively being used to perform a task, in a form of partnership. Effects 'of' technology represent the cognitive residue from interacting with technology. In our own study we came across an interesting phenomenon: in the post test subjects in the CS condition knew what they had to do to solve the problem (i.e. make a scattergraph) but did not really know how to do it! The most striking illustration comes from John, a pilot subject: in the post test he readily realized that a scattergraph would be required to solve the problem. He was given paper and pencil but seemed to be extremely confused as to what to do in order to produce a scattergraph: he drew two axes and then was striving to remember what needed to be done after. On the post test CS students, when asked to solve the problem without the aid of the spreadsheet, resembled the PP ones when they were faced with making a scattergraph for the first time during exercise one: they knew more or less what a scattergraph is and how to make one, but they lacked all the detailed knowledge of how to produce one. The have had scattergraphs in the past and knew basic facts about them; what they lacked was practical knowledge of how to construct them. John said: "I know I have to make a graph, but how on earth am I gonna do it?" This comment by the student is remarkable in that it indicates that when the tool is unavailable the problem solver is rather hopeless. If a certain activity is learned with the aid of a tool, then eventually the tool becomes invisible in the whole process: what matters is the activity objective itself. When the tool is removed or breaks down the solution to the problem or the performance of an activity is in jeopardy.

Salomon, Perkins & Globerson (1991) argued that the use of paper, slide rule or work processor may redefine the tasks of memorization, computation or writing and increasing performance on these skills but does this “make students any *smarter*, better skilled communicators, or better skilled learners (or alternatively less skilled) as a result?” (p. 3, emphasis added). They claim that it is debatable whether the interaction with these cognitive technologies leaves any cognitive residue. Based on evidence from the present study, it might be argued that this question is not the most appropriate to ask. It is legitimate to raise such questions if and only if students will be expected to perform a certain task without the aid of the tool or if a task can be defined irrespective of the tool. This question makes sense only if we assume that the technology will not be available for practicing a certain skill, either by design or by accident. In educational settings due to deliberate design no technological devices (such as calculators or computers) are allowed. In our study for example, we were initially planning to ask students solve the post test using paper and pencil. For some of the subjects this proved to be impossible, especially in regards to making a graph, because they lacked knowledge and skill. We agree with Salomon, Perkins & Globerson (1991) in that we need to redefine what ‘smarter’ means. If smarter is taken to suggest been able to perform a cognitive skill or complete a cognitive task autonomously, then it is most likely the case that the users will not be smarter. As Olson (1976) argued, however, “when you consider the man’s strength or power, you must look at the man-machine system; the underlying processes that go into an act of strength differ depending on the machine that the man is ‘hooked’ to” (p. 191-92). Consequently, to define intelligence one should look at man-cognitive technology system, that is, consider the technologies at one’s disposal, because these technologies by definition partake in ‘intelligence’.

Moreover, Salomon, Perkins & Globerson (1991) argued that “even if computer technology became as ubiquitous as the pencil, students, would still face an infinite number of problems to solve, new kinds of knowledge to mentally construct, and decisions to make, for which no intelligent technology would be available or accessible”. They claim that some problems “need an independent and capable thinking mind, not one that constantly depends on the partnership with technology, intelligent as it might be” (p. 5). Of course, there is a flip side to this argument. What they fail to acknowledge is that technology inevitably transforms the task along many different dimensions. In fact, technology may restructure a certain task to such an extent that the task can not be defined irrespective of technology or simply be meaningless without it. This is what Wertsch (1998) calls the ‘developmental path’ of technology. As he put it, designing an airplane in the 1960s required a lot of draftsmen working for months with slide rules and other drafting equipment. In sharp contrast, today the same task might be performed by a single designer who uses complex imaging software within hours. In a way, the modern designer lacks the skill of using slide rules and the refined knowledge of complex mathematical formulas and, thus, is less skilled compared to a 1960s designer. What is important to note is that lacking this knowledge and skill does not matter anymore in the present day context; what is absolutely called for, however, is knowledge and skill related to the computer tool available. In a similar vein, John’s remarks and behavior seem to suggest that the requirements of the task and the resulting understanding might substantially change so that performing the activity without the tool might be at best troublesome or downright impossible. Therefore, we might speak of ‘*effects without*’ the technology: when technology does eventually become ubiquitous, at least in respect certain activities can only have meaning in relation to it.

8.4.5 The interface *is* the problem

“If you ask people what computer they use, they will often say ‘Windows’”
Winograd (1997, p. 52).

As already discussed, in each condition there are a number of terms – which correspond to activities or actions – which are either unique or more frequent. In each condition the problem is talked about in terms of the particular tools available for its solution. The tools afford specific actions. On the basis of such findings, it is argued that *the interface is the problem*, in the sense that the problem elements are talked about and referred to in terms of the specific interface elements and tools. Other studies have reported similar results. Student’s talk appears to be revolving around and be tied to various interface items (Saljo, in press) and this basically is indicative of what enters student talk first (Kollias, 1997).

The issue of how something is learned as a function of how it is taught, or, better, how media influence learning, has been long debated in education. Salomon (1974; 1994) spoke of media attributes which lead to or afford the formation of unique cognitive representations, which in turn may facilitate learning. In the early 1980s Clark (1983; 1985) proposed the truck delivery metaphor to describe media effects on learning, arguing that no changes in nutrition can be effected by the truck delivering the groceries. More recently, Clark (1991; 1994) argued that there is confounding between medium and method, and that media will never influence learning. More particularly, in a rebuttal of Kozma’s (1994) views, Clark claimed that “one way to begin to answer questions about the structural necessity of media attributes is to ask whether other learners have achieve similar learning results with different instructional treatments. Have learners acquired problem-solving techniques similar to these presented in ThinkerTools or Jasper in the past? If so, the media attributes available from expensive computers and video disks are not structurally important in learning problem-solving skills” (1994, p. 27). Even though the argument is sound, as in principle students can learn a skill through different instructional methods and media, it is essentially a product-based argument. That is, the test Clark proposes is one based on performance alone; what is missing is the *unique* learning experience which can be acquired from working with a particular tool (medium). What Clark's argument overlooks is that the same learning goals might be reached in terms of test performance, but that learning as a whole might be qualitatively different in the two cases. *Performance alone may not reflect the unparalleled learning qualities acquired from working with a particular medium/tool*. Therefore, the important issue is the particular qualities of learning acquired by working with different tools and not whether students reached the same competence levels.

The findings of the present study support the arguments by Salomon (1974; 1994) and Kozma (1991; 1994), but not Clark's views. On the one hand, *both groups of students learned to solve correlational problems but at the same time acquired different sets of skills*. For instance, PP students acquired more knowledge and skills concerning the making of graphs, particularly shortcuts which allowed them to produce graphs quickly and relatively accurately. CS students, on the other hand, seemed to be more competent in reading graphs, drawing trendlines, and estimating the specific magnitude of the correlation coefficient on the basis of the spread of dots. In principle, both groups could make a graph, even though it certainly was most difficult for the CS students to make one within the allotted time period. Additionally, both groups could make a prediction about the strength of the relationship while CS students would most likely be more accurate. Therefore, *even though on the basis of performance Clark's condition is met* (i.e. both groups acquired comparable skills), *the fact that each group was more skilled in some respects disproves the argument*.

On the other hand, it was found that *the problem is talked about and referred to in terms of particular properties/affordances of the tools available for its solution*. The tool (medium) employed in the solution of a task has certain affordances which make the solution of the task possible in some ways and difficult or impossible in others. If we assume that there is a connection between what is talked about and what is learned, then we would expect the use of different tools to lead to some sort of unique understanding of the task within each treatment condition – unique in the sense that it is inextricably tied to the specific tool. As a consequence, reasoning would be also effected in terms of the concrete tool or interface elements as well. Hence, as indicated by the analysis of the genre, each tool affords unique ways of working and, as a result, unique ways of understanding. The findings of the present study do not support Clark's (1991; 1994) contentions about the confounding of medium and method.

8.5 Implications for the teaching and learning practice

First, the analysis of the time spent on the different phases of the graph showed that the use of the spreadsheet minimizes the time required for the production of the graph. Thus, the spreadsheet proved to be particularly helpful in reducing the time required to produce graphs. Point-to-point graph construction is an indispensable problem solving tool and it takes some time to develop the set of cognitive skills required for graph-based problem solving. When the main principles of graph construction are mastered by the students and some skill in constructing accurate graphs is acquired, the computer spreadsheet (or any other graphing program) might be used to reduce the time called for the production of the graph. A certain type of problems in physics, mathematics, and geography may be solved by constructing and studying graphs and relationships between variables. *The findings of the study suggest that in the long run, if the computer is used for the production of graphs some time might be saved for other learning activities, like additional practice, discussion or reflection*. Needless to say that the spreadsheet might greatly compress the time needed to make a graph, but how that time is instructionally exploited depends upon the teacher (or the instructional designer) and the students themselves.

Second, discourse analysis indicated that CS students made more errors. Moreover, in the PP condition errors had devastating and very time consuming effects on the problem solving process. In this case, the teacher-student dyads needed to detect the errors in the offing, especially errors related to graph construction. Such an error discovered during plotting (i.e. inappropriate scale) would require making the graph all over again and commencing plotting. This was costly in terms of time, as well as in terms of moral: the students seemed to easily disappointed and rather bored. Mistakes, thus, had to be detected and the student was alerted to them early on. The most common errors were related to graph construction: disproportionate axes; improper scale; variable units; inaccurate plotting. On the other hand, in the CS condition students made a lot of errors as well. The most important difference is that these errors were interface-related ones: the student would drag a graph object to the side more than necessary so the whole object would have to be traced and moved to the initial position again; sometimes entering data was not quite accurate; clicking on the wrong spot resulted in pop up windows which were not relevant to the object of the activity. Therefore, on the basis of these observations, it may be argued that *by using the spreadsheet students are essentially relieved from the anxiety of making an error and may freely focus on other, more important aspects of the task*. There is also more freedom and possibility for exploration and, thus, the errors acquire a rather more instructive role, as learning possibilities.

Third, task engagement was higher in the CS condition. For example, most student task specific problem solving behaviors were more frequent in the computer condition, mostly due to the fact that more graphs were made per exercise. Additionally, more teacher factual and conceptual questions were asked in the same condition. The possibilities of these findings with respect to student engagement on the task are clear. *The use of the spreadsheet creates more possibilities for active task engagement, especially with respect to stating variable relationships and providing task related answers and information*. Again, provided that there were no performance differences, the most decisive factor is *how* exactly the computer is incorporated in the teaching and learning process.

Finally, given the transformation effects of the spreadsheet on the solution of correlational problems, it may be argued that *the whole problem solving curriculum needs to be reformed with different objectives in mind*. If it is indeed our aim to produce thinkers, then we should perhaps move into this specific direction, from an instructional perspective as well. For example, it is often assumed that the use of the computer creates more opportunities for higher order thinking, for devising plans and problem solutions, for generating and testing hypotheses and for evaluating the evidence. This hypothetical-deductive mode of thinking is not explicitly emphasized in the current curricula. In principle, the fact that the computer may assume the burden of testing those hypotheses and rapidly implementing those plans cannot be disputed. But should this be our direct goal, then we must restructure the learning and problem solving curriculum in such a way that indeed it places emphasis on the generation, testing and evaluation of hypotheses and plans. The computer may then assume the responsibility for implementing those plans/hypotheses. Such an approach takes into account the transformation effected by the computer tool and the student is then expected to play a different role: instead of carrying out all computations (or equivalent operations) and solving one problem, it might make more sense to ask the student to check a number of hypotheses, in more than one direction and for specific data ranges, and taking other factors into account. The selection of tasks will have to be also modified appropriately to suit this new student role. For example, tasks which are rather straightforward and require a single solution and interpretation might only be appropriate for the initial stages of learning in a domain. To sustain new student roles, the tasks should not have one and only, clear-cut, final solution; rather they should be more realistic, allowing for multiple interpretations-solutions, each of which has certain pros and cons. As has already been stressed in the literature time and again, when the computer is introduced for supporting learning, *the whole culture of the learning environment needs to be changed to conform to the new situation.*

8.6 Concluding remarks

The study of *regulation* provides new perspectives and possibilities for studying learning and enriching our perception of it. Relatively little attention has been given to regulation in the literature since the teacher has been generally perceived of as the provider of information. However, simply presenting new information to the students is only one aspect of teaching and learning because the information may be too complex to comprehend, especially if the task is conceptually demanding. Even if we assume that the student can follow all new information provided by the teacher, this does not amount to mastering the task or learning how to solve it. For instance, in the case of correlational reasoning, the teacher may provide all the information needed and demonstrate the algorithm in a few minutes. Assuming that the students can indeed apprehend the procedure, does it mean that they are able to solve correlational problems? From the point of view of new information, the students can be taught nothing more but have quite a lot to learn. On the other hand, providing new information and concepts does not mean that they are acquired automatically in their entirety. It takes time and involves a lot of supervised practice. In the recent years this has been described in terms of cognitive apprenticeship in the instructional literature (cf. Pieters & de Bruijn, 1992). In this type of studies, the student is gradually introduced to the task, works under close supervision, and is being given more freedom as mastery increases. The emphasis on regulatory processes in this dissertation aims to stress the fact that just as the acquisition of knowledge and facts in a domain is a gradual and time consuming process, so is the development of regulatory skills called for in performing a task (i.e. knowledge of the procedures, why, how and where they can be applied). Research in the area of metacognition has convincingly demonstrated that mere knowledge of facts and strategies is not sufficient for effective task performance unless it is known where, how, and why to apply it. The regulatory dimension has received relatively little attention in the instructional literature and hardly any in the field of computers and learning.

On the other hand, the concept of *genre* can be combined with the acquisition of scientific concepts (c.f. study 1) and the appropriation of the activity (c.f. study 2). In both cases the study of the genre in instructional contexts might be very helpful for understanding learning. For example, using the model developed in chapter 4, instructional discourse may be explored in many different ways and student’s understanding many be appraised in multiple dimensions. Because quite a number of teacher questions are factual or definitional ones, students adept at genre will give the teacher the impression that they have knowledge and understanding of the concepts while they may actually ignore the principle or have no substantial understanding of it. This is because the appropriation of the genre is not equivalent with the understanding of the underlying concept. Therefore, students might do ostensibly well simply by recalling concept names (that is, using the appropriate genre), but perform poorly when some understanding of the procedures or principles is required.

With respect to the contribution of the *computer spreadsheet*, it has always been assumed that the use of the computer speeds up the task, makes its execution easier and leads to increased productivity. In educational contexts it has been established that the use of the computer improves student performance. A recent review, however, showed that this supposed influence on productivity is largely a myth as far as the workplace is concerned (e.g. Gibbs, 1997). The results of the present study did not confirm amplification views, while transformation views were substantially validated. Provided that these existing assumptions about what computers can do to assist learning have been around for too long with comparatively little evidence to support them, it is perhaps time to be seriously concerned with what the actual contribution of computers to learning is and how it can be facilitated. If it is indeed true that computers transform the task, then we need to revise the curriculum, change our instructional approaches, and develop new tasks which engage students in higher thinking processes. If no measure is taken, the very use of artifacts in instruction and learning would unquestionably entail that the students have by definition less thinking opportunities because of the fact that artifact designers have already done part of the thinking involved.

In this dissertation we have focused on the role of the teacher from a regulatory point of view. In the context of the school environment, however, fellow students are also social others who can assist with regulation, provided that they have higher experience or expertise in a domain. Future research might explore further the role of the teacher as well as consider the role of peers form a regulation perspective, especially in the context of small group learning.

In the present work, we have examined discourse from a qualitative point of view, particularly with the development and application of the discourse model. The frameworks synthesized in the model (Vygotsky, Bakhtin, Leont'ev) should be more integrated theoretically in future research and, possibly, enriched with other perspectives. Moreover, the discourse model per se needs to be further validated with other types of tasks and discourse.

For the purposes of quantitative discourse analysis we have employed sequential analysis in this dissertation. It is interesting to note that nowadays and due to the computer mediated nature of communication there is a bulk of data available in electronic format e.g. email, newsgroups, WWW-based discussions etc. Future research may explore the potential usefulness of sequential analysis with such data as well as in areas like log file analysis, and data mining.

We are only beginning to understand how computers contribute to learning. In this dissertation we have focused on two important viewpoints, i.e. amplification and transformation, in studying the impact of computers on learning. It is a task for future research to inquire the issue further, and draw connections with student learning. New tools, artifacts, and technologies are being developed today at a rapid pace. It is now possible within one's lifetime to experience the rise and fall of a certain technology, from the moment it is introduced to the market to the point where it becomes obsolete. The possibilities for explorations in this area from an educational and a psychological point of view are many and may be exploited in future research.

In this dissertation we have attempted a modest holistic approach to the issue of computers and learning. A theoretical framework enabling us to study cognition in a distributed way was employed, thus, moving beyond the individual student as a unit of analysis. A psychological theory describing the role of teacher and artifacts in learning was used for studying their impact on the development of correlational reasoning skills. A set of methodological tools was also employed in this application of the theory. Understanding how learning is influenced by both social agents (teacher, fellow students, parents) as well as by artifacts (e.g. computer) is of primary importance. Improvement of instructional and learning practice will only come about if we acquire a more profound and thorough understanding of what learning is and how it is aided, facilitated, and effected by others and artifacts. There is no doubt that we still have a very long way to go in accomplishing this goal but possibilities abound. “We only lack scholarly, investigatory boldness, and without this we cannot rise to the heights or descend to the depths” (Bakhtin, 1986, p. 7).

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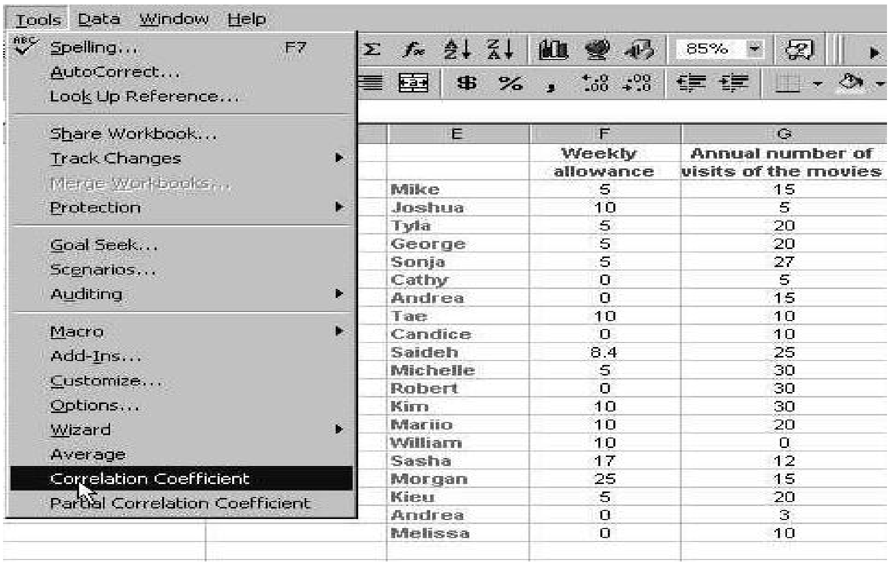
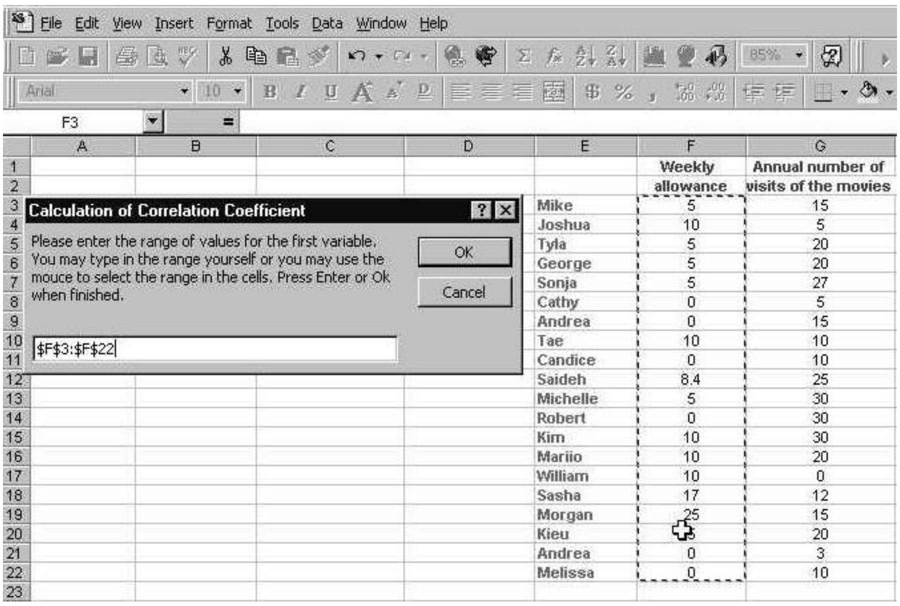
11 Appendices

APPENDIX – A: Calculation of the Correlation Coefficient

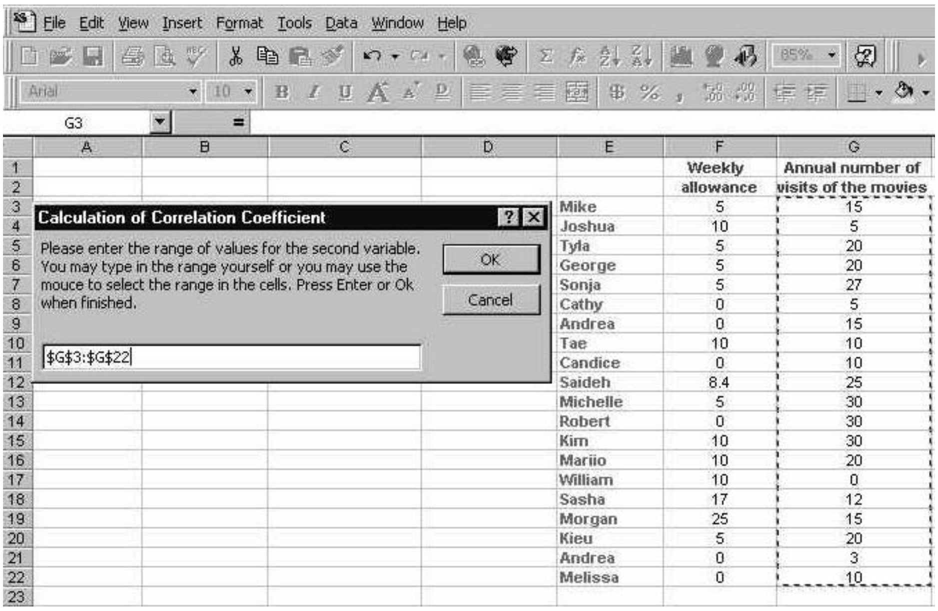
Step 1 of 4



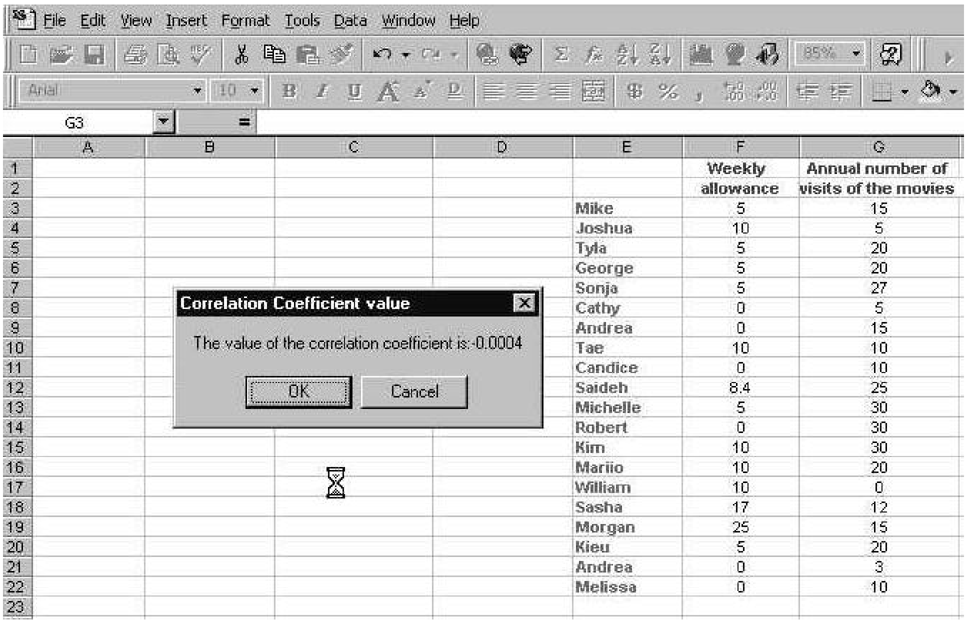
Step 2 of 4



Step 3 of 4



Step 4 of 4



APPENDIX – B: Teacher categories: definitions and examples

TEACHER CARRIES OUT A TASK SPECIFIC PROBLEM SOLVING ACTION

TR Teacher reads

Definition: the teacher is reading the exercise text. This is always marked with quotation marks in the transcripts.

Example: T: "If weekly allowance increases then the number of visits to the movies will increase, decrease or stay the same?"

TM Teacher marks

Definition: the teacher is engaged in some sort of physical problem solving activity like marking certain locations on a map, drawing a graph in order to illustrate a point etc.

Example: T: hang on…see you drew this (draws two axis again)

TEACHER CARRIES OUT A GENERAL PROBLEM SOLVING ACTION

TPE Teacher provides example/explanation

Definition: the teacher is providing an explanation and/or example to illustrate a point just made.

Example: T: what do you think would happen? Cause these guys …this one, whatever his name is reckons that Sasha must get a big allowance because
she has been to all the movies, but then Sasha says no, I only 17 bucks a week but then there are some people who don't get as much money but they've seen a lot more movies. But she reckons that there are other people who get less! money and see more! movies

TREF Teacher refers to material covered earlier

Definition: The teacher is drawing student's attention to concepts and/or information discussed or presented earlier in the tutorial

Example: T: remember I said that the correlation coefficient is a number that tells you how strong the relationship is?

TEL Teacher elaborates

Definition: the teacher is not adding new information to the present topic of discussion but is explicating it in a sense. Elaboration is a default category of all teacher actions.

Example: S: why do I think that way?
T: why do you think that way? That's a matter of interest

TPNI Teacher provides new information

Definition: the teacher is providing new concepts, among which: correlation, correlation coefficient, scattergraph, trendline, independent variable, dependent variable, control variable, partial correlation coefficient.

Example: T: this thing down here is called the independent variable

TPII Teacher provides interface information

Definition: the teacher is providing information related to some specific aspect of the computer interface.

Example: T: This icon over here in the toolbar is the chart wizard icon.

TESK Teacher evaluates student's knowledge

Definition: the teacher refers to knowledge, concepts etc covered in previous exercises or even school grades and attempts to determine student's knowledge.

Example: T: do you remember what the correlation coefficient is?

TRAI Teacher requests additional information

Definition: the teacher is requesting more information in order to understand what the student is trying to say.
Example: S: no
T: what no?

TIN Teacher interprets

Definition: the teacher is either asking a question or is arguing a statement in which she is trying to make sense of and understand what the student has said.
Example: T: so you mean people who move out in the country, then it becomes so expensive, then they move out back into the cities, so the population would go down?

TEACHER REGULATES IN A DIRECT WAY

TFA Teacher focuses attention

Definition: the teacher draws student's attention on some specific aspect of the problem solving process.
Example: T: ok…now take a look at all these other places Lizie,

TSG Teacher sets a goal

Definition: the teacher is proposing a course of action, being it a general strategy or a more specific sub step.
Example: T: so why don't you check it out, and see what happens?

TSIG Teacher sets an interface goal

Definition: the teacher is setting a goal which is only related to performing a specific action with the spreadsheet
Example: T: click 'finish' to make the graph

TSST Teacher summarizes step

Definition: the teacher is describing all the steps taken, the desired goals and reviewing the current state, to provide an overview for the student.
Example: T: so look, basically this one worked out fine (referring to the latitude - degree days graph), just as you expected it would go, right?

TCE Teacher corrects error

Definition: the teacher is providing a correct answer, interpretation or step.
Example: S: So this is perfect
T: no this is not perfect…the perfect is -1

TCS Teacher confirms step

Definition: the teacher confirms a student action, step, or interpretation.
Example: S: make a graph?
T: yeah

TCT Covers the table

Definition: The teacher is covering the table that contains the exercise data so that it is easier for the student to find the next pair of values to be plotted.
Example: T: is this easier Elizabeth? (covers the table with a sheet of paper)

TCON Calls out the numbers

Definition: the teacher is calling out the numbers (exercise data) so that the student does not have to look at the table to find each pair of numbers, so he/she can work faster.
Example: T: hang on, hang on, I've got one more Penticton, with elevation of 342
S: uh hm
T: and 2126…and 49 and 2126

TSS Teacher starts sentence
Definition: the teacher is trying to make the student state something, and by starting a sentence she provides the much needed structure.
Example: T: so if the weekly allowance increases, then the number of visits to the movies will (waiting for input)

TEACHER REGULATES IN AN INDIRECT WAY

TRPL Teacher requests planning information
Definition: the teacher is asking a question which prompts the student to think ahead and determine a course of action.
Example: T: but if you were to use some kind of diagram then to show this information, what of diagram would you use?

TREV Teacher requests evaluation information
Definition: the teacher is asking a question which requires the student to look back and ascertain whether the outcome reached was expected or not.
Example: T: and did you expect that to happen?

TRIN Teacher requests interpretation
Definition: the teacher is asking a question which invokes the student to interpret an aspect of the problem solving process, make sense of a solution or strategy
Exercise: T: ok so when it says as latitude increases, what does it mean?

TRFI Teacher requests factual information
Definition: the teacher is asking a question that can be answered on the basis of the information present in the task environment or on the basis of real world knowledge.
Example: T: how many degree days does it have?

TRCI Teacher requests conceptual information
Definition: the teacher is asking the student a question the answer to which cannot be found in the perceptual field; the student has to refer to material and concepts presented thus far, has to consult the visual information available and then has to integrate all the above before a conclusion can be reached.
Example: T: so what's your conclusion now?

TRE Teacher requests explanation
Definition: the teacher is explicitly asking the student to justify something, an idea, concept, a step etc by means of an example or explanation.
Example: T: then how can you say whether your prediction was true or not?

TIE Teacher indicates error
Definition: the teacher is indicating that an error has been committed by the student.
Example: T: then we're gonna need one hell of a long graph honey

TAS Teacher alerts student
Definition: the teacher is asking the student to concentrate, think carefully etc.
Example: T: think carefully

TEACHER CHECKS IF STUDENT IS FOLLOWING

TCSF Teacher checks if students is following

Definition: question tags which serve the purpose of making sure that the student is following, is understanding and does not have any problems with the concept/material presented.
Example: T: right?

TEACHER SHOWS THAT STUDENT WAS UNDERSTOOD

TCNF Teacher confirmation

Definition: a teacher utterance made up of one word showing that the teacher is following student's line of reasoning.
Example: T: yeah

TEACHER EMOTIONAL SUPPORT

TSUS Teacher supportive statement

Definition: the teacher is providing emotional support for the student.
Example: T: that's my girl

TEACHER TASK IRRELEVANT STATEMENT

TCOM Teacher comment

Definition: the teacher is making some task irrelevant statement
Example: T: you're welcome

APPENDIX – C: Student categories: definitions and examples

STUDENT CARRIES OUT A TASK SPECIFIC PROBLEM SOLVING STEP

SR Student reads
Definition: The student reads the exercise text.
Example: S: "Sasha and Kieu were sitting in their school cafeteria with a group of friends…."

SP Student predicts
Definition: the student is making a prediction regarding the direction of the relationship between two variables referred to in the exercise.
Example: S: the number of speeding tickets will decrease

SDIV Student determines independent variable
Definition: the student decides which the influencing variable is
Example: S: ….age influences the number of speeding tickets

SDA Student draws axis
Definition: the student draws an axis
Example: S: 5, 10, ….(draws the y axis)

SLA Student labels axis
Definition: the student labels the axis
Example: S: …ok…age (labels the x axis)

SDVP Student determines variable position
Definition: the student decides on what axis the independent variable will be on
Example: S: so latitude goes here (meaning on the x axis) and degrees (meaning temperature) over there (meaning on the y axis)

SDCV Student determines control variable
Definition: the student decides on which the control variable is.
Example: S: latitude

SSD Student selects data
Definition: the student uses the mouse to select the variable data. Always indicated in parentheses in the transcript
Example: (student selects data)

SDU Student determines the unit
Definition: the student determines what the unit is
Example: S: …I'll go by 50

SDAU Student divides axis into units
Definition: the student divides an axis into units
Example: S: here…30…(dividing the x axis into units),

SPS Student puts in scale
Definition: the student is putting in scale on an axis.
Example: S: ok, 0, 5,10, 15,20, 25, 30 (putting these values on the y axis)

SCLA Student changes the length of the axis

Definition: the student edits the graph and then modifies the length of the scale. Always described in parentheses in the transcripts
Example: (student changes the length of the axis)

SPL Student plots
Definition: the student plots the data of the exercise
Example: S: ok, so he gets 5 and goes 15…there (puts a dot)

SDT Student draws a trendline
Definition: the student draws a trendline
Example: S: well it's let's say like this (draws a line again)

SCT Student calculates a trendline
Definition: the student makes use of the 'insert trendline' feature of the spreadsheet and has Excel draw a trendline. Always indicates in parentheses in the transcripts.
Example: (student uses Excel to calculate a trendline).

SPG Student produces a graph
Definition: the student clicks on the 'ok' or 'finish' buttons on the last chart wizard window. Always indicated in parentheses in the transcripts.
Example: (the graph appears on the screen).

SRG Student reads the graph
Definition: the student decides on the nature of the correlation, i.e. positive, negative or no.
Example: S: well, there is no correlation

SSC Student reports variable relationship
Definition: the student is stating how the two variables are related.
Example: S: that the older they get, the less tickets they get

SCCC Student calculates correlation coefficient
Definition: the student uses one of the built-in macros to calculate the correlation coefficient. Always indicated in parentheses in the transcript.
Example: (Student calculates the correlation coefficient).

SCPC Student calculates partial correlation coefficient
Definition: the student uses one of the built-in macros to calculation the partial correlation coefficient. Always indicated in parentheses in the transcript.
Example: (student calculates the partial correlation coefficient).

STUDENT CARRIES OUT A GENERAL PROBLEM SOLVING STEP

SEL Student elaborates
Definition: the student is elaborating on or explicating an existing discussion topic. This is a default category for student utterances.
Example: T: five hundred
S: right, five hundred

SPFI Student provides factual information
Definition: the student is providing an answer to a teacher factual information request or providing general world knowledge information.
Example: S: in Brazil it's winter when here it's summer!

SPCI Student provides conceptual information

Definition: the student is usually providing an answer to a teacher conceptual information request or providing task related information.

Example: S: Something here (pointing to the y axis) influences something here (pointing to the x axis) or something here (x axis) influences something there (y axis)

SFII Student follows interface instruction

Definition: the teacher has set an interface goal for the student and the student implements it. Usually indicated in parentheses in the transcripts.

Example: T: ok (meaning click on the 'ok' button) (Student does so)

STUDENT REGULATES HIM/HERSELF

SSG Student sets goal

Definition: the student is either deciding on what strategy to follow or simply stating a next step

Example: S: a line graph

SSIG Student sets interface goal

Definition: the student sets a goal which is cast in interface terms

Example: S: I have to go to the next window

SPE Student provides explanation

Definition: the student is providing an example or explanation to illustrate a point made

Example: S: cause I thought, the higher you get to the pole, the colder it gets

SDI Student indicates difficulty

Definition: the student exhibits lack of understanding.

Example: S: yes…what must I do?

STUDENT REQUESTS TEACHER REGULATION

SRAI Student requests additional information

Definition: the student requests more information in order to understand what the teacher said, or what the teacher expects him/her to do.

Example: T: how can you tell?
S: how can I tell?

SRCI Student requests conceptual information

Definition: the student is asking the teacher a question that has to do with the subject matter being taught.

Example: S: isn't that possible?

SRFI Student request factual information

Definition: the student is asking the teacher a question the answer to which can be given by simply looking at the environment.

Example: S: yeah….that! the….are these what you measure?

SRII Student requests interface information

Definition: the student raises a question which is related to the spreadsheet interface

Example: How do I edit the graph?

SAGE Student asks for goal evaluation

Definition: the student is asking the teacher for feedback in regards to a step or action he is planning to take.
Example: S: ok…say I…can I go up to five?

SAGI Student asks for goal interface evaluation
Definition: the student is proposing an interface related action and wants to know whether it is appropriate or not
Example: ..and now I go here (menu) to find the correlation coefficient?

SAEU Student asks for evaluation of his/her understanding
Definition: The student is asking the teacher for feedback concerning his/her understanding of the task.
Example: S: so if you wouldn't take this into consideration these would be different?

STUDENT STATES THAT TEACHER WAS UNDERSTOOD

SCNF Student confirms
Definition: the student indicates that the teacher was understood and/or that he/she is following teacher's line of reasoning.
Example: S: yeah

STUDENT COMMENT

SCOM Student task irrelevant comment
Definition: the student is uttering a task irrelevant statement
Example: S: it's warm, the weather does this to my brains

APPENDIX – D: Segmentation instructions

Segmentation Unit: <u>*speech function*</u>. Whenever any interlocutor's speech is serving a different discourse function, a new segment should be created. In terms of Searle's speech act theory, a function – in the way we use the term – could be defined as an illocutionary act. In terms of Bakhtin's theory, a function could be defined as the 'plan' of the utterance.

Segmentation rules:

- *Although turn taking is the most natural way of segmentation, it still is quite typical for a single teacher or student utterance to perform more than one function, and this is manifested through a change in topic or a change in goal.*

Example:

T: "Is Andrew right?"
S: no
T: it's not true
S: of course not
T: why of course not?
S: ok, if it's colder you have more chance to get snow, but uh…let me take an example…in… there isn't always snow when it's colder, is it? no

The last student utterance is made up of two parts: in the first part, the student is arguing a statement; in the second part, the student attempts to provide an example and a justification of his reasoning. There is no doubt that the two are intertwined, but for analytic purposes two functions are simultaneously served and thus the utterance should be divided up into two segments. Therefore, each turn is usually a natural segment in its own right, but each turn is further segmented when it serves more than one function.

- *Pauses in the discourse may mark the initiation of a new speech function*

Example:

T: …so what would you say,
if elevation increases, then the number of degree days (waiting for input)
…if you were to state a conclusion that is
…if elevation increases (waiting for input)

In this example there is a single teacher utterance. In this utterance there are two pauses which indicate that the student did not respond – for whatever reasons – or was not expected to respond. So in the first case after the pause the teacher is providing an explanation of what she is expecting the student to do, namely to state a conclusion. The student however fails to respond and eventually the teacher starts the conclusion sentence herself.

- *A segment can continue across utterances if and only if one interlocutor fails to respond in any way to what was said by the other.*

Example:

T: I mean it could be possible to put them on the same graph, but…
S: yes it increases]
T: how are you gonna do that?
S: yes
T: and how do you intend to do that?

In the example above it can be seen that this episode is initiated by the teacher and the student responded. The student response, however, is not acknowledged by the teacher.

- *Utterances with no clear content – like 'uh hm' – should not be segmented unless a question precedes. In that case, they have to be necessarily taken as a response to the question.*

Example:

T: so you've got information on how much pocket money these kids get and how many movies they saw
S: uh hm
T: and then the question is what is your prediction, what do you think would happen?

In this example two teacher utterances are taken to be one segment because the student is simply stating that he/she is following.

APPENDIX – E: Definitions of problem phases

Read

The reading phase includes all behavior revolving around reading the exercise text and making sense of it; examples include rephrasing by the teacher, interpretation, explanations concerning terms, new words, and concepts. Typical behaviors in this respect are: Student reads (SR) and student predicts (SP). The teacher and the student return to the exercise text from time to time later on, but this type of second reading serves a different purpose from the initial ones.

Plan

The planning phase includes all behavior on what to do and how to do it, properties of the object or the strategy to be employed etc. Planning can be distinguished into two parts. The first part concerns the actual 'what to do' discussion between teacher and student. This discussion is characterized by either student goal setting (SSG) or by student planning questions (SAGE). The second part focuses on the discussion of particular properties of the selected strategy (i.e. make a graph). Typical student planning decisions involve a selection of the independent variable (SDIV) and the control variable (SDCV).

Graph

The phase of making a graph includes all behavior related to graph construction: deciding the nature of the scale, drawing the axes, and putting in scale (respective student events: SDA, SDU, SDAU, SLA, SPS).

Plot

The plotting phase includes all behavior related to plotting the data. It is characterized by the presence of student plots data event (SPL).

Conclude

The concluding phase involves reading the graph and reporting the kind of correlation it features. It usually includes drawing a trendline, reading the graph and stating the nature of the precise relationship. It is characterized by the presence of the following student events: student draws trendline (SDT), student reads graph (SRG) and student states conclusion.

APPENDIX – F: First student goal set for the first and the last exercise

Subject 1	Exercise	Phase
S: I would test it like taking a lot of people with, who take five dollars allowance and how many movies they watch, and average ten dollars and zero dollars allowance, something like that	1	Plan
S: uh maybe we should find out which one of these is new and old	8	Plot
Subject 2		
S: yeah I can make a line graph	1	Plan
S: ok, uh…all right…..paper please	7	Plan
Subject 3		
S: a line graph	1	Plan
S: yes, I will find out if there are more accidents when people drink, ok	7	Plan
Subject 4		
S: put the lowest at the top and the highest at the bottom	1	Plan
S: we make a graph	7	Plan
Subject 5		
S: I could also draw a bar graph	1	Plan
S: so I'll make the other one 6 cm,	7	Graph
Subject 6		
S: I think you should put it in order so maybe you can see directly	1	Plan
S: so I have to put these on the graph	7	Plan
Subject 7		
S: a bar graph	1	Plan
S: x axis, y axis	7	Graph
Subject 8		
S: look at the numbers here T: yeah S: and how many times they go…	1	Plan
S: a graph.	7	Plan
Subject 9		
S: by putting them on a graph	1	Plan
S: so one number is two boxes	7	Graph