The mediating effect of task presentation on collaboration and children's acquisition of scientific reasoning

FIRST PAGE DETAILS

TITLE	**The mediating effect of task presentation on collaboration and children's acquisition of scientific reasoning**		

AUTHOR(S)	**First Names**	**Family Name**	**Institution**
1	Dorothy	Faulkner	Open University, UK.
2	Richard	Joiner	Open University, UK.
3	Karen	Littleton	Open University, UK.
4	Dorothy	Miell	Open University, UK.
5	Linda	Thompson	Open University, UK.

ABSTRACT

There has been considerable research concerning peer interaction and the acquisition of children's scientific reasoning. This study investigated differences in collaborative activity between pairs of children working around a computer with pairs of children working with physical apparatus and related any differences to the development of children's scientific reasoning. Children aged between 9 and 10 years old (48 boys and 48 girls) were placed into either same ability or mixed ability pairs according to their individual, pre-test performance on a scientific reasoning task. These pairs then worked on either a computer version or a physical version of Inhelder and Piaget's (1958) chemical combination task. Type of presentation was found to mediate the nature and type of collaborative activity. The mixed-ability pairs working around the computer talked proportionally more about the task and management of the task; had proportionally more transactive discussions and used the record more productively than children working with the physical apparatus. Type of presentation was also found to mediated children's learning. Children in same ability pairs who worked with the physical apparatus improved significantly more than same ability pairs who worked around the computer. These findings were partially predicted from a socio-cultural theory and show the importance of tools for mediating collaborative activity and collaborative learning.

FIRST PAGE FOOTNOTE

This study was conducted with the help of Gillian Cohen, Jenny Gove, Rachel Reynolds and Michelle Potts and was supported by a grant from the Open University Research Development Fund. We would like to express our gratitude to the staff and children of Springfield Middle School and Meadfurlong Middle School, without their kindness and co-operation this study would not have been possible.

RUNNING HEAD

Mediating Effect of Task Presentation

KEY WORDS

Collaborative Learning, Tool Mediated Activity, Scientific Reasoning, Children, Computer-Based Learning

The mediating effect of task presentation on collaboration and children's acquisition of scientific reasoning

Dorothy Faulkner, Richard Joiner, Karen Littleton, Dorothy Miell & Linda Thompson.

Social Dynamics in Development and Learning Research Group

Open University, Milton Keynes, UK.

Abstract

There has been considerable research concerning peer interaction and the acquisition of children's scientific reasoning. This study investigated differences in collaborative activity between pairs of children working around a computer with pairs of children working with physical apparatus and related any differences to the development of children's scientific reasoning. Children aged between 9 and 10 years old (48 boys and 48 girls) were placed into either same ability or mixed ability pairs according to their individual, pre-test performance on a scientific reasoning task. These pairs then worked on either a computer version or a physical version of Inhelder and Piaget's (1958) chemical combination task. Type of presentation was found to mediate the nature and type of collaborative activity. The mixed-ability pairs working around the computer talked proportionally more about the task and management of the task; had proportionally more transactive discussions and used the record more productively than children working with the physical apparatus. Type of presentation was also found to mediated children's learning. Children in same ability pairs who worked with the physical apparatus improved significantly more than same ability pairs who worked around the computer. These findings were partially predicted from a socio-cultural theory and show the importance of tools for mediating collaborative activity and collaborative learning.

Key Words: Collaborative Learning, Tool Mediated Activity, Scientific Reasoning, Children, Computer Based Learning

Introduction

Vygotskian and socio-cultural theories have been used increasingly to explain the beneficial effects of peer interaction on learning and development. An important concept in socio-cultural theory is the notion of mediation, which refers to the fact that we do not interact directly with reality but through psychological (e.g. language) and technical tools (e.g. a calculator). Vygotsky (1981) identified two major properties of tools. The first was that psychological tools by their very nature are social artefacts. By this he meant that tools are products of socio-cultural history neither invented nor discovered by a solitary individual. The second was that the introduction of either category of tool into an activity qualitatively changes the nature of that activity. Change the tools and you change the activity.

Computers are powerful, flexible, technical tools, which have been used for some time now to support learning in schools. Although originally intended to support individualised instruction, they are now more and more used to support children working in groups or pairs on some shared activity. Understanding the role the computer plays in mediating collaborative learning and consequent individual cognitive gain is a recurrent theme in much recent work. For example, the research literature has offered a number of striking illustrations of the ways in which computer software structures and re-organises the social processes of problem-solving and teaching and learning (Järvelä, 1995, Golay-Schilter et al, 1999). Our own work has also highlighted the role computer equipment and interface devices play in mediating joint activity. Light and Littleton (1999), for example, describe the way in which the use of a keyboard dual input device was vital in ensuring that the children engaged with one another as well as with the task in hand.

Clearly, cultural psychologists are not interested in computer technology simply as a new vehicle for transmitting knowledge or as a new way of providing exploratory environments, rather they are interested in how computers can uniquely transform how human cognitive activity is organised (Crook, 1994, Saljo, 1996, 1999). Thus there is a real need to consider the special relevance of computers for re-ordering the contexts of education by re-organising interactions among people. More specifically there is a need to understand how the use of educational software serves to re-organise the social processes of children's joint problem solving (Crook, 1992). Keogh, Barnes, Joiner and Littleton (2000), for example, compared the nature of the talk and joint activity observed in same or mixed-gender pairs of children engaged in an identical language problem solving task (involving the assembly of a poem from a jumbled collection of phrases) presented either on or off the computer. They demonstrated that the presence of the computer influenced the activity of the mixed gender pairs: boys dominated the task when it was presented on the machine. When the task was off-computer, however, the activity was distributed more equally between boys and girls.

The study reported below was designed to explore the mediating effects of different types of task environment on children's joint problem solving. The primary aim of the study was to compare the nature of pairs of children's talk and joint problem solving activity when they worked on a computer version of a scientific reasoning task with that of children working on the same task using physical apparatus. As discussed above, we would expect from socio-cultural theory that if we change the nature of the tool used to mediate a particular activity then the nature of that activity will also change. We would predict, therefore, that there would be qualitative differences in the nature of children's social interaction and joint problem solving activity when a computer environment is compared with a physical environment. Classroom-based observational studies suggest that the computer acts as an effective motivator for group work (Cummings, 1985) and that it has the potential to support collaboration on joint projects (Hawkins, Sheingold, Gearhart & Berger 1982). For example, Teasley and Roschelle (1993) reported a case study of a pair of 15-year-old children using a computer simulation, (the Envisioning Machine), to learn about the Newtonian concepts of velocity and acceleration. From their observations, Teasley and Rochelle identified three ways in which the computer could act as a resource for mediating collaborative learning: (i), it can provide a means for disambiguating language; (ii) it can resolve impasses and, (iii) it can constrain interpretations.

A second aim of our study was to compare the beneficial effects of working with a partner of the same ability compared with working with a partner of different ability. This is because Howe and her colleagues have shown consistently that children's scientific understanding improves to a greater extent when they work in mixed ability groups than when they work in same ability groups, (for a review see Howe & Tolmie, 1999). As well as exploring the effects of ability on performance, however, we were also interested to see whether type of environment interacted with ability.

A final aim of the study was to examine whether collaborative problem-solving would lead to individual cognitive gain as measured by pre-to-post-test gains on a test of combinatorial reasoning. As a number of researchers have reported findings which suggest that working around a computer facilitates collaborative learning, (e.g. Järvelä, 1995; Teasley & Roschelle, 1993), it is reasonable to suppose that this type of environment might enhance cognitive gain to a greater extent than the real-world physical environment. As Forman and McPhail (1993) point out, however, traditional, quantitative, assessments of cognitive gain such as pre-to-post test comparisons tell us little about qualitative differences in the intellectual and interpersonal processes taking place when children engage in collaborative problem-solving relationships. The primary focus of our study, therefore, was not to investigate whether one or other type of environment would produce greater cognitive gains but to investigate whether working in a computer environment would result in qualitative differences in the nature of children's social interaction and joint problem-solving activity when compared with a non-computer environment.

The remainder of this paper reports an investigation to compare the patterns of activity of mixed ability pairs and same ability pairs working on an identical scientific reasoning task in either a computer-simulated environment or in a real world, physical environment. It was predicted that there would be qualitative differences in the pattern of children's talk and problem solving activity in the two types of environment; that the computerised version of the task would provide a more supportive collaborative learning environment; that children from mixed ability pairs would benefit more from the interaction in terms of pre-to-post test gain on tests of individual reasoning ability than children from same ability pairs.

Method

Design

The study was a two factor, between participants design with type of presentation environment (computer versus physical) and relative ability of the pairs (mixed ability versus same ability) as the two factors. The study had four phases: an individual pre-test, an interaction session (where the participants either worked with the computer presentation or the physical presentation of the task), an individual post-test and a delayed post-test.

Participants

Ninety-six, 9-10 year old children, (48 girls and 48 boys) from two schools in Milton Keynes, U.K. participated in the study. Both schools served the same mixed catchment area.

Pre-test, Post-test and Delayed Post-test measures

For the pre-test and the post-tests we used a standard test of scientific reasoning developed by Kuhn and Ho, (1980) called the Candy Task to test children's combinatorial reasoning ability. This requires children to discover all possible combinations of five elements without replication. They were given five bowls of different kinds of candy and a stack of paper plates. They were told that at a party each child was allowed to choose a plate of sweets. No child was allowed to take more than one of each kind of sweet. Every plate of sweets should look different. Participants were asked to arrange as many plates of sweets as they could, to show what each child at the party had. Their responses were assigned to one of five levels according the framework devised by Kuhn and Ho, (1980).

> Level 0: Concrete Operational. Participants produce a series of combinations where there is no discernible order or systemisation to the series.

> Level 1: Emergent Formal Operational. Participants produces some systematic combination by combining one element with all possible others (e.g. 1+2, 1+3, 1+4 and 1+5).

Level 2: Transitional. Participants produce more than one two-way chain but falls short of producing all 10 possible chains. Alternative participant produces at least one two-way chain and one three-way combination. A three-way chain consists of all possible combinations of three kinds of candy where two of the three are held constant (e.g. 1+2+3, 1+2+4 and 1+2+5).

Level 3: Early Formal Operational. Participants produce all 10 possible combinations of two kinds of candy.

Level 4: Consolidated Formal Operational. Participants produce all possible two-way and three way combinations. In addition a number of four-way and one possible five-way combination may occur.

In the post-test we used a structural isomorph of the Candy Task called the Pizza Problem. Children were given five bowls of different 'pizza toppings', (paper pictures of the pizza toppings), and a stack of paper plates and told that a pizza restaurant makes every possible type of pizza it can with this range of toppings. They were then asked to make as many combinations of pizza toppings as possible to demonstrate the pizzas available at this restaurant. The delayed post-test employed an identical isomorph of the Candy Task called the Sandwich Problem. Here children were given five bowls of different 'sandwich fillings', (paper pictures) and a stack of paper plates and told that a sandwich bar makes every possible type of sandwich it can with this range of fillings. They were then asked to make as many different types of sandwich as possible.

Physical and Computer tasks

In the interaction session the participants worked in pairs on either a physical version or a computerised version of Inhelder and Piaget's (1958) Chemical Combinations Task. This task requires children to carry out a series of experiments to discover which combination of five different chemicals, (labelled A,B,C,D and E), plus a reagent (the 'mixer') make a yellow-coloured liquid. The correct solution requires two of the chemicals, (B and E), plus the mixer. Children in the Computer condition sat side by side in front of an Apple Performa 475. The computer task was especially developed for the study in HyperCard 2.2. Children in this condition could test various combinations of chemicals by using a mouse to click on the taps of the flasks to release particular chemicals or the 'mixer' into a beaker. Children in the Physical condition used real flasks of chemicals, droppers, test-tubes, safety goggles and gloves.

Procedure

Participants were given an individual pre-test to assess their scientific reasoning ability using the Candy Task. Approximately 2 weeks later the participants took part in the interaction session. The children worked in same sex pairs and were allocated on the basis of their pre-test scores to either: (i) mixed ability pairs - computer environment (12 boys and 12 girls); (ii) same ability pairs - computer environment (12 boys and 12 girls); (iii) mixed ability pairs - physical environment (12 boys and 12 girls); (iv) same ability pairs - physical environment (12 boys and 12 girls).

Same ability pairs consisted of children who at the pre-test were either both at level 0 or both at level 1. Mixed ability pairs consisted of pairs where one child was at level 0 and the other child was at level 2, or pairs with one child was at level 1 and the other at level 3. Conditions were balanced for relative ability of the pair.

At the start of the interaction session the experimenter demonstrated either the computer or the physical task to each pair and showed that mixing certain combinations of chemicals with the ‘mixer’ turned the liquid yellow. The children were then asked to work together on a new problem and arrive at a mutually agreed solution to the problem. As mentioned previously, children in the Physical condition kept a paper-and-pencil record of the tests they carried out and the computer kept an on-screen record for children in the Computer condition. Both types of record could be used to identify the solution to the problem if children scrutinised the various outcomes of the combinations they had tested. Pairs were given 20 minutes to find out which combinations of chemicals A, B, C, D and E plus the 'mixer' produced a yellow liquid. While all combinations containing both B and E produced the desired result, the optimum solution to the problem was B, E and the mixer.

Two weeks after the interaction session, participants were given a post-test using the Pizza version of the Candy Task. Approximately 3 months after the interaction session children were given a delayed post-test using the Sandwich version of the Candy Task.

Measures of Talk and Social Interaction During the Paired Interaction Session

The videotapes of the interaction were transcribed and two different coding schemes were used to analyse children's utterances.

Types of Talk

Based on the work of Bennett and Dunne (1992), the utterances were initially classified into four broad categories of talk:

(i) Task related - utterances relating to the cognitive aspects of the task (i.e. selecting chemical combinations to test, identifying the answer, making predictions, and observations);

(ii) Social - utterances used to managing social aspects of the interaction, (e.g. turn-taking and role allocation);

(iii) Procedural - utterances which referred to some aspect of the practical situation, (e.g. using how to use the keyboard and mouse, features of the computer display, using the apparatus and chemicals in the physical condition).

(iv) Off-task (extraneous) - all utterances not assigned to any of the above categories.

Transactive Analysis

As previous research has shown that transactive discussion is positively related to learning in children (Kruger, 1992; Montgomery & Azmitia, 1993), the interaction was also classified in terms of the quantity and quality of any 'transactive discussion' taking place between the pairs of children. Based on the work of Kruger (1992) transacts were defined as utterances that operated on a partner's reasoning (Other-oriented), or that significantly clarified a child's own reasoning (Self-oriented). The unit of analysis was an utterance and each utterance was first classified according to whether it was transactive or non-transactive. Next three specific types of transacts, (each according to the two orientations) were coded. These were: Transactive Statements (Self-oriented, Other oriented); Transactive Questions (Self-Oriented, Other Oriented) and Transactive Responses (Self-oriented, Other oriented).

(i) Transactive statements were defined as spontaneously produced critiques, refinements, extensions or significant paraphrases of ideas. Operations on the partner's ideas were labelled as Other-oriented. Spontaneously produced clarifications of a child's own ideas were coded as Self-oriented.

(ii) Transactive questions were defined as spontaneously produced requests for clarifications, justification, or elaboration of the partner's ideas. Operations on a partner's idea were labelled Other-oriented. Requests for evaluative feedback regarding a child's own ideas were labelled Self-oriented transactive questions.

(iii) Transactive responses were defined as clarifications, justifications or elaboration of one's ideas given in answer to a transactive question. They included critiques, refinements, extensions or significant paraphrases of the partner's ideas given in response to a transactive question. Other-oriented Responses elaborated on the partner's ideas; those that elaborated on a child's own ideas were classified as Self-oriented. Response transacts were given only directly following a transactive question.

Measures of Other Types of Problem-Solving Activity During the Paired Interaction Session

Time taken to complete task

This was a simple measure of the amount of time each pair took to complete the task within the 20 minutes allowed.

Number of combinations tested

In the Computer condition the computer kept a record of the number of combinations children tried. In the Physical condition this measure was calculated by counting up the number of combinations pairs entered on their record sheets.

Use of the Feedback Record

Utterances that referred to the use of the Feedback Records were analysed into three broad categories.

(i) Check combinations - instances when children used either the computer record or their paper-and-pencil record to check whether they had actually tested that particular combination before.

(ii) Check answers - instances when children used the record to check if the answer was correct

(iii) Counting - instances where children simply counted how many combinations they had tested or the number of 'yellows' they had produced.

Number of correct solutions per pair

When the children judged they had arrived at a solution (or at the end of the 20 minutes allotted to the task), they were asked to enter their answer into the computer using the keyboard or to write it on their feedback sheet .

Solutions were classified as:

(i) Completely Correct - combination B + E plus mixer;

(ii) Partially correct - any combination of three or four out of the five chemicals containing both B and E; single chemical answers giving B or E in combination with the mixer;

(iii) Incorrect - any combination not containing B and E; answers which gave all five chemicals; single chemical solutions that were neither B nor E.

Results

Unless stated otherwise, the results from this study were analysed using 2 x 2 between participant ANOVA with Environment (Physical versus Computer) and Ability (Same versus Mixed ability pairs) as the between participant factors. The findings from the analyses of the non-talk related problem solving activity measures are reported first followed by the analyses of the children's talk. Finally findings from the pre-to-post test change analysis are given. Three pairs of children in the Physical condition had to be dropped from some of the analyses as they were not present for all of the testing sessions.

Performance in the Interaction Session - Non-Talk Related Activity

---

Insert Table 1 about here

Time taken

In terms of Time, there was a main effect of Environment, (F (1,44) = 89.3, $p < 0.05$, eta^2=0.67). Children in the Physical Condition took nearly twice as long than children in the Computer Condition. As can be seen from Table 1 most of the children in the Physical Condition took the full 20 minutes to complete the task. There was no main effect of Ability and no interaction effect for Time Taken.

Number of combinations tested

There was a main effect of Environment for the Number of Combinations tested, (F (1,44) = 6.6, $p < 0.05$, $eta^2=0.13$). Pairs working with the computer environment carried out a mean of 17.0 tests compared to a mean of 10.9 tests in the physical environment. There was also a significant main effect of Ability in terms of the number of combinations tested, (F (1,44) = 4.0, $p < 0.05$, $eta^2=0.08$). Mixed Ability pairs carried out a mean of 16.9 tests compared with a mean of 11.6 tests carried out by the Same Ability pairs (see Table 1). There was no interaction effect for this measure.

Use of Feedback record

Table 2 shows the number of children who referred to the feedback record in the three ways categorised. Frequency data was used rather than means because of the very skewed distribution. Analysis revealed that there was a main effect of Environment in terms of using the record to check the answer. Children in the Computer condition were more likely to use the record to check their proposed solutions than children in the Physical condition ($\chi^2= 17.8$, $df = 1$, $p< 0.05$). In fact none of the children in Same Ability pairs in the Physical condition used the record for this purpose.

There was no main effect of Ability across conditions. However, within conditions there were significant effects of type of ability pairing. In the Computer condition children in the Mixed Ability pairs were more likely to use the record to check their combinations than children in the Same Ability condition ($\chi^2= 4.1$, $df = 1$, $p< 0.05$). In the Physical condition children in the Mixed Ability pairs used the record sheet to check their solutions (Fisher exact < 0.05, Fisher exact was used because two cells had frequencies < 5).

Insert Table 2 about here

Types of problem solution

The number of pairs producing the three different types of problem solution was analysed using Chi Square analyses. The only significant effect was that the distribution of types of solution was different depending on the environment children had experienced, ($\chi^2 = 7.3$, $df = 2$, $p < 0.05$). Thirteen out of 24 pairs, (54%) using the computer environment gave a completely correct answer compared with only four pairs (19%) using the physical apparatus, (see Table 2). Thirteen out of 21 pairs (62%) in the physical condition, however, arrived at a partially correct solution. The number of pairs giving incorrect solutions was approximately equal in the two conditions, (see Table 3).

Insert Table 3 about here

Analyses of talk and interaction

Type of Talk

Table 4 shows the proportion of Task-related, Social, Procedural and Off-task talk in the interaction session. There was a main effect of Environment for all types of talk:

Task-related ($\underline{F}$ (1,86) = 10.8, $\underline{p}$<0.05, eta^2=0.11); Social ($\underline{F}$ (1,86) = 26.4, $\underline{p}$<0.05, eta^2=0.24); Procedural ($\underline{F}$ (1,86) = 32.3, $\underline{p}$<0.05, eta^2=0.27) and Off-task talk ($\underline{F}$ (1,86) = 12.2, $\underline{p}$<0.05, eta^2=0.12). The children in the Computer Condition made proportionally more Task-related utterances and Social utterances, but less Procedural and Off-task utterances compared with the children in the Physical Condition. There was a main of effect of Ability for Task-Related talk, ($\underline{F}$ (1,86) = 6.2, $\underline{p}$<0.05, eta^2=0.07); and Procedural talk ($\underline{F}$ (1,86) = 10.4, $\underline{p}$<0.05, eta^2=0.11). Children in Mixed Ability pairs made more Task-related utterances and fewer Procedural utterances than the children in Same Ability pairs. There were no interaction effects for any type of talk.

Insert Table 4 about here

Transactive Talk

Insert table 5 about here

Table 5 shows the amount of transactive discussion expressed as a percentage of the total amount of discussion in the interaction session. There was a main effect of Environment in terms of total number of Other Oriented Transacts, (F (1,86) = 16.7, $p<0.05$, $eta^2=0.16$) and proportion of Other Oriented Transactive Statements (F (1,86) = 41.9, $p<0.05$, $eta^2=0.32$). Table 5 shows that children in the Computer Condition made proportionally more transacts and proportionally more Transactive Statements than children in the Physical Condition. There was a main effect of Ability in terms of the percentage of Other Oriented Transactive Questions, (F (1,86) = 7.1, $p<0.05$, $eta^2=0.08$) and Other Oriented Transactive Responses (F (1,86) = 4.4, $p<0.05$, $eta^2=0.05$). Table 5 shows that children in the Same Ability pairs make proportionally more Other Oriented Transactive Questions and proportionally more Other Oriented Transactive Responses than children in the Mixed Ability pairs. There were no significant interaction effects with Other Oriented Transacts and there were no significant main effects or interaction effects with Self-Oriented Transacts.

Pre-test to Post-test and Pre-test to Delayed Post-test Change

Only children who were initially classified as level 0 or level 1 were included in this analysis. The others were excluded: as they started from an initial high base-line they could not show as great pre-to-post test changes (see Table 6).

Insert Table 6 about here

Immediate learning gains were analysed using pre- to (two-week) post-test changes. There was no significant main effect of Environment, no significant main effect of Ability and no significant interaction effect.

Long term learning gains were analysed using pre- to delayed (three month) post-test changes. There was no significant main effect of Environment or of Ability. The interaction between Ability and Environment was significant, however, (F (1,66) = 5.0, $p< 0.05$, $eta^2 = 0.07$). Simple effects analysis revealed that children from Same Ability pairs working in the physical environment had significantly greater pre-test to delayed post-test change scores than those from Same Ability pairs in the computer environment (F (1,46) = 8.6, $p < 0.05$, $eta^2 = 0.16$). Also, children from Mixed Ability - Computer environment pairs had significantly greater pre-test to delayed post-test scores than children from Same Ability - Computer Environment pairs (F (1,34) = 6.2, $p< 0.05$, $eta^2 = 0.15$).

Discussion

This study investigated differences in the nature of the collaborative activity and learning outcomes which occurred when pairs of children worked on a scientific reasoning task in a computer-mediated environment compared with those occurring when pairs working in a real world, physical environment. The first main finding was that the presentation environment, as predicted by socio-cultural theory, did indeed mediate children's collaborative activity. There were both qualitative and quantitative differences in the nature of the children's talk and discussion as well as in their problem solving activity when the computer environment was compared with the physical environment. Children who worked on the computer version of the task displayed significantly more task-related talk and social talk than pairs working with the physical apparatus, (91 percent versus 79 percent respectively). They also displayed significantly less procedural and off-task talk than pairs in the Physical condition, (nine percent versus 21 percent respectively). There were also large differences in the quality and amount of transactive discussion which occurred in the two environments. A significantly greater proportion of children's utterances in the Computer condition were transactive (38 percent) compared to those of children in the Physical condition, (18 percent). The quality of transactive interactions also differed in the two conditions. Children made significantly more Transactive Statements when working on the computer task (26 percent) than when working with the physical apparatus, (seven percent).

There were also differences in the quantity and quality of children's non-verbal problem solving activities in the two conditions. In the Computer condition children tested significantly more combinations than children in the Physical condition (a mean of 17.6 versus 10.8 respectively). Furthermore, as well as testing a greater number of combinations they took less time to complete the task. On average they completed the task in approximately 9 - 10 minutes whereas most of the pairs using the physical apparatus used the whole 20 minutes allowed. The way in which the children used their record sheets was also different. Out of 111 references to the record sheet 61 percent of these were made by children in the Computer condition. These children were more likely to use the feedback record to check their proposed answers, (29 references) than children in the Physical condition, (seven references). Finally, 13 out of 24 pairs working on the computer task arrived at the correct solution to the problem compared with only four of the 21 pairs working with the physical apparatus. It should be pointed out, however, that the majority of pairs in the physical condition (17/21) arrived at either a partially correct or totally correct solution and that the number of pairs giving an incorrect solution was approximately the same in both conditions, (see Table 3.)

Despite the fact that the nature of the reasoning required to solve the task was identical in the two conditions it is clear from these findings that the tools available to the children in the two environments had an important influence on their discussions and problem solving activity. The Computer condition allowed children to test a greater number of combinations in less time. Hence they had more information available to them to work out the solution compared with children in the Physical condition. Also they were not distracted by the procedural aspects of the task in the same way that the children using the physical apparatus were. The pairs using real chemicals talked a lot about the actual mechanics of the situation. They also had to grapple with a considerable amount of ambiguity and uncertainty when carrying out their tests. Solutions took time to turn yellow, test tubes and droppers became contaminated and there was much discussion about whether particular mixtures were really yellow or only very pale yellow, and if so did they count? By contrast, each time pairs working with the computer carried out a test, they got clear, reliable and accurate results: the mixture was either yellow or it was colourless.

More importantly perhaps, the computer software mediated the children's problem solving activity by keeping an accurate record of the number and types of combinations they had attempted. These could then be used to check whether a proposed solution was supported by the data available. In the Physical condition no such mediation occurred. Not only did pairs have to remember to fill out the record, but due to the unreliable nature and variable length of time it took for the chemical reactions to take place, they frequently had to change the record. For many pairs this caused considerable confusion and meant that their records did not provide reliable data to check proposed solutions against. Only seven pairs in the Physical condition used their records to try to check proposed solutions compared with 13 pairs in the Computer condition. Given these constraints it is not surprising that the majority of pairs in the physical condition could only generate partially correct solutions to the problem.

It is clear from these results that, as predicted, working with the computer-mediated version of the task fundamentally changed the nature of the problem solving activity for the children. The findings are consistent with the socio-cultural view of development that stresses the importance of the type of tools for mediating activity. They support Järvelä's (1995) argument that the computer has a unique role to play in mediating paired work as it reduces off-task activity and enhances meta-cognitive activity, (in our case knowing that the record could be used to verify or disprove possible solutions). They also support Teasley and Rochelle's (1993) contention that computers can mediate problem-solving activity by disambiguating language, resolving impasses and constraining interpretations. In our study it is clear that the computer-mediated version of the task provided children with a much more reliable joint problem solving space than did the real-world, physical version. Our findings replicate those of Keogh et al., (2000) and Fitzpatrick and Hardman (2000), who also showed that children's collaborative activity was mediated by the presentation environment.

The second main finding of the study was that, in general, the nature of the problem solving activities and interactions between children in mixed ability pairs were qualitatively different to those of children in same ability pairs. Mixed ability pairs tested significantly more combinations than same ability pairs (16.0 versus 11.6). They talked more about the task, (84 percent versus 78 percent of utterances), and less about procedures (10 percent versus 17 percent) than same ability pairs. By contrast, the proportion of transactive utterances produced by same ability pairs (32 percent) was significantly greater than that produced by mixed ability pairs (24 percent). While these differences are interesting it is worth noting that in all analyses except one, (pre-to-post-test change scores), the main effect of Environment accounted for a greater proportion of the variance than that of Ability.

At the outset of this study we predicted that children from mixed ability pairs would show greater cognitive gains in terms of pre-to-post-test change on Kuhn and Ho's (1980) tests of combinatorial reasoning. Unexpectedly, however, there was a significant Environment by Ability interaction. This revealed that while all children made pre-to-post test gains, children from same ability - Physical pairs showed significantly greater gains than children from same ability- Computer pairs. This was somewhat of a puzzle as the children from same ability - Computer pairs appeared to have more productive interactions than those in the Physical condition. They talked proportionally more about the task and less about procedure and displayed less off-task talk than children working with the physical apparatus. They also engaged in significantly more transactive discussion than all other pairs. This was a particularly challenging finding as transactive discussion has previously been found to be positively related to learning outcome (Kruger 1992, Montgomery & Azmitia, 1993). One is forced to conclude that differences in the amount of transactive discussion are not implicated in pre-to-post-test gains in the study reported here. This conclusion is strengthened by the finding that while all children showed cognitive gains, mixed ability pairs engaged in less transactive discussion than same ability pairs.

Also while both same and mixed ability pairs in the computer condition appeared to make better use of the feedback record to check their proposed combinations and solutions significantly than pairs in the physical condition, this did not appear to have had a significant impact on the development of children's scientific reasoning, as measured by pre-to-post test changes in combinatorial reasoning ability. which is what Kuhn and Ho's tests measure. Kuhn and Ho's task, however, does not test improvement in children's ability at isolating variables in a multivariable experiment, an ability that is necessary to solve Piaget's chemical combinations problem. The analysis of children's talk and problem solving strategies presented in this study shows that it was only children in the Computer condition who were using the feedback record deductively to make and test predictions. This strongly suggests that the computer version of the chemical combinations task provides a more sophisticated environment for developing children's abilities to isolate variables than the physical environment. Our findings show that the computer mediated children's performance by providing clear and unambiguous information that allowed them to test their predictions in a systematic and rigorous manner. This type of support was not available to children in the Physical condition and consequently they could only arrive at partial solutions to the problem. The results also suggest that in order for children to derive full benefit from this type of computer-mediated environment, they need to be in mixed ability rather than same ability pairs.

A number of studies have shown that working with a more able child facilitates learning. The interesting aspect of this finding was that inspection of the transcripts showed that the more able child in the Computer condition would often use the feedback record to structure the testing process for the less able child, in a way that did not occur with the same ability pairs. This suggests that in the Computer condition as well as having access to accurate, computer-mediated feedback, the less able children in mixed pairs also had access to 'expert' peer tuition which was not available to children in same ability pairs. Jarvela's (1995) finding that computer-mediated environments facilitate scaffolded learning discussions between teachers and their pupils lends some support to this interpretation. Unfortunately this interpretation can not explain why both same and mixed-ability children who had experienced the physical environment showed equivalent pre-to-post-test gains in reasoning ability which, moreover, were sustained over a three month period. As noted above, however, the pre- and post-tests measured combinatorial reasoning. As both the Physical and the Computer conditions afforded practice in the systematic combination of chemicals during the intervention phase of the study, then it is not surprising that children in the physical condition showed post-test improvement on this measure.

In conclusion, the main finding of the study was that the type of presentation mediated the nature and type of the collaborative activity. The pairs working around the computer talked proportionally more about the task and management of the task; had proportionally more transactive discussions and used the record more productively than children working with the physical apparatus. The other main finding was that the type of presentation mediated the acquisition of children's scientific reasoning. Children in same ability pairs who worked with the physical apparatus improved their combinatorial reasoning skills significantly more than same ability pairs who worked with the computer. Both types of mixed ability pairs also showed pre- to post-test improvement in combinatorial reasoning. It was only the mixed ability pairs in the Computer condition, however, who showed evidence of using a more sophisticated isolation of variables strategy during the intervention phase of the study. These findings were predicted from a socio-cultural perspective and show the importance of tools for mediating collaborative activity.

References

Bennett, N., & Dunne, E. (1992). The nature and quality of talk in co-operative classroom groups. Learning and Instruction, 1, 103-118.

Crook, C. (1994). Computers and the collaborative experience of learning. London: Routledge.

Cummings, G. (1982). Small group discussions and the microcomputer. Journal of Computer Assisted Learning, 1, 149-58.

Dimant, R. J., & Bearison D. J. (1991). Development of formal reasoning during successive peer interactions. Developmental Psychology, 27 (2), 277-284.

Fitzpatrick, H., & Hardman, M. (in press). Mediated activity in the primary school classroom: Girls, boys and computers. Learning and Instruction.

Forman, E.A., & McPhail, J. (1993). Vygotskian perspectives on children's collaborative problem-solving activities. In E.A. Forman, N. Minick, & C. Addison Stone (Eds.), Contexts for Learning: Sociocultural Dynamics in Children's Development (pp. 213-229). Oxford: Oxford University Press.

Golay-Schilter, D., Perret, J-F., Perret-Clermont, A-N., & De Guglielmo, F. (1999). Socio-cognitive interactions in a computerised industrial task: Are they productive for learning? In K. Littleton, & P. Light (Eds.), Learning with Computers: Analysing Productive Interaction (pp. 118-143). London: Routledge.

Hawkins, J., Sheingold, K., Gearhart, M., & Berger, C. (1982). Microcomputers in schools: Impact on the social life of elementary classrooms. Journal of Applied Developmental Psychology, 3, 361-373.

Howe, C. J., & Tolmie, A. (1999). Productive Interaction in the context of computer-supported collaborative learning in science. In K. Littleton, & P. Light (Eds.), Learning with computers: analysing productive interaction (pp. 24-45). London: Routledge.

Inhelder, B., & Piaget J. (1958). The growth of logical thinking from childhood to adolescence. New York: Basic Books.

Järvelä, S. (1995). The cognitive apprenticeship model in a technologically rich learning environment: Interpreting the learning interaction. Learning and Instruction, 5 (3), 237-59.

Keogh, T., Barnes, P., Joiner, R., & Littleton, K. (2000). Gender, pair composition and computer versus paper presentations of an English language task. Educational Psychology, 20 (1), 33-44.

Kruger, A-C (1992). The effect of peer and adult-child transactive discussions on moral reasoning. Merrill-Palmer Quarterly, 38, 191-211.

Kuhn D., & Ho, V. (1980). Self directed activity and cognitive development. Journal of Applied Developmental Psychology, 1 , 119-133.

Montgomery R., & Azmitia, M. (1993). Friendship, transactive dialogues and the development of scientific reasoning. Social Development, 2 (3), 202 - 221.

Saljo, R. (1996). Mental and physical artefacts in cognitive processes. In H. Spada, & P. Reiman (Eds.), Learning in Humans and Machines (pp. 83-96). Oxford: Pergamon.

Saljo, R. (1999). Mental and physical artefacts in cognitive processes. In. K. Littleton, & P. Light (Eds.). Learning with computers: Analysing productive interaction (pp. 144-161). London: Routledge.

Teasley, S. D., & Roschelle, J. (1993). Constructing a joint problem space the computer as a tool for sharing knowledge. In S. P. Lajoie, & S. J. Derry (Eds.), Computers as cognitive tools (pp. 229-258). Hillsdale: New York Erlbaum.

Tudge, J., & Winterhoff, P. (1993). Can young children benefit from collaborative problem solving? Tracing the effects of partner competence and feedback. . Social Development, 2 (3), 242 - 259.

Vygotsky, L. (1981). The genesis of higher mental functions. In J. V. Wertsch (Ed.), The concept of activity in soviet psychology (pp. 144-188). Armonk, NY: Sharpe.

Table 1: Performance of pairs in the interaction session in terms of time-taken in seconds and number of combinations tested

	Computer				Physical			
	Mixed (n=12)		Same (n=12)		Mixed (n=12)		Same (n=12)	
	M	SD	M	SD	M	SD	M	SD
Time	606	312	516	323	1200	0.0	1165	74
Number of Combinations tested	21.6	15.5	13.7	8.7	12.2	3.2	9.5	1.8

Table 2: Number of children in each condition using the record.

Use of Record	Computer		Physical	
	Mixed (n=24)	Same (n=24)	Mixed (n=20)	Same (n=22)
	n	n	n	n
Check Solution	14	15	7	0
Check Combination	17	10	12	13
Count	6	6	5	6

Table 3: Distribution of types of solution

Number of Pairs	Computer	Physical
	n= 24	n= 21
Correct	13	4
Partially Correct	6	13
Incorrect	5	4

Table 4: Type of utterance expressed as a percentage of the total number of utterances.

Percentage of Utterances/pair	Computer				Physical			
	Mixed (n=12)		Same (n=12)		Mixed (n=10)		Same (n=11)	
	M	SD	M	SD	M	SD	M	SD
Task	86.9	10.9	83.6	9.7	81.8	10.7	73.9	11.1
Social	5.7	6.6	5.9	4.7	0.5	1.3	1.5	2.0
Procedural	6.8	5.5	10.1	8.0	14.6	8.7	22.9	11.2
Off-Task	0.6	1.8	0.3	0.9	3.1	4.2	1.6	2.4

Table 5: Other Oriented Transacts expressed as a percentage of total number of utterances

Percentage of Other Oriented Transacts/pair	Computer				Physical			
	Mixed (n=12)		Same (n=12)		Mixed (n=10)		Same (n=11)	
	M	SD	M	SD	M	SD	M	SD
Statements	26.0	12.4	26.9	23.4	7.3	4.1	7.2	4.5
Questions	5.0	4.1	8.9	13.4	3.9	4.1	9.0	4.9
Responses	3.1	5.6	5.7	9.4	2.9	2.7	5.7	4.7
Total Transacts	34.1	13.2	41.6	40.6	14.2	8.9	21.9	8.4

Table 6: Mean pre- to post-test and pre- to delayed post-test change scores for children scoring level 0 or 1 at pre-test

Change Scores/child	Computer				Physical			
	Mixed (n=12)		Same (n=24)		Mixed (n=10)		Same (n=22)	
	M	SD	M	SD	M	SD	M	SD
Pre- to Post-test Change	1.3	1.1	0.8	1.1	1.2	0.9	1.3	1.2
Pre- to Delayed Post-test Change	1.4	1.1	0.5	1.0	1.1	1.0	1.5	1.3