DOCUMENT RESUME

ED 406 151 SE 059 811

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TITLE	Conceptual Change in Science through Collaborative Learning at the Computer.
PUB DATE	Mar 97
NOTE	19p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (70th, Oak Brook, IL, March 21-24, 1997).
PUB TYPE	Reports - Evaluative/Feasibility (142) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Attitude Change; *Cognitive Processes; *Computer Uses in Education; *Concept Formation; *Cooperation; Foreign Countries; High Schools; Interaction Process Analysis; Mechanics (Physics); Science Instruction
IDENTIFIERS	Australia (Melbourne)

ABSTRACT

This paper describes a study of whether and how collaborative learning at the computer fosters conceptual change. A suite of computer simulation programs developed to confront students' alternative conceptions in mechanics was integrated into a grade 10 science class in a high school in Melbourne, Australia. A Conceptual Test was administered as a pre-, post-, and delayed post-test to determine students' conceptual change. Students worked collaboratively in pairs on the programs, carrying out predict-observe-explain tasks according to a set of worksheets. Conversational interactions of seven pairs in the class were analyzed for mode of collaboration by joint on-task engagement and by equality and mutuality of engagement. Collaborative sequences were categorized as co-constructions of shared understanding or peer conflicts. Inferences were made as to whether these led to conceptual change. Computer-supported collaborative learning provided students with experiences of co-constructions of shared understanding and peer conflicts, which led to conceptual change for those who were cognitively engaged in the tasks and prepared to reflect on and reconstruct their conceptions. To achieve long-term and stable conceptual change, this should be accompanied by students' personal construction and sense-making of the new understanding. Contains 43 references. (Author/PVD)

Paper presented at

1997 National Association for Research in Science Teaching Annual Meeting,

March 21-24, 1997
Oak Brook, IL, USA

Conceptual Change in Science Through Collaborative Learning at the Computer

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Abstract

The purpose of this classroom study was to investigate whether and how collaborative learning at the computer fosters conceptual change. A suite of computer simulation programs was developed to confront students' alternative conceptions in mechanics. This was integrated into a 10-week physics instruction of a Grade 10 science class in a Melbourne high school. A Conceptual Test was administered to the class as a pre-, post- and delayed post-test to determine students' conceptual change. Students in the class worked collaboratively in dyads on the programs carrying out predict-observe-explain tasks according to a set of worksheets. While the dyads worked on the tasks, their conversational interactions were recorded. A range of other data were also collected at various junctures during instruction. The conversational interactions of 7 dyads in the class were analyzed for the mode of their collaboration using three indices: joint on-task engagement, and equality and mutuality of engagement. Their collaborative sequences were categorized as co-constructions of shared understanding or peer conflicts and inferences were made as to whether or not these led to conceptual change. Case studies of collaboration were written up for the 7 dyads. The study showed that the computer-supported collaborative learning provided students with experiences of co-constructions of shared understanding and peer conflicts which led to conceptual change for those who were (i) cognitively engaged in the tasks and (ii) prepared to reflect on and reconstruct their conceptions. It also showed that whilst co-construction was important, to achieve long-term and stable conceptual change this needed to be accompanied by students' personal construction and sense making of the new understanding.

Conceptual Change in Science Through Collaborative Learning at the Computer

INTRODUCTION

Research has established that students' alternative conceptions in science are very tenacious and that conventional instruction is notably ineffective in promoting conceptual change (Driver, Guesne & Tiberghien, 1985; Osborne & Freyberg, 1985; Wandersee et al., 1994). Special teaching strategies have been developed to address such conceptions but they have not always proved to be successful (Scott et al., 1992). One common strategy to foster conceptual change is to confront students with discrepant events that contradict their conception. This is intended to invoke a disequilibration or cognitive conflict (Piaget, 1985) that induces students to reflect as they try to resolve the conflict. The discrepant events may be a demonstration or a phenomenon which require students to explain or make a prediction.

Computer simulation which supports exploratory learning (Papert, 1980; Bliss & Ogborn, 1989) can also be used to provide such discrepant events. This has the additional advantage that students can freely explore the microworld of the program by changing the parameters and variables and visualizing immediately the consequences of their manipulations. Students can interpret the underlying scientific conceptions of the program and compare them with their own conceptions. They can also formulate and test hypotheses and reconcile any discrepancy between their ideas and the observations in the microworld. Computer simulations have been shown to be effective in fostering conceptual change (e.g. Zietsman & Hewson, 1986; White & Horwitz, 1988; McDermott, 1990; Gorsky & Finegold, 1992).

Computer programs offer individualized learning. However, it is increasingly recognized that there are many cognitive benefits in arranging students to work collaboratively in dyads or small groups on the programs. This move from solitary to collaborative learning is influenced by the growth of interest and development in peer learning during the past decade (Sharan, 1990).

Peer collaboration is one of three main approaches to peer learning, the other being peer tutoring and cooperative learning. It involves two (or more) students working together on a task that neither could do on their own prior to the collaborative engagement. The students start at roughly the same level of competence, and they work jointly on the task rather than individually on separate components as in cooperative learning. Damon and Phelps (1989) contend that peer collaboration provides a supportive environment that encourages students to experiment with and test new ideas and thereby critically re-examine their own conceptions. They assert that the engagement of peer collaboration is "rich in mutual discovery, reciprocal feedback, and frequent sharing of ideas" (p.13). Drawing from their own research, they claimed that peer collaboration is particularly useful for tasks that require "new insights, conceptual shifts, and the development of deep knowledge structure" (p.14), but it is not very effective for tasks that rely on formulae and given procedures.

Damon and Phelps define two indices for describing the interactions in peer learning: equality and mutuality of engagement.

- *Equality* of engagement refers to the contribution towards the tasks made by students, with high equality indicating more or less equal contribution by each student, and low equality indicating unequal contributions.

- *Mutuality* of engagement refers to the discourse in the engagement, with high mutuality indicating "extensive, connected and intimate" discourse, and low mutuality indicating limited, unconnected discourse, with each student not publicly making known their ideas.

They contend that the engagement in peer collaboration, in the ideal manifestation, is high in both equality and mutuality. A high equality assures that the engagement is truly collaborative and a high mutuality is important since it helps all students make explicit their ideas.

Crook (1994) suggests that peer collaboration offers three cognitive benefits: *articulation*, *conflict*, and *co-construction*. He argues that in peer collaboration students have to make their intuitive and emerging ideas explicit and public. For the sake of the joint activity students need to articulate their opinions, predictions, and interpretations. The pressure to communicate well with their partners helps them gain a greater conceptual clarity for themselves.

Conflict sometimes arises in peer collaboration when students disagree with each other in their interpretations or approaches to the task. To resolve the conflict, they have to justify and defend their positions and this forces them into reflection. This second cognitive benefit is based on the Piagetian perspective which claims that socio-cognitive conflict arises when students holding inadequate or differing views work together (Piaget, 1985). The disequilibration thus engendered demands resolution and this requires students to reflect on their own conceptions.

When working on a task or solving a problem, students co-construct shared knowledge and understanding by complementing and building on each other's ideas. This third cognitive benefit is based on the Vygotskian perspective which views learning as the sharing of meaning in a social context. According to this perspective, learning involves a social process in which understanding is first rehearsed between people before it is developed within the learner as an internal process. Vygotsky speaks of an intermental and an intramental category of "higher mental function" and he argues that "any higher mental function was external and social before it was internal" (quoted in Scott, 1995, p.1). In the intermental cateogory, students' collaborative talks and activities on shared tasks play an important role in the development of their understanding.

Arranging students to work collaboratively at the computer reaps both the benefits of the use of computer simulation as an exploratory tool and of peer collaboration. Computer-supported collaborative learning (CSCL) is a rapidly emerging field of study which started in the late 1980s. So far there have been two international conferences (in 1991 and 1995), two special issues of journals (Koschmann, 1992, 1994), two books on the subject (Crook, 1994; O'Malley, 1995), and a sizable body of research. The early work on CSCL was mostly concerned with the outcomes of collaborative learning. For example, Howe et al. (1992) found that conceptual change in mechanics was facilitated by computer-based tasks which encouraged joint decisions by members of the dyads undertaking the tasks. Blaye et al. (1991) found that children working in pairs on a game-like task performed better in subsequent individual tasks than children who previously had worked individually. Light et al. (1987) obtained similar results when they constrained children to collaborate by a 'dual-key entry' requirement (both children in the dyad had to key in their responses before the program provided feedback).

More recently, studies in CSCL have been concerned with the roles played by conflict and co-construction in peer collaboration. For example, Whitelock et al. (1993) studied problem solving on elastic collisions using a computer simulation and found that co-construction of shared meaning, rather than conflict, was more important for successful collaboration. O'Malley and Scanlon

(1990) also argue that learning can take place in peer interactions without there being conflict. They suggest that the differing conceptions in the dyad may not necessarily compete or be inconsistent with each other — these may be just alternative viewpoints which contribute in different ways to the construction of new conceptions. There is still much debate about the roles of conflict and co-construction in CSCL.

There is little research on how collaborative learning at the computer leads to conceptual change. Roschelle (1992), in one of the few studies in this area, describes a case study of a dyad working collaboratively on a simulation program in mechanics ('The Envision Machine'). He conceptualizes collaboration as "a process that gradually can lead to convergence of meaning" and argues that conversational interactions enable students "to construct increasingly sophisticated approximations to scientific concepts collaboratively, through gradual refinement of ambiguous, figurative, partial meanings" (p.237). While this study presents a very interesting analysis that integrates collaboration and conceptual change, it attaches considerable importance to some of the apparently casual utterances of the students during peer interactions. Also, while conceptual change was shown to have been achieved during the conversation, there was no follow-up study to find out whether the conceptual change was sustained at a later time.

This paper reports part of a classroom study of high school students' conceptual development during physics instruction in which students were arranged to work collaboratively in dyads on some computer simulation programs. The study aimed to investigate the process of conceptual change and the role of peer collaboration in that process (Tao, 1996). This paper focuses on students' collaborative learning at the computer. It involves the analysis of students' conversational interactions while they worked in dyads on some simulation programs. The purpose was to investigate whether and how collaborative learning at the computer fostered conceptual change. Detailed conceptual change data from the study are reported in Tao and Gunstone (1997).

It should be noted that CSCL can be organized within the classroom, across classrooms (with computers connected to a network or via the Internet), and outside the classroom (Koschmann, 1994). The research reported in this paper was restricted to collaborative learning within the classroom, with students in the class grouped in dyads to work collaboratively at the computer.

METHODS

The Force and Motion Microworld

A suite of computer simulation programs, collectively called *Force and Motion Microworld* (FMM), was developed to match and confront three of the prevalent alternative conceptions in 'force and motion', viz. force-of-motion, motion-implies-force, and effects of force. These alternative conceptions, listed in Table 1, have been identified by a large body of previous studies (e.g. Clement, 1982; McCloskey, 1983; Gunstone & Watts, 1985; Halloun & Hestenes, 1985). FMM provided three contexts (model car, spaceship and skydiver) in which the effects of force on motion could be explored.

FMM was integrated into the 10-week physics unit of a Grade 10 science class in a Melbourne high school. Students worked collaboratively in dyads on the FMM programs carrying out predict-observe-explain (POE) tasks (White & Gunstone, 1992) according to a set of worksheets. These

tasks were designed to provide cognitive conflicts that facilitated conceptual change. There was a total of 48 tasks for the three programs of Model Car, Spaceship, and Skydiver.
Each task required students to jointly

- make a prediction about the consequences when certain changes were made to the program
- explain their prediction
- run the program to test their prediction
- reconcile any discrepancy between their prediction and the observation in the microworld

Students were required to write down their prediction, explanation and observation in the worksheets. More details about FMM and the accompanying worksheets can be found in Tao (in press) and Tao and Tse (in press).

1. *Force-of-motion*: A moving body has a 'force of motion' in it; it slows down and stops as its force is gradually used up.
2. *Motion-implies-force*: If a body is not moving there is no force acting on it; if it is moving there is a force on it in the direction of motion.
3. *Effects of force*: A constant force acting on a body produces a constant speed; an increasing force produces an acceleration.

Table 1 Alternative conceptions in 'force and motion' addressed by the study

The Instruction

The Grade 10 science class was taught the physics unit in Term 4 of a 4-term year. All the lessons were taught by the science teacher except for 5 FMM lessons in the middle of the physics unit which were taken by one of the researchers (PKT). This researcher was present for the whole unit. FMM provided the predominant instruction in 'force and motion' but it was preceded and followed by conventional lessons, lab work, and problem solving on the topic. This was the first formal instruction in mechanics for the students.

Assessment of Conceptual Change

To assess students' conceptual change subsequent to instruction, a Conceptual Test was compiled to cover the three alternative conceptions of concern in the study. Most of the questions were taken from previous studies (LISP, 1980; Gunstone et al., 1989; Osborne & Gilbert, 1980) and a few were generated for the research to relate to the FMM programs. The questions were of multiple-choice format but students were also required to explain their answers. The test was validated by a panel consisting of three physics teachers and a teacher educator. Details of the test is given in Tao (1996).

The test was administered, in identical form, to the class before and after the instruction. It was also administered 5 months later to the 10 students who went on to study physics in Grade 11; there was no instruction in 'force and motion' in the intervening period for these students. To take account of the variation of students' performance in the pre-test, conceptual change was determined from (i) the *gain* in answer scores and (ii) the changes in the open responses from pre-test to post- or delayed post-test.

The Class

The school was chosen for the study based on the following criteria: (i) its students were regarded as generally of average ability, (ii) its science staff were generally aware of the research on students' alternative conceptions and conceptual change, and (iii) it had suitable and adequate computer facilities for running the FMM programs. The students in the class were assigned to 13 dyads to work on the FMM programs based on (i) their pre-test results with students of low scores being paired up with students of relatively higher scores to maximize the chance of peer conflicts, and (ii) friendship patterns to ensure that the two partners could work together for a prolonged period of time.

Data Sources and Analysis

While students worked on the FMM programs, all their within-dyad conversational interactions were audio-recorded. In addition, a wide range of other data were collected at various junctures during and after the instruction to investigate students' conceptual development. These included students' (qualitative) responses to the pre-, post- and delayed post-tests, a quiz and an end-of-unit test; transcripts of interviews with some students at three junctures (after the pre-test, the FMM lessons, and the delayed post-test); and fieldnotes of classroom observation.

Sufficient data were collected on 7 dyads so that the conceptual change and conceptual development of these students could be determined. For each dyad, the transcripts of students' conversational interactions were analyzed for the modes of collaboration using three indices:

- *Joint on-task engagement* (high/medium/low)
- *Equality* of engagement (high/low)
- *Mutuality* of engagement (high/low)

Joint on-task engagement, a necessary condition for collaboration, was taken to be the percentage of tasks on which students in the dyad worked together, with over 80% regarded as high, 60-80% as medium, and less than 60% as low. This arbitrary categorization was used to make crude comparisons between the dyads. The conversational interactions were examined to make inferences on whether the equality and mutuality of the engagement were high or low. These inferences were based on an interpretive assessment of the collaborative sequences, rather than the counting of occurrences of certain events or utterances.

Next, the collaborative sequences were analyzed and categorized as co-constructions or conflicts. The co-constructions were examined to find out how students complemented each other in the construction of shared knowledge. The conflicts were examined to find out whether they led to convergence or divergence of understanding, and how they were resolved in the face of observed results in the microworld. The analysis was written up as case studies of peer collaboration for all 7 dyads, each with extensive excerpts of their collaborative sequences. Inferences were made as to whether and how conflicts and co-constructions contributed to conceptual change.

STUDENTS' CONCEPTUAL CHANGE

The 14 students in the 7 dyads were grouped according to two dimensions: (i) amount of conceptual change (substantial, some, or none), and (ii) pre-test answer scores (high, medium, or low). Students were regarded to have achieved substantial, some or no conceptual change if their gain in answer score from pre-test to post- or delayed post-test was 20% or more, 10-20% , and less than 10% respectively. Pre-test scores were regarded as high, medium and low if they were more than one standard deviation above the class mean, within one standard deviation above the mean, and below the mean respectively. The categorizations in these dimensions were arbitrarily defined for crude comparison. The resulting grouping of the students is given in Table 2. All student names are pseudonyms

Pre-test score	None (< 10% gain)	Some (10-20% gain)	Substantial (> 20% gain)
High	Paul (p) (✓, –, ✓) #		Clive (p) (✓,✓, ✓) ↑
Medium	Terry (p) (✓, –, ✓) Martin (p) (✓,✓, –) Mick (✓,✓, –)		Colin (✓,✓, –) Mike (p) (✓,✓, ✓) ↑
Low	Don (✓,✓, –) Stan (✓,✓, –) Jim (p) (✓,✓, ✓)	Derek (p) (✓, –, ✓)	Sid (p) (✓,✓, ✓) ↓ Sam (p) (✓,✓, ✓) → Nigel ^ (✓,✓, –)

Conceptual Change

Symbols within brackets indicate students' taking (✓)or not taking (–) the pre-, post, and delayed post-test respectively
↑ = showed improvement, ↓ = showed deterioration, → = no change, in delayed post-test
^ showed no change at post-test but substantial change at final interview
(p) = students who opted to study physics in Grade 11

Table 2 Grouping of students according to conceptual change and pre-test score

Of the 14 students, 6 showed substantial conceptual change (one of whom achieved no conceptual change at the post-test but showed substantial change at the final interview), one showed some change, and 7 showed no change at the post- or delayed post-test. Of the 5 students who achieved substantial conceptual change at the post-test, two showed further improvement in the delayed post-test (Clive and Mike), one sustained his change (Sam), one showed deterioration (Sid), and one student was absent (Colin).

When students' conceptual understanding subsequent to instruction was examined, only 2 students (Clive and Mike) showed reasonably comprehensive understanding; 4 students (Colin, Sid, Sam, and Nigel) showed partial understanding although they were deemed to have achieved substantial or some conceptual change from their gain in answer score; one student (Paul) showed partial understanding but this had remained unchanged from pre- to post-test; and 6 students (Terry, Martin, Mick, Stan, Don and Jim) showed minimal understanding. This result confirms that students' alternative conceptions in 'force and motion' were indeed very difficult to change.

MODES OF COLLABORATION

Table 3 gives the modes of collaboration of the 7 dyads in terms of three indices: joint on-task engagement, and equality and mutuality of engagement. The table also indicates the students' conceptual change and whether they went on to study physics in Grade 11. Where the equality of engagement was low, the student in the dyad who contributed more towards the tasks is shown.

Dyad	No. of tasks completed (% of total no. of tasks in worksheet)	No. of tasks completed jointly (% of total no. of tasks completed)	Joint on-task engagement	Equality	Mutuality
Sam**(p) /Mick	48 (100%)	48 (100%)	high	high	high
Nigel^/Stan	48 (100%)	48 (100%)	high	high	high
Sid**(p) /Colin**	37 (77%)	37 (100%)	high	high	high
Derek*(p)/Jim(p)	48 (100%)	48 (100%)	high	low (Derek)#	low
Clive**(p)/Don	45 (94%)	27 (60%)	medium	low (Clive)#	low
Mike**(p) /Terry(p)	35 (73%)	18 (51%)	low	low (Mike)#	low
Paul(p)/Martin(p)	46 (95%)	?	low	low (Paul)#	low

** showed substantial conceptual change at post- or delayed post-test; * showed some change
^ showed no change at Post-test but substantial change at Interview after the delayed post-test
(p) students who went on to study physics in Grade 11
contributed more to tasks
? not quantifiable due to loss of data

Table 3 Students' modes of collaboration

Table 3 presents an interesting range of modes of collaboration. The first two dyads, Sam/Mick and Nigel/Stan, completed all the tasks together and their engagement was high in both equality and mutuality. The third dyad, Sid/Colin, also had high joint on-task engagement which was high in both equality and mutuality but they failed to complete all the tasks and so missed some of the learning experiences in the FMM programs. The fourth, Derek/Jim, completed most of the tasks together but their engagement was low in both equality and mutuality. The fifth, Clive/Don, had medium joint on-task engagement which was low in both equality and mutuality.

The last two dyads, Mike/Terry and Paul/Martin, had low joint on-task engagement which was low in both equality and mutuality. Terry and Martin in these two dyads went off-task from time to time leaving their partners to work alone. Some of the tapes for Paul/Martin had been tampered with resulting in some loss of data. Their joint on-task engagement could not be quantified and was determined qualitatively to be low from classroom observation.

It should be noted that even amongst dyads considered to have a high equality (or mutuality) of engagement, the degree of equality (or mutuality) might differ. A dichotomy of high/low was used for the two indices for simple data presentation, to provide a 'global' picture of the modes of collaboration of the 7 dyads under study. This dichotomy applied to inter-dyad rather than intra-dyad comparison. Also, for a dyad considered to have a high equality of engagement, the contribution from the partners might not be exactly the same; one student might contribute more by, for example, initiating more predictions or giving more explanations than the other student.

It is intriguing to find that in 5 dyads, one student showed substantial or some conceptual change (Sam, Nigel, Derek, Clive and Mike) whereas the other student showed no change (Mick, Stan, Jim, Don and Terry). It appeared that peer collaboration benefited some students but not others. In the remaining 2 dyads, both students in one dyad (Sid and Colin) showed substantial conceptual change whilst in the other dyad both students (Paul and Martin) showed no change.

The collaboration of two of the dyads are briefly described below. Details of the case studies of peer collaboration are given in Tao (1996).

Sam/Mick

Sam and Mick collaborated very well and jointly completed all the tasks. Their engagement throughout the FMM lessons was uniformly high in both equality and mutuality. Among the 7 dyads, they had the largest number of peer conflicts (totaling 8); they reached shared understanding in 5 of these conflicts but did not come to any agreement in the other 3. In all the other tasks, they constructed shared knowledge by complementing and building on each other's ideas.

Sam was a 'low scorer' at the pre-test who achieved substantial conceptual change at the post-test and sustained his change in the delayed post-test. It was clear from the conversational interactions that he and his partner achieved conceptual change during the FMM lessons. However, even though he retained aspects of this change, he reverted to some of the alternative conceptions in the quiz, end-of-unit test and post-test. His conceptual understanding subsequent to instruction was, in fact, limited. At the delayed post-test, 5 months after instruction, he still retained the 'force-of-motion' conception and showed understanding of the 'effects of force' in 'skydiver' but not in 'model car' and 'spaceship'. At the final interview, Sam was asked to recall the FMM programs and probed further for his understanding. This appeared to trigger him into relating the contexts in the FMM programs to those in the test. This triggering and thinking led to Sam developing a greater understanding during the interview.

Mick was a 'low scorer' at the pre-test who showed no conceptual change after instruction. Although he and his partner's engagement was regarded as high in equality (compared with other dyads), Mick made slightly less contribution than his partner to the tasks, in terms of initiating predictions and explanations. This may have been because of his decision early on in the term not to take physics in the following year. Although it was apparent that he achieved conceptual change during the FMM lesson, he showed no conceptual change in the post-test. One possible explanation could be that Mick did not cognitively engage himself to personally construct meaning from the learning experiences.

Mike/Terry

Mike and Terry worked together quite well at first, but later, influenced by a disruptive student in the next dyad, Terry frequently went off task. Terry was absent from the lesson on 'skydiver' and Mike had to work alone. When they worked together, Terry was often not fully attentive and Mike had to repeat some of the tasks as well as coach Terry on how to carry them out. This resulted in rather extensive exchanges between them. It appears that the coaching gave Mike the opportunity to verbalize and to consolidate the conceptions he acquired from the FMM programs. There were five peer conflicts which helped Mike change his conceptions.

Mike was a 'medium scorer' at the pre-test who showed substantial conceptual change in the Post-test, further improvement in the delayed post-test, and comprehensive understanding at the final interview. His conceptual change was a slow and "erratic" process during which he vacillated between his alternative conceptions and the scientific conceptions during instruction. It appears that the FMM programs were effective in facilitating his conceptual change and that the peer conflicts he experienced and the coaching he provided to his partner helped him consolidate his conceptual change. Mike was a reflective student: he gave careful thoughts and articulate responses to the tests. At the final interview, he could recall the FMM programs and clearly state his conceptual change.

Terry was a 'medium scorer' at the pre-test who showed a deterioration of his conceptual understanding at the delayed post-test (he was absent from the post-test). He went off-task from time to time, and when he did work together with Mike, he was not fully cognitively engaged. He did not contribute much to formulating the predictions except when he disagreed with Mike. His alternative conceptions were highly resistant to change despite several peer conflicts.

COLLABORATIVE SEQUENCES

As illustrations, several collaborative sequences from the case studies are quoted below. Obviously the examples are from groups showing high joint on-task engagement; examples were rare in the other groups. Excerpts of transcripts follow the following conventions:

[ ]	Words enclosed in square parentheses have been added to aid understanding and readability of the dialogue.
( )	Words enclosed in parentheses indicate non-verbal actions, e.g. reading from worksheet.
...	Short pause, typically of about 3 seconds
=	Indicates a point at which the current speaker's talk is overlapped by the talk of another, with the overlapping talk preceded by = in the line below.

Co-constructions

This following excerpt is taken from Nigel/Stan during the Spaceship lesson when they predicted the motion of the spaceship when all the rockets were shut down (Task 1):

Nigel: I reckon it'll sort of float, 'cause there is nothing ...
Stan: You know why it would do it? Or it's like constant ...
Nigel: There is no friction, and it'll be really slow in the movement forward.
Stan: So, it'll be slow and constant speed.
Nigel: Yeah, ... It would go like this because there is no friction. We'll run it and see how it looks.
Stan: Begin.
Nigel: See, it's a very big rocket and it's slowly increasing its ...
Stan: It's not increasing, it stays constant in fact.
Nigel: It's gone past the 10 second ... Friction is zero (reading from Meters Window on screen).
Stan: Force is zero as well (reading from Meters Window).
Nigel: Why is it moving?
Stan: Initial speed is 20 m/s.
Nigel: Cause it's got an initial speed, that's why.

Nigel first suggested that with all the rockets shut down, the spaceship would "sort of float", for which Stan sought clarification and justification. Nigel attributed the motion to "no friction" in space and Stan elaborated that the spaceship moved slowly at constant speed. When they ran the program to test their prediction, Nigel first thought that the spaceship slowly increased its speed, but Stan corrected him and said it was constant speed. They then checked the Meters Window on the screen for the forces acting on the spaceship. Nigel observed that friction was zero and Stan concurrently noted that the applied force was also zero. Nigel then raised the question as to why the spaceship was moving when there was no force on it, to which Stan replied that the spaceship had an initial speed of 20 m/s. In these exchanges, they built on each other's ideas and incrementally developed shared understanding.

Conflicts

Students experienced conflict when they disagreed on the prediction/explanation. Some of the conflicts were resolved with one student eventually agreeing with the other, i.e. they reached shared understanding as in a co-construction. The following excerpt is taken from Sam/Mick during the Model Car 1 lesson when they applied a backward force on the car (Task 8).

Mick: Off it goes. I think it would move backward immediately. You think it would?
Sam: It [The speed-time graph] wouldn't [go] down really quickly.
Mick: You don't [think so]?
Sam: Yeah.
Mick: So, it'll go up like this. Pause there ...
Sam: And then it'll go back down ...
Mick Just like that?
Sam: Under the line [to negative speeds], yeah. It just slows down first and then reverses.
Mick: Let's see that.

Drawing on his 'motion-implies-force' conception, Mick predicted that the car would move backward immediately. He sought support from Sam but Sam disagreed and contended that the car would slow down to rest and then reverse. During these exchanges, Mick sought clarification twice ("You don't [think so]?"; "Just like that?") before testing the prediction. In this conflict, Sam verbalized and made explicit his ideas, to which Mick eventually agreed.

Some of the conflicts did not lead to any agreement. The following excerpt is taken from Sam/Mick during the same lesson in the task on reducing the applied force to equal friction after accelerating the car from rest (Task 5):

Mick: I think that ... so what we'll do we leave it on about 3 [newtons], then we press 'pause' halfway through =
Sam: = Take it back to 2 [newton] =
Mick: = And reduce it to ... So what ... it'll, uh, ... it [the speed-time graph] would go ... it'll rise up when it's on 3 [newton]. After pause, it would drop ...
Sam: It would drop down to 2 [newton].
Mick: It would drop down to 2 [newton].
Sam: And it would continuously go up the speed.
Mick: It would continuously go up again.
Sam: No, it won't go up 'cause it'll be equal to the force, or the friction.
Mick: No, it will go up again.
Sam: No way!
Mick: Do we get to draw a graph? I want to draw what I think will happen. Could be wrong but I want to ...
(Sam wrote down in the worksheet "Go up and then stay at the speed" and drew a speed-time graph of the motion.)
Sam: Draw the graph.
Mick: This is I think what will happen (Mick drew a different graph of his own prediction).
Sam & Mick (in unison): Push the button, begin ... it goes then go to pause and we change the force to 2 [newton] and then we go again.
Sam: It's exactly what I said it'll do.
Mick: Oh, why didn't ... ? Alright then, so it [the graph] went up then went down and then stay level. How did you know that's what's going to happen?
Sam: I guessed it.

Mick and Sam worked well together in following the procedure of the task but they disagreed on the prediction. Mick predicted that, when the applied force was made equal to friction, the car would continue to speed up whereas Sam contended the car would move with a constant speed. They did not come to any agreement and each drew a separate graph in the worksheet. After running the program, Sam's prediction was proved to be correct. Mick was very surprised but accepted and re-stated the observation. In this conflict, Sam gave justification for his prediction but Mick simply stated his position.

In each of the above three collaborative sequences, it was clear that both students in the dyad achieved conceptual change in the context of the tasks.

PEER CONFLICTS

For most of the tasks, students co-constructed shared understanding and agreed on the predictions, but there were also instances of peer conflicts. These instances are summarized in Table 4 for each dyad across the FMM lessons. The number of peer conflicts ranged considerably among the 7 dyads, from 0 to 8. To some extent, this depended on the contrasting conceptions held by students in the dyad prior to instruction.

	FMM Lessons				
Students	Model car 1	Model car 2	Spaceship	Skydiver	Total
Sam**(p)/Mick	5	0	2	1	8 S (4 ✓), M (4 ✓)
Nigel^/Stan					0
Sid**(p)/Colin**					0
Derek*(p)/Jim(p)	2		1		3 D (2 ✓), J (0 ✓)
Clive**(p)/Don	1	3	1	3	8 C (7 ✓), D (1 ✓)
Mike**(p)/Terry	2	2	1		5 M (3 ✓), T (1 ✓)
Paul(p)/Martin(p)		1			1 P (1✓) M (0✓)
Total	10	6	5	4	25

** showed substantial conceptual change at post- or delayed post-test * showed some change
^ showed no change at post-test but substantial change at Interview 3
(p) students who went on to study physics in Grade 11
✓ correct prediction × wrong prediction

Table 4 Instances of Peer Conflict

Paul/Martin experienced only one conflict since Martin went off-task most of the time; these two students showed no conceptual change. Sid/Colin and Nigel/Stan experienced no peer conflict. Sid, Colin, and Nigel in these two dyads achieved substantial conceptual change apparently without the benefit of peer conflicts. It appeared that they were able to reflect on and reconstruct their conception through the learning experiences in the FMM programs. Stan showed no conceptual change possibly because he was not fully cognitively engaged in the tasks and not contributing much to the predictions.

In the three dyads with the largest number of peer conflicts (Sam/Mick, Mike/Terry, Clive/Don) one student showed substantial conceptual change subsequent to instruction whilst the other student showed no change. Sam, Mike and Clive, who achieved substantial change apparently benefitted from the conflicts. In the conflict situations Sam made the same number of correct predictions as his partner, Mick (4 out of 8 conflicts). Where he made wrong predictions, he later showed conceptual change in the relevant conceptions. Mike also changed his conceptions subsequent to the conflicts where he made the wrong predictions. It appeared that the peer conflicts had induced Sam and Mike to reflect on and reconstruct their conceptions. Clive made the correct predictions in 7 of the 8 conflicts. Rather than effecting change, these conflicts were likely to have consolidated and reinforced the scientific conceptions that Clive acquired from the FMM programs, which he was able to sustain after instruction. On the other hand, Mick, Terry and Don showed no conceptual change after instruction. The conflicts appeared not to have any impact on them. One possible explanation is that Mick was not fully cognitively engaged although he completed all the tasks, and Don and Terry were inattentive and frequently went off-task during the FMM lessons.

In the remaining dyad, Derek achieved some conceptual change but Jim showed none. They experienced 3 peer conflicts. One conflict was concerned with making the model car move at constant speed by balancing the force and friction. This conflict had a great impact on Derek. At the final interview, when probed, Derek could recall this task in detail, after which he readily used the notion of balanced forces to explain the constant speed of the 'model car' and 'skydiver'. On the other hand, the conflicts had no effect on Jim. Jim took a passive role when working on FMM — he simply read out the tasks from the worksheets for Derek and did not contribute towards any prediction.

FINDINGS

The findings, derived from the 7 case studies of collaboration, are presented now as assertions:

1. Collaborative learning provided students with experiences of co-constructions of shared knowledge and understanding as well as peer conflicts. It gave peer support and helped students get through the tasks.

Most of the tasks were carried out by the dyads as co-constructions in which students complemented and built on each other's ideas and incrementally developed shared understanding. Peer conflicts occurred in tasks in which students disagreed on the prediction and this required them to justify and defend their positions. Although the research did not use a treatment-control-group design, there appeared to be strong support from the rich qualitative data that students would not have been able to carry out the tasks as successfully as they did if they had worked on the tasks alone. Collaborative learning provided peer support and helped students get through the tasks. However, this might or might not have resulted in conceptual change. This appeared to depend on whether the students were willing to cognitively commit themselves to the tasks, a point discussed in the next assertion.

2. A high joint on-task engagement which was high in equality and mutuality did not necessarily mean cognitive engagement; it appeared that students also needed to reflect on and reconstruct their conceptions.

Collaborative learning requires a high joint on-task engagement which is high in equality and mutuality. In two of the dyads with high joint on-task engagement (Sam/Mick and Nigel/Stan), one student achieved substantial change but the other student showed no change. Both dyads' conversational interactions clearly showed that they achieved conceptual change during the FMM lessons. However, after instruction, only Sam and Nigel sustained their conceptual change; Mick and Stan reverted to their alternative conceptions. Both Mick and Stan contributed less towards the tasks than their partners in that they initiated fewer predictions/explanations and were generally more acquiescent. It appeared that this might account for their failure to achieve any change. In another dyad with high equality and mutuality in engagement, both Sid and Colin were cognitively engaged in the tasks and both showed substantial conceptual change after instruction.

Engagements of high equality and mutuality were a means to getting students to reflect on their conceptions. They were not the only means. Clive and Mike, the two students who achieved a comprehensive understanding of the conceptions, had medium and low joint on-task engagements respectively with their partners and their engagements were low in equality and mutuality. The large number of cognitive and peer conflicts that they experienced appeared to be sufficient to help them reflect on and reconstruct their conceptions. Their partners, Don and Terry, did not achieve any conceptual change. This is likely because they were not fully cognitively engaged and went off-task from time to time.

Collaborative learning with high joint on-task engagement which was high in equality and mutuality helped foster conceptual change but did not necessarily ensure change. To achieve conceptual change it appeared that students needed to reflect on and reconstruct their conceptions.

3. Peer conflicts did not always produce conceptual change. They appeared to only work for students who were prepared to reflect on and reconstruct their conceptions.

Peer conflicts appeared to have impact on some students but not on others, and some students achieved conceptual change without experiencing any peer conflicts at all. It appeared that the crucial factor was whether students were prepared to reflect on and reconstruct their conceptions. This assertion has already been considered in detail in an earlier section.

4. Developing shared knowledge and understanding was important, but to achieve conceptual change, this needed to be accompanied by students' personal construction and sense making of the new understanding. Both personal and social construction of knowledge appeared to be significant in the type of context provided in this research.

The FMM programs provided students with many opportunities for co-construction of shared knowledge. During the process, students complemented and built on each other's ideas and incrementally reached shared understanding. Students' conversational interactions showed unequivocally that this led to conceptual change during the FMM lessons. However, not all students sustained their conceptual change after instruction. In the two best collaborating dyads, Sam/Mick and Nigel/Stan, one member of each dyad (Sam, Nigel) achieved 'substantial' conceptual change whilst the other member (Mick, Stan) showed no change after instruction. Nigel/Stan completed nearly all the 48 tasks successfully as co-constructions with no peer conflict. Sam/Mick experienced peer conflicts in 8 tasks and carried out all other tasks as co-constructions. The collaboration of these two dyads was intense and mutually supportive. There were three other dyads (Derek/Jim, Clive/Don, and Mike/Terry) in which one member showed conceptual change and the other member showed no change. The co-constructions found in these three dyads also clearly indicated conceptual change.

One possible explanation for this is that, in addition to construction of shared understanding, the students who sustained their conceptual change also underwent personal construction of the new understanding. The peer interactions helped students get through the tasks and develop shared understanding, but students needed to make sense of the new knowledge before they could internalize it. They needed not just to complete the task but also to reflect on their conceptions and decide whether or not to change them in the light of the shared understanding. Those students who reverted to their alternative conceptions shortly after the FMM lessons apparently did not internalize their new, shared understanding. They appeared to be satisfied with the completion of the tasks and not to have given much thought to the new understanding. This research gives support to the claim that both social and personal construction of knowledge are important for conceptual change.

DISCUSSION

In recent years, considerable attention has been given to research on social construction of knowledge in the science classroom (Solomon, 1987; Driver, 1989; Driver et al. 1994, Scott, 1995). Much of this can be attributed to the growth interest in Vygotsky's work (Bruner, 1985). According to the Vygotskian perspective, learning science involves an introduction to the 'symbolic world' and practices of science. This entails individuals constructing knowledge and understanding by engaging socially, with the teacher and peers, in conversation and activities of common concern. This perspective contrasts markedly with the personal construction of knowledge perspective which places great emphasis on the physical experiences to which students are exposed and the effect this has on learning.

This research shows that social construction of knowledge took place in peer collaboration and in many cases this led to students' conceptual change in the context of the tasks attended to. However, when probed at a later time, many students had regressed to alternative conceptions. It is suggested that in the co-construction of shared knowledge students needed also to personally make sense of the new understanding. When the co-construction of knowledge was accompanied by personal construction, conceptual change became stable over time. When students did not personally make sense of the new understanding, their conceptual change was short-lived. Some support for this assertion can be found in other recent studies. Howe et al. (1990, 1992) arranged primary school children to work in small dyads on some physics tasks on sinking and floating, and motion down an incline. They found that children with differing views working together generally achieved better understanding than children with similar views. However, they contended that the resulting conceptual change was due to children's private conflict resolution rather than due to group effort. In a study on high school biology students' understanding of photosynthesis, Lumpe and Staver (1995) found that students working in collaborative groups developed more scientifically correct conceptions than did students working alone. However, they also found that not all the group-generated views were internalized by all group members when students were assessed individually after the instruction.

Personal construction of knowledge is basically a private and personal process to which only students can decide whether or not to commit themselves and over which the teacher ultimately does not have much control. As shown in this research, many students developed shared knowledge with their partners in the collaborative tasks but they failed to personally make sense of the new understanding. Consequently, these students could not sustain their conceptual change after instruction. Personal construction of knowledge requires metacognitive skill on the part of the students. White and Gunstone (1989) contend that this involves the student (a) recognising his/her conceptions or beliefs, (b) evaluating the worth of these beliefs, and (c) personally deciding whether or not to reconstruct them. This research has not been designed specifically to investigate students' metacognitive skills but there was some indirect evidence from the data. At the final interview, several students who achieved substantial conceptual change indicated that they were aware of their alternative conceptions and could clearly state the conceptual change they had undergone. They also claimed that they constantly tried to understand and make sense of what they learned.

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