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ABSTRACT

The process of students' conceptual change was evaluated during a computer-supported physics unit in a Grade 10 science class. Computer simulation programs were developed to confront students' alternative conceptions in mechanics. A conceptual test was administered as pre-, post-, and delayed post-tests to determine students' conceptual change. Students worked collaboratively in pairs on the programs carrying out predict-observe-explain tasks according to worksheets. While the pairs worked on the tasks, their conversational interactions were recorded. A range of other data were collected at various junctures during instruction. At each juncture, data for each of 12 students were analyzed to provide a "conceptual snapshot" at that particular juncture. All conceptual snapshots together provided a delineation of the students' conceptual development. Many students vacillated between alternative and scientific conceptions from one context to another during instruction; i.e., their conceptual change was context-dependent and unstable. The few students that achieved long-term conceptual change appeared to be able to perceive commonalities and accept the generality of scientific conceptions across contexts. These findings led to a tentative model of conceptual change. The paper concludes with consequent implications for classroom teaching. Contains 51 references. (Author/PVD)

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The Process of Conceptual Change in 'Force and Motion'

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Abstract

The purpose of this classroom study was to investigate the process of students' conceptual change during computer-supported physics instruction. 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. In addition, a range of other data were collected at various junctures during instruction. At each juncture, the data for each of 12 students were analyzed to provide a "conceptual snapshot" at that juncture. All the conceptual snapshots together provided a delineation of the students' conceptual development. Case studies of conceptual change were then written up. It was found that many students vacillated between alternative and scientific conceptions from one context to another during instruction, i.e. their conceptual change was context-dependent and unstable. The few students who achieved long-term conceptual change appeared to do so by being able to perceive the commonalities across contexts and accept the generality of scientific conceptions across contexts. These findings led to a tentative model of conceptual change. The paper concludes with this model, and some consequent implications for classroom teaching.

The Process of Conceptual Change in 'Force and Motion'

Students' alternative conceptions have been a dominant area of research in science education for more than two decades. The proliferation of research is well documented in books (e.g. Driver, Guesne & Tiberghien, 1985; Osborne & Freyberg, 1985; Driver et al., 1994; Treagust, Duit & Fraser, 1995), reviews (e.g. Driver & Erickson, 1983; Wandersee, Mintzes & Novak, 1994) and bibliographies (Carmichael et al., 1990; Pfundt & Duit, 1994). The field of study has now reached a stage where it is perhaps no longer fruitful to continue to survey students' conceptions in more domains. Instead, a more productive approach is to focus on the process of conceptual change and to search for theoretical underpinnings for the field of study. Whilst the survey of prevalent alternative conceptions in a specific domain helps curriculum developers and teachers develop teaching strategies to promote conceptual change, understanding the process of conceptual change is of more fundamental importance. As Vosniadou (1994a) puts it:

> The question of how conceptual change is achieved and the specification of the mechanisms that bring it about is one of the fundamental problems of cognitive psychology today. A theory of conceptual change is a prerequisite for any comprehensive account of learning and can have important implications for instruction. (p.3)

In the early 1980s, Posner, Strike, Hewson, and Gertzog (1982) first proposed a Conceptual Change Model (CCM) consisting of two patterns of change analogous to those in theory change in science, viz. assimilation and accommodation. According to the CCM, assimilation refers to "the use of existing concepts to deal with new phenomena" and accommodation involves "replacing or reorganizing the learner's central conceptions" (p.212). Of the two patterns of change, accommodation signifies a radical change involving the abandonment of the existing conception and the acceptance of a new conception. It is rationally directed in that the learner has to be satisfied that the new conception is more intelligible, plausible and fruitful than the existing one before deciding to make any change. Hewson (1981) calls these two types of changes 'conceptual capture' and 'conceptual exchange' respectively and Carey (1985) uses the terms 'weak restructuring' and 'radical restructuring'.

Since its inception, the CCM has been very influential and widely accepted, but in recent years it is increasingly seen as inadequate. The criticisms are mainly leveled at its rational nature – that it neglects non-cognitive factors (e.g. motivational and classroom contextual factors) which may also affect conceptual change (Dreyfus, Jungwirth & Eliovitch, 1990; Lee & Anderson, 1993; Pintrich, Marx & Boyle, 1993). Strike and Posner (1992), in a further explication of the CCM, also argued that a wide range of factors needs to be taken into account in conceptual change. In recent years, more elaborate models of conceptual change have been proposed, e.g. Chi, Slotta, and de Leeuw's model grounded in ontological categories (1994), Bliss and Ogborn's commonsense theory of motion (1994), and Vosniadou's "naive framework theory of physics" (1994b). However, these models have yet to gain as wide acceptance as the CCM.

The CCM's accommodation involves the replacement of an existing conception by a new conception. As such, it implies an abrupt change. However, other researchers offer different views on the process of change. Fensham, Gunstone and White (1994) contend that conceptual change is rarely an abrupt change but more often "an accretion of information and instances that the learner uses to sort out contexts in which it is profitable to use one form of explanation or another" (p.6). They call this 'conceptual addition' since old ideas are not abandoned but revised incrementally. In a similar vein, Linder (1993) also suggests that the learner has a range of conceptions which are invoked according to specific contexts. He argues that even scientists use different conceptions of the same concept in different contexts (e.g. electric current is conceptualized as a flow of electrons in metal, ions in aqueous solutions, or holes in semiconductors) and the same could well be true for students. Driver et al. (1994) offer a similar notion of 'conceptual profile', suggesting that individuals have different ways of thinking within specific domains. Maloney and Siegler (1993) extend this view and propose the notion of 'conceptual competition', suggesting that different competing conceptions coexist in the learner and that after a prolonged period of learning one of these achieves dominance.

Dykstra, Boyle and Monarch (1992) assert that conceptual change is a progressive process of refinement of students' conceptions and propose a taxonomy of conceptual change consisting of differentiation, class extension and reconceptualization. Similarly, Niedderer and Goldberg (1994) describe conceptual change as a process of change from the learner's prior conceptions to some intermediate conceptions and then to scientific conceptions. More recently, in a study of conceptual change in evolution, Demastes, Good and Peebles (1996) identify four patterns of change. These are (a) cascade of changes (a sequence of conceptual changes triggered by change in one conception), (b) wholesale changes (alternative conceptions discarded in favor of scientific conceptions), (c) incremental changes (alternative conceptions changing incrementally to scientific conceptions), and (d) dual constructions (students holding two logically incompatible conceptions).

Views on the process of conceptual change are very diverse and warrant further research. The study reported in this paper is an attempt in this direction. It is a classroom study of high school students' conceptual development during computer-supported instruction in introductory mechanics. The study aimed to investigate the process of conceptual change and the role of collaborative learning at the computer in that process (Tao, 1996). The focus of this paper is the process of conceptual change.

This study espouses the constructivist view of learning, that individuals construct their own meanings from experiences which are influenced by and linked to their prior knowledge and beliefs (Driver, 1989; Gunstone, 1992; Tobin, 1993). It subscribes to the Piagetian view that the provision of discrepant events may invoke disequilibration (cognitive conflict) in students which may induce them to reflect on and reconstruct their conceptions (Piaget, 1985).

The study used computer simulation programs which support exploratory learning (Papert, 1980; Bliss & Ogborn, 1989) as the major means to foster conceptual change. In using a simulation program, students can freely explore the domain of knowledge presented in the microworld by changing the parameters of the program and visualizing immediately the consequences of their manipulations. They can formulate and test hypotheses and reconcile any discrepancy between their ideas and the observations in the microworld. All these require students to reflect on their conceptions, comparing with those presented 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).

Methods

The domain of study

'Force of motion' was selected as the domain for studying the process of conceptual change. There were two reasons for such choice:

- Phenomena involving 'force and motion' are ubiquitous in everyday life and constantly impact on students in a great way from an early age. The alternative conceptions that students develop have served them well in providing satisfactory interpretations and predictions of motion in the world around them. They are highly resistant to change and hence 'good' alternative conceptions for studying the change process.

- Mechanics is a difficult topic to teach and to learn and conventional instruction is notably ineffective in fostering students conceptual understanding. It was therefore tempting to try a new, computer-based approach which has shown some promise in promoting conceptual change.

The study was concerned with three prevalent alternative conceptions which are listed in Table 1. These alternative conceptions have been identified by a large body of previous studies (e.g. Clement, 1982; McCloskey, 1983; Gunstone & Watts, 1985; Halloun & Hestenes, 1985).

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 Force & Motion Microworld

A suite of four computer simulation programs, collectively called the Force & Motion Microworld (FMM), was developed to match and confront students' alternative conceptions in the domain. A brief description of FMM is given here; further details can be found in Tao (in press) and Tao and Tse (in press). The first program, Motion Graphs, aims at facilitating students' understanding of speed-time graphs as representations of motion. The other three programs, Model Car, Spaceship, and Skydiver, provide three contexts for exploring the effects of force on motion. Model car is concerned with horizontal linear motion with or without friction; Spaceship is concerned with linear motion without friction/resistance; and Skydiver is concerned with vertical fall under gravity with or without speed-dependent air resistance. In Model car and Spaceship, forces of different magnitudes, in the forward or backward direction, can be applied to the object at any time and for any duration, and the effect is shown by the on-screen motion of the object and the plotting of a speed-time graph. In Skydiver, the fall (acceleration followed by terminal speed) is shown by the on-screen motion and a speed-time graph and the forces (weight and air resistance) on the skydiver are shown by two scaled bars in opposite directions. During the fall the parachute can be opened at any time.

Model Car, Spaceship and Skydiver were each accompanied by a set of worksheets consisting of predict-observe-explain (POE) tasks (White & Gunstone, 1992). The POE tasks were designed to provide cognitive conflicts that facilitated conceptual change. Students worked collaboratively in dyads on these tasks.

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.

There was a total of 46 POE tasks in the three sets of worksheets. As an illustration, a task in Model Car is given below:

> Task 5: Apply a force to move the car from rest, then pause the motion in the middle of the run. Reduce the force to equal to the friction. Apply this force to the car.
> What would happen to the car? What would be the net force acting on the car? Sketch the speed-time graph.

This task is intended to confront the 'motion-implies-force' conception. Students holding this conception is likely to predict that the model car would slow down or stop moving when the net force is zero.

The three contexts (model car, spaceship, and skydiver) enable students to revisit the scientific conceptions in different situations for reflection and consolidation. Table 2 gives, in abbreviated forms, the effects of force on motion in the three contexts, together with the generalization across contexts which, it is intended, students will have achieved after instruction.

Effects of force in 3 contexts:	
Model car: force = friction → at rest force = friction → constant speed if moving force > friction → acceleration opposing force → deceleration *Spaceship:* zero force → constant speed forward force → acceleration backward force → deceleration force 'off' → constant speed *Skydiver:* weight > air resistance → acceleration weight = air resistance → constant speed	*Generalization*: zero net force → at rest zero net force → constant speed if moving net force → acceleration opposing net force → deceleration

Table 2 Effects of force on motion in three contexts and the generalization across contexts

The class

The study was carried out in a Grade 10 science class of a Catholic boys' high school in Melbourne. The school was chosen based on the following criteria: (i) its students were regarded as generally of average ability, (ii) its science staff were appreciative of the constructivist view of learning, (iii) it had suitable and adequate computer facilities for running the FMM programs. A Grade 10 class was used because its curriculum was more flexible and not dictated by the Victorian Certificate of Education Examination, as was the case with Grade 11 and 12 classes. This made it easier for the researchers to secure approval from the school for carrying out the research and to incorporate the FMM programs into the science course. The physics unit of the Grade 10 science course was the first formal instruction in mechanics for the students.

The field study took place in Term 4 of the four-term year over a period of 10 week. There were 27 students in the class, 10 of whom had decided early in Term 4 to continue to study physics in Grade 11. Naturally, students' decision to opt for or out of physics in Grade 11 had some effect on their attitude towards and performance in the physics unit.

The Conceptual Test

To assess students' conceptual change subsequent to instruction, a Conceptual Test was compiled to cover the three alternative conceptions in 'force and motion' listed in Table 1. Most of the questions in the test were taken from previous studies; some were generated for the research to relate to the FMM programs. The test was validated by a panel consisting of three physics teachers and a teacher educator. Details about the test is given in Tao (1996). A brief description of the questions, in 5 groups, is given below with their sources indicated:

Q1-3 – 'Throw ball up' (LISP, 1980)
These questions ask about the force (down, up, or zero) on a ball thrown straight up when it is (i) on the way up, (ii) at the top of its flight, and (iii) on the way down.

Q4-5 – 'Throw ball obliquely' (Gunstone et al., 1989)
These questions ask about 'all the forces on a ball' thrown along a parabolic path when it is (i) at its highest point, and (ii) on the way down.

Q6-8 – 'Push car' (Osborne & Gilbert, 1980)
These questions consider a car being pushed on a level road. The car is "out of gear", "the engine is not going" and "brakes are off". The questions ask if there is a net force on a car when it (i) remains at rest, (ii) moves slowly at a steady speed, and (iii) moves faster and faster.

Q9-13 – 'Spaceship'
These questions were generated for the research to relate to the program Spaceship. They ask (i) if there is a net force on a spaceship which travels at constant speed with all its rockets shut down; (ii) about the effects on motion of firing and shutting down the stern rockets (for forward thrust) and the retro-rockets (for backward thrust).

Q14-15 – 'Skydiver'
These questions were generated for the research to relate to the program Skydiver. They ask if there is a net force on a skydiver when he/she (i) initially falls faster and faster, and (ii) eventually falls at a constant speed.

The questions were of multiple-choice format but students were also required to explain their answers. Thus the test provided both quantitative and qualitative data, in the answer scores and open responses to explanations respectively. 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. The test was not intended as an evaluation of FMM or the instruction. It was used for assessing individual students' conceptual change which was determined from (i) the *gain* in answer scores and (ii) the changes in the open responses from one test to the next. The test results helped identify students for in-depth case studies of conceptual change.

The instruction

FMM was incorporated into the 10-week physics unit of the Grade 10 science class. All lessons were taught by the science teacher of the school except for 5 FMM lessons in the middle of the physics unit which were taken by one of the researchers (PKT). The class spent one lesson on Motion Graphs, two lessons on Model Car, and one each on Spaceship and Skydiver. Students were assigned to work in dyads on the FMM programs based on (i) their pre-test results, with students of high score paired up with students of relatively lower scores to maximize the chance of peer conflicts, and (ii) friendship patterns so as to ensure that the two partners could work together for a prolonged period of time.

Prior to the FMM lessons, the class was taught 3 lessons on speed and acceleration and carried out trolley experiments using ticker-timers. After the FMM lessons, the class was taught 'force, inertia and acceleration' in one lesson. The class spent two more lessons on problem solving on force and acceleration. Thus FMM provided the dominant but not the sole learning experiences in 'force and motion'.

Data sources

This study entailed the collection of a wide range of data on students' conceptions at various junctures in order to make inference on the change process. Naturally, an interpretive approach to data analysis was required.

While students worked on the FMM programs, the within-group conversational interactions of all groups were audio-recorded. The transcripts of the tapes formed the major data source of the study.

In addition to the pre-, post- and delayed post-tests, a Quiz was administered to the class shortly after the FMM lessons. The 4 multiple choice questions in the Quiz considered the situations of a wooden block being pushed to move on the floor. They asked about the force, in relation to friction, when the block was (i) stationary, (ii) moving with a constant speed, (iii) moving with a uniform acceleration, and (iv) decelerating to rest. These questions are similar to the 'push car' questions in the Conceptual Test.

Also, the End-of-Unit test, set by the teacher for assessment purposes, coincidentally contained three questions relevant to the study. The first was a true/false question: "All objects need a force to keep moving". The second question considered a car traveling at 100 km/h on a freeway and asked students to (i) sketch a diagram showing all the forces on the car, and (ii) find the net force on the car. These two questions tested if students held the 'motion-implies-force' conception. The third question asked students to (i) describe the motion of a toast from a "pop-up" toaster and (ii) consider the forces on the toast at various stage of the motion of the toast. This question is similar to the 'throw ball up' questions in the Conceptual Test.

Interviews were conducted for some students after (i) the pre-test, (ii) the Quiz, and (iii) the delayed post-test. The first two rounds of interviews were used to clarify students' conceptions identified in the pre-test and the Quiz respectively. The third round of interviews attempted to find out about students' awareness of their conceptual change, their approach to learning physics and conceptual understanding across different contexts.

The data collected, in chronological order, were:

1. Students' responses in the pre-test and transcripts of follow-up interviews for some students
2. Transcripts of students' within-group conversational interactions during the 2 lessons on Model Car, and the single lesson on each of Spaceship and Skydiver, together with responses in the accompanying worksheets. (The tapes of the Motion Graphs lesson were not transcribed and analyzed since the program was not concerned with 'force and motion' *per se*.)
3. Students' responses in the Quiz and transcripts of follow-up interviews for some students
4. Students' responses in the End-of-Unit test
5. Students' responses in the post-test
6. Students' responses in the delayed post-test
7. Transcripts of final interviews with students

Furthermore, fieldnotes were taken during all the lessons. The classroom lessons which were directly concerned with the teaching of 'force and motion' were audio-recorded. During a revision lesson at the end of the unit, the teacher discussed two questions that would appear in the End-of-unit Test. One question was concerned with the 'throw ball up' situation and the other with motion under zero net force. These questions invoked a lively discussion and heated debate as students used their alternative conceptions to interpret them. For some students, this was a crucial lesson for their conceptual understanding. The lesson was audio-taped and fully transcribed for analysis.

Identifying students for case studies of conceptual change

Of the 27 students in the class, 14 students took the pre-test plus the post- and/or delayed post-test, which made it possible to assess their conceptual change. These 14 students were grouped according to two dimensions: (i) 'amount' of conceptual change (substantial, some, or none) as measured by the *gain* in answer score from pre-test to post- or delayed post-test, 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 were 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 both dimensions were arbitrarily defined for crude comparison. The grouping of the students is given in Table 3. It should be noted that the students with high scores were found to espouse nearly the same alternative conceptions as students with medium and low scores when their open responses to the questions were analyzed qualitatively. They obtained a high aggregate score by giving correct answers to more parts, but not all the parts, of the groups of questions than other students.

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

All student names are pseudonyms
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 Interview 3
(p) = students who opted to study physics in Grade 11

Table 3 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 Interview 3), one showed some change, and the remaining 7 showed no change. Table 3 shows that there was no correlation between the amount of conceptual change and pre-test score. Of the 5 students who achieved substantial conceptual change at the post-test, two showed further improvement (Clive and Mike) in the delayed post-test, one sustained his change (Sam), one showed deterioration (Sid), and one student was absent (Colin).

Data presentation and analysis

The data collected on each student at various junctures during instruction were analyzed according to 4 dimensions. The first 3 dimensions were concerned with the alternative conceptions of 'force-of-motion', 'motion-implies-force' and 'effects of force' listed in Table 1; the fourth dimension identified instances of cognitive conflict (from the transcripts of students' conversational interactions during the FMM lessons). A cognitive conflict was an instance in which the prediction jointly made by the students in the dyad differed from the observation in the microworld.

At each juncture, the data were examined for the presence or absence of these dimensions and an interpretive summary was prepared as a "conceptual snapshot" at that juncture. All the snapshots together provided a delineation of the student's conceptual development. The interpretive summaries, in condensed forms, were recorded in a conceptual progression/regression matrix for easy reference. Case studies of conceptual change were written up for each student. This analysis was carried out for 12 students. Two students, Martin and Terry, were excluded because they frequently went off-task during the FMM lessons thus making it difficult to ascertain their conceptual understanding from the transcripts. The conceptual development of the students with substantial conceptual change was compared with those with minimal change.

The data collected at various junctures were probes of students' conceptual understanding of, in particular, the 'effects of force' in a range of contexts. These contexts can be grouped into three categories: model car, spaceship, and skydiver.

- '*Model car*' was concerned with motion opposed by friction and included the 'push car' questions in the pre-, post- and delayed post-test (T1, T2, and T3), the first lesson of the Model Car program (MC1), 'push wooden block' in the Quiz, and 'car traveling at constant speed' in End-of-unit Test (EUT), and the probe on 'push car' at Interview 3 (I3)
- '*Spaceship*' was concerned with frictionless motion and included the 'spaceship' questions in the pre-, post- and delayed post-test, the second lesson on the Model Car program on frictionless motion (MC2), and the Spaceship program (SS).
- '*Skydiver*' was concerned with free fall under gravity which was opposed by speed-dependent air resistance; it included the 'skydiver' questions in the pre-, post- and delayed post-test, the Skydiver program (SD), and the probe on skydiver at Interview 3 (I3).

The scientific conceptions in these three categories are given in Table 2. Analysis of the data would show whether students developed and sustained their understanding in similar contexts and across contexts.

Students' conceptual understanding subsequent to instruction

Students' conceptual change was initially determined from the gain in answer scores from one test to the next. However, it is also useful to consider their conceptual understanding at the post-test, delayed post-test, or Interview 3, whichever was the last probe of understanding. Table 4 presents such information on the three alternative conceptions of 'force-of-motion', 'motion-implies-force' and 'effects of force'. Of these, 'effects of force' is considered in three contexts, viz. 'model car', 'spaceship' and 'skydiver'. In each context, students' understandings of different situations are indicated in the table: in 'model car' the force on the car when it is stationary, moves at a constant speed, and accelerating; in 'spaceship' whether a force acts on it when it travels at constant speed, and the effects on motion of firing and shutting down the stern and retro-rockets; in 'skydiver' the force acting when the skydiver falls with acceleration and constant speed.

Table 4 shows that students' conceptual understanding subsequent to instruction differed widely. Only one student (Mike) showed reasonably comprehensive understanding; several students (Clive, Sam, Nigel, Derek, Sid and Colin) 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-test to post-test; and some students (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.

Student	Force-of-motion	Motion-implies-force	Effects of force									Tally (out of 11)
			Model car			Spaceship				Skydiver		
			Rest	Constant speed	Accel.	Constant speed	Forward force	Backward force	Force 'off'	Accel.	Constant speed	
Mike*(p)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	11
Clive*(p)	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
Paul(p)	×	×	✓	✓	✓	×	✓	✓	✓	✓	✓	8
Sam*(p)	✓	×	×	✓	✓	✓	×	✓	✓	✓	✓	8
Nigel^	✓	✓	×	×	×	×	✓	✓	✓	✓	✓	7
Derek*(p)	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	8
Sid*(p)	×	×	✓	×	×	✓	✓	✓	✓	✓	✓	7
Colin*	×	✓	×	×	×	✓	✓	✓	✓	×	×	5
Mick	×	×	×	×	×	✓	×	✓	×	✓	✓	4
Stan	×	×	×	×	×	✓	×	×	×	✓	✓	3
Don	×	×	×	×	×	✓	✓	✓	×	×	×	3
Jim(p)	×	×	×	×	×	×	✓	×	×	×	×	1
Tally (out of 12)	3	4	4	5	5	9	9	10	8	9	9	

* showed substantial or some conceptual change at post- or delayed Post-test as measured by the gain in answer score
^ showed no change at post-test but substantial change at Interview 3
(p) opted to study physics in Grade 11
✓ = developed scientific conception. × = showed alternative conception

Table 4 Students' conceptual understanding in the last probe (post-test, delayed post-test or Interview 3)

Table 4 also provides a means of comparing the three alternative conceptions in terms of their tenacity. 'Force-of-motion', 'motion-implies-force' and 'effects of force' in the context of model car were most resistant to change, with only 3, 4 and 4 students showing understanding respectively. The 'effects of force' in the context of spaceship proved to be less difficult: 4 students already showed some understanding at the pre-test and 8 showed understanding in the last probe. Although no students showed understanding of the 'effects of force' in the context of skydiver in the pre-test, 9 achieved a good understanding at the last probe. Possibly, 'skydiver' is a new context in which students hold very few prior ideas and so they found it easier to accept the scientific conceptions.

Case study of Mike

Each of the 12 case studies is interesting in its own right and represents a particular mode of conceptual development. As an illustration, the case study of Mike's conceptual development is briefly presented below; details of all 12 case studies together with accompanying conceptual progression/regression matrices can be found in Tao (1996).

Mike was a 'medium scorer' in the pre-test who showed substantial conceptual change in the post-test, some further improvement in the delayed post-test, and reasonably comprehensive understanding at Interview 3. He gave extended and articulated explanations when attempting the pre-, post- and delayed post-tests and was unable to finish all the questions. He worked diligently on the FMM programs but his partner, Terry, frequently went off-task. When Terry returned to work, Mike often repeated the tasks for him and so could not complete all the tasks in Model Car and Spaceship. Terry was absent from the Skydiver lesson and Mike had to work alone.

Force-of-motion. In the pre-test, Mike was one of two students in the class who gave correct answers to 'throw ball up' and 'throw ball obliquely', that only gravity acted on the ball. In 'throw ball up', he explained that "the momentum (of the ball) was slowed down to a halt by gravity". However, his notion of 'force-of-motion' was evident in his responses in 'throw ball obliquely' ("The force of throw upwards has been halted by gravity") and in 'spaceship' ("The spaceship moves faster to add to the original force, then keeps going at that speed afterwards."). During the FMM lessons he showed a notion of 'force-of-motion' which became gradually used up when countered by an opposing force. In the post-test, he gave correct answers to 'throw ball up' and 'throw ball obliquely' but again betrayed his 'force-of-motion' conception in 'spaceship'; he explained that the spaceship slows down when the retro-rockets were fired "because they are continually slowly counteracting the original force." In the delayed post-test, he finally discarded the notion of "original force" and contended that "the momentum must be countered".

Motion-implies-force. Mike revealed his 'motion-implies-force' conception in the Spaceship program. He was puzzled to find that that the spaceship could move at a constant speed when all the rockets were shut down ("This doesn't make sense. If there is no force, it doesn't move.") In the End-of-unit test, he contended that the statement "all objects need a force to keep moving" was false. This suggested that Mike had by then given up this alternative conception.

Effects of force. In the pre-test, Mike showed understanding of the effects of force in 'spaceship' but not in 'push car' and 'skydiver'. During the Model Car 1 lesson, he contended that (i) the car remained at rest if the force was "not large enough" (the transcript showed that he noted that the force was equal to friction); (ii) the car moved with an acceleration when the force was greater than friction; and (iii) the car reversed immediately when an opposing force was applied (he appeared to be oblivious to the slowing down of the car to a stop before reversing). Mike did not know how to pause the car and reduce the force to equal to the friction (Task 5, quoted earlier) and so missed out on this learning experience. In the Model Car 2 lesson, after some prompting by the researcher, Mike succeeded in moving the car at a constant speed. He recorded in the worksheet: "Need to pause it and use a balanced force after going a speed." Thus Mike developed some understanding of the effects of force in the context of 'model car'. However, he failed to transfer such understanding to the contexts covered in the tests that followed: (i) in 'push wooden block' in the Quiz, he maintained that the wooden block moved at a constant speed if the pushing force was greater than friction; (ii) in 'push car' in both the post- and delayed post-tests, he believed that a net force gave rise to constant speed and a greater net force to acceleration.

Mike showed understanding in 'spaceship' in the pre-test and during the FMM lessons, but in the post-test he contended that when a forward force was applied the spaceship travels at a higher constant speed (rather than accelerating). Later in the delayed post-test, he reverted back to the scientific conception, that the spaceship accelerated when a force was applied.

In the pre-test, Mike attributed the skydiver's acceleration to a "stronger gravity near the ground". In the Skydiver lesson, he contended that the terminal speed was the maximum speed that gravity could pull the skydiver ("Because he needs to gain speed and gravity can only pull at a certain speed."). Mike continued to use this conception in the post-test but changed to 'balanced forces' ("the weight balanced by air resistance") in the delayed post-test.

During Interview 3, Mike showed a good understanding in the different contexts. In 'throw ball up', he explained: " ... but if it leaves the hand you're not putting any force on it, and it's just out of your control what happens to it." In 'push car', he gave an articulate explanation:

> "OK, when the car is not moving, the forces between the person and the friction are balanced. And when it's moving steadily, there has been a force applied, but the net force is now also balanced [zero], because it's not moving any faster, and not moving any slower also. And when it keeps increasing, the constant force on the car makes the car go faster."

In 'skydiver', he contended that when the skydiver fell with acceleration "the pull of gravity is a lot more than the friction between him and the air" and when he fell with a constant terminal speed "the friction between him and the air couldn't let him go any faster, and so was balanced with gravity."

Cognitive conflicts. There were four instances of cognitive conflict. These were concerned with 'turning off' the force on the model car; allowing the spaceship to travel without firing any of the rockets; skydivers of different masses falling from the same height and from different heights. All four cognitive conflicts appeared to have a significant impact on Mike.

At Interview 3, Mike could remember the FMM programs very well. He claimed: "Yeah, I suppose I could use it if you put it in front of me. Yeah, I remember fairly well, how the thing [graph] went up and down." When asked about his conceptual change, he cited two changes. In the first, he claimed that he had previously believed that a force gave rise to speed but changed to associating force with acceleration: "With the force, I thought it [the speed] would be constant if you kept on applying the force whereas it increases." His second change was that the spaceship moved at a constant speed even if all its rockets were shut down; previously he believed that the spaceship would stop.

On his approach to learning physics, he stressed the importance of understanding the concepts under study. He said: "I suppose I've got to know what things mean and then we can apply them ... "

Mike developed conceptual understanding during the FMM lessons, but he failed to transfer his understandings to the other contexts. In the Quiz, End-of-unit test, post- and delayed post-tests, Mike shifted back and forth between alternative and scientific conceptions. Mike finally showed conceptual change in all the contexts at Interview 3.

Findings

The findings pertaining to the process of conceptual change, derived from the 12 case studies, are presented as two assertions below.

> *Assertion 1. Cognitive conflicts did not always produce conceptual change. Where conflicts did lead to change it appeared that the students were prepared to reflect on and reconstruct their conceptions.*

There was a total of 19 instances of cognitive conflict for the 7 dyads. Table 5 gives a summary across the FMM lessons. Eight conflicts occurred in the Model car 1 and 2 and Spaceship lessons combined. Most of these were concerned with the 'motion-implies-force' conception. They occurred in tasks on (i) making the applied force on the model car equal to friction, (ii) turning off the force on the model car, and (iii) shutting down the rockets of the spaceship. These cognitive conflicts appeared to work for some students but not for others. For example, Mike, as described in the case study above, benefited from the cognitive conflicts, but his partner, Terry, did not. The two students differed in their cognitive engagement on the tasks and willingness to reflect on their conceptions. Mike gave careful thoughts to the tasks and articulated his predictions/explanations, whereas Terry worked half-heartedly and went off-task from time to time. When confronted with discrepant events Mike pondered over them for a considerable time.

	FMM Lessons				
Students	Model car 1	Model car 2	Spaceship	Skydiver	Total
Clive**(p)/Don	1				1
Mike**(p)/Terry	1		1	2	4
Sam**(p)/Mick				2	2
Paul(p)/Martin(p)	1			3	4
Nigel^/Stan					0
Derek*(p)/Jim(p)	1	1	1	2	5
Sid**(p)/Colin**	1			2	3
Total	5	1	2	11	19

** Students achieving substantial conceptual change; * student achieving some change
^ showed no change at post-test but substantial change at Interview 3
(p) Students who opted to study physics in Grade 11

Table 5 Number of instances of cognitive conflict

For the group of Paul and Martin, the cognitive conflict in Model Car 1 (the task on making the force equal to friction) helped them successfully moved the car at constant speed in the forward and backward directions in the next lesson, Model Car 2. However, in the Quiz and post-test/delayed post-test they reverted to their alternative conception that a net force gives rise to constant speed. At Interview 3, Paul retracted his alternative conception after being asked to recall the cognitive conflict and contended that the car would move at a constant speed when the force and friction were balanced. Paul was a very able student. However, he experienced very little peer interactions which might have induced him into reflection since his partner, Martin, frequently went off-task. Paul was "triggered" into reflection during Interview 3 and he subsequently accepted the scientific conceptions. On the other hand, at Interview 3 Martin still maintained that the car would stop when the force and friction were balanced and retained his alternative conceptions in 'model car'.

In another group, despite having experienced three cognitive conflicts in 'motion-implies-force' in Model car 1 and 2 and Spaceship, Derek and Jim retained their alternative conception at the delayed post-test. Derek was very interested in the programs and keen to explore them but apparently did not give much thought to the tasks. Jim was not cognitively engaged and did not contribute to any of the predictions. At Interview 3, Derek first explained 'push car' in terms of the person's strength, as he did in the pre-test. After being reminded of the discrepant event in *Model car 1*, he then readily explained the constant speed of the 'push car' and 'skydiver' in terms of balanced forces. As with Paul, Derek was "triggered" into reflecting on his conceptions.

There were 11 cognitive conflicts in Skydiver. These conflicts appeared to be quite effective in promoting conceptual change, possibly because skydiver was a new context in which students had not yet formulated any prior ideas.

In general, when students were confronted with discrepant events there were not many outbursts of surprise or disbelief. Instead, expressions such as “Well, we got this one wrong. What’s the next task?” were common. The interactions between students and the computer were ‘asymmetrical’ in that students often accepted discrepant events as something they did not know but needed to learn. They treated the computer with deference and usually accepted the results in the microworld without much reflection. Such approach was unlikely to lead to conceptual change.

> *Assertion 2. Students vacillated between alternative and scientific conceptions from one context to another during instruction. Their conceptual change was context-dependent and unstable. To achieve long-term and stable conceptual change it appeared that students needed to be able to perceive the commonalities across contexts and accept the generality of scientific conceptions across contexts.*

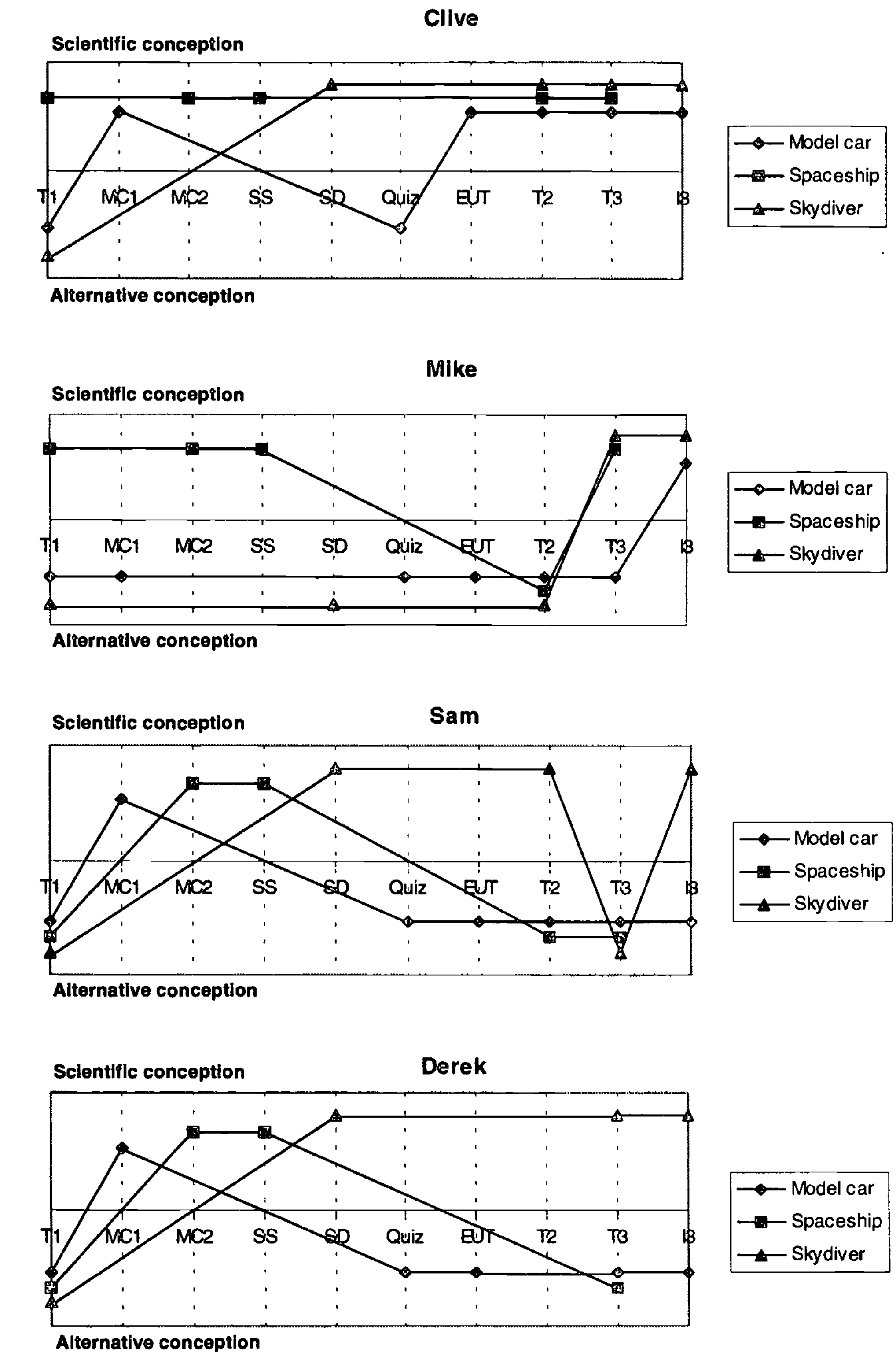
In the pre-test, the 12 students selected for case studies showed little understanding of the conceptions. During the FMM lessons most students completed nearly all the tasks successfully and achieved conceptual change in the contexts presented in the programs. Some students gave extensive and articulated exchanges in their peer interactions, indicating a good understanding of the conceptions. For example, Derek, in an exchange with Jim in the task on changing the rocket thrust in Spaceship, argued that "It[the graph]'ll be straight up, got a greater angle than that. This has 5^o, that has 10^o. It's not a curve. That's exactly straight." Another group, Nigel and Stan, correctly predicted the fall of the skydiver and said “the skydiver would keep getting faster but the rate of acceleration would decrease the further he falls."

However, after the FMM lessons, most students failed to transfer their understanding to the contexts probed in the Quiz and End-of-unit test. None of the students correctly answered all the four questions in 'push wooden block' in the Quiz. In the End-of-unit test, only two students contended that the net force on a 'car traveling at constant speed' was zero. Nearly all students regressed in their conceptual understanding in these two contexts. The responses in the Post- and Delayed Post-test and Interview 3 showed that students' conceptual understanding in the three contexts subsequent to instruction was not uniform: 4 students showed understanding in 'push car', 8 in 'spaceship', and 9 in 'skydiver'. Only two students, Clive and Mike, showed understanding across all three contexts; the other students showed understanding in only one or two contexts. Students' conceptual regression in the Quiz and End-of-unit test and the differential understanding in the three contexts give a strong support to the claim that their learning was contextually based.

In general, students went through a series of conceptual progressions and regressions in the course of the instruction. After achieving understanding (conceptual progression) in one context, they might suffer from regression in a new context. Figure 1 shows pictorially the conceptual progression and regression of four students in 'effects of force' in the three 'broad' categories of 'model car', 'spaceship', and 'skydiver'. The markers on the chart represent probes of understanding at various junctures. Markers above the horizontal axis indicate scientific conceptions and those below indicate alternative conceptions.

The first chart in Figure 1 showed that Clive displayed understanding in 'spaceship' both prior to and after the instruction; achieved conceptual change in 'skydiver' during the FMM lessons which he sustained thereafter; showed understanding in 'model car' during the FMM lessons, regressed to alternative conception in the Quiz, then showed progression thereafter. On the other hand, as described in the case study above, Mike showed alternative conceptions in 'model car' and 'skydiver' until towards the end of the instruction; showed understanding in 'spaceship' at the pre-test which was reinforced during the FMM lessons but took a retrograde step at the post-test, and then a progression again at the delayed post-test.

Both Clive and Mike showed a comprehensive understanding of the 'effects of force' across the three contexts at Interview 3. It was likely that they achieved this by being able to resolve the conflicts between alternative and scientific conceptions, perceive commonalities across the contexts, and accept the generality that the scientific conceptions apply to all the contexts. Clive developed understanding that a zero net force gave rise to constant speed in Model car 1 and Spaceship but regressed to the alternative conception that a non-zero net force accounted for constant speed in 'push wooden block' in the Quiz. He resolved the conflict by developing a deep understanding of zero net force. He argued at Interview 3: "The car won't speed up or slow down, it'll stay at the same speed. It won't start moving and it won't stop moving." Mike showed a similar deep understanding of zero net force, as described in the case study above.



Keys: T1 = Pre-test; T2 = Post-test; T3 = Delayed Post-test; MC1 = Model car 1; MC2 = Model car 2; SS = Spaceship; SD = Skydiver; EUT = End-of-unit test; I3 = interview 3

Figure 1 Students' conceptual progression/regression in the contexts of 'model car', 'spaceship', and 'skydiver' at different junctures during instruction

The other two students, Sam and Derek, showed understanding only in 'skydiver' in the last probe. In this broad category, Sam shifted back and forth between scientific and alternative conceptions, and Derek achieved understanding during the FMM lessons which he sustained thereafter. Both students showed understanding in 'model car' during the FMM lessons but regressed thereafter. At Interview 3, after being asked to recall a discrepant event in *Model car 1* (the task on making force equal to friction), they could readily explain the constant speed of the 'model car' and 'skydiver' in terms of balanced forces. This "trigger" apparently helped them see the commonalities between the two contexts and transfer the understanding they developed in the Model car 1 task to the 'model car' context. However, they both maintained that the force was smaller than friction when the car remained stationary; hence they were regarded as not having achieved full understanding in the broad category of 'model car'.

The ability to see the commonalities across contexts and accept the generality of scientific conceptions across contexts appeared to be crucial in bringing about the conceptual change in associating constant speed with a zero net force. Clive and Mike achieved this on their own, but Sam and Derek had to be "triggered" to do so.

Discussion

The process of conceptual change explored in this study can be described as follows. Students bring with them a set of prior conceptions to bear on the learning tasks. These conceptions strongly influence the learning outcome. When confronted with a discrepant event arising from the task, some students may choose to ignore the discrepancy and retain their conceptions whilst others may resolve the cognitive conflict by reconstructing their conceptions. For those students who achieve conceptual change, their change is likely to be restricted the context of the task. When carrying out analogous tasks in different contexts at later times, students may apply their newly acquired scientific conceptions or may regress to their prior conceptions. Students undergo a series of conceptual progressions and regressions as they vacillate between alternative and scientific conceptions from one context to another. Alternative and scientific conceptions coexist in students' mind and one or the other is invoked depending on the context. For many students this is the final outcome of their learning and they continue to apply alternative or scientific conceptions according to the context. However, some students are able to achieve long-term and stable conceptual change across contexts. They do so by perceiving the commonalities across contexts and accepting the generality that the scientific conceptions apply to all contexts. A few students are able to do this on their own, but many students require explicit instruction on this.

The process described above suggests that conceptual change, as explored in this study, is a slow process during which students acquire contextually based scientific conceptions in a range of contexts, and based on these conceptions they may reorganize and systematize their cognitive structure and acquire deep conceptual understanding. Long-term conceptual change is exceedingly difficult and students may fail at any intermediate stage during the process. They may fail to achieve conceptual change in any one of the contexts and/or to generalize across the contexts. The difficulty lies mainly in the transfer of learning — from the scientific conceptions that students acquire in one context to another context in which they use alternative conceptions. It is well established in research on cognition and problem solving that transfer of learning across contexts is very difficult (Gick & Holyoak, 1987; Singley & Anderson, 1989). Ceci and Roazzi (1994) contend that:

> The failure to transfer learning from one context to another is pervasive, including both the young and old, educated and uneducated, and high and low IQ. (p.82)

They claimed that for most people transfer of learning requires explicit instruction. This research shows that at Interview 3, once reminded of a discrepant event in *Model car 1*, several students were able to transfer the scientific conceptions they acquired from that context to the context of 'model car' in which they initially used their alternative conceptions.

Several researchers have proposed that students hold a range of conceptions each being invoked according to the context (e.g. Linder, 1993; Driver et al., 1994; Fensham et al., 1994). The findings of this research confirm that students acquire scientific conceptions in some contexts but may retain their alternative conceptions in analogous tasks in other contexts. But the findings further suggest that long-term and stable conceptual change is possible if students are able to perceive the commonalities across contexts and recognize the generality of scientific conceptions.

Other researchers suggest that conceptual change is a process of progressive refinement of students' conceptions (Dykstra et al., 1992; Niedderer and Goldberg, 1994). The data in this research do not support such progressive refinement of conceptions in students' conceptual development. Within a context, the conceptual change appeared to be abrupt with students giving up their alternative conceptions for the scientific conceptions. For example, the change from associating a non-zero net force to constant speed in 'push car' to attributing zero net force to constant speed in *Model car 1* appeared to be an abrupt change. However, students' recognition of the generality of scientific conceptions was a lengthy process during which students were exposed to a range of contexts.

This research shows that before students achieved long-term conceptual change, they shifted back and forth between alternative and scientific conceptions from one context to another. The vacillation shows that students accepted the scientific conceptions in some contexts but were unwilling to give up their alternative conceptions in other contexts. In a recent microgenetic study of young children's mastery of number conservation, Siegler (1995) found that children generated multiple ways of thinking about number conservation and that their use of these different ways of thinking changed in frequency over time. He conceptualizes the children's change in cognition in terms of an "overlapping waves model". This pattern of change suggests that the different ways of thinking are in competition and eventually one or more ways of thinking gain dominance after a prolonged period of time (Maloney & Siegler, 1993). This pattern of change is not the same as that proposed by the current research, but both patterns show that the change is neither a discrete step-wise nor a gradual process. The current research argues that it is not so much that the scientific conceptions gain dominance over the alternative conceptions, but that they are perceived to have the generality to apply to all contexts.

A tentative model of conceptual change

The process of conceptual change described above can be represented in Figure 2. Conceptual change first takes place contextually. A student may change from alternative to scientific conception in one context, but retain his/her alternative conception in another. The student is seen to vacillate between alternative and scientific conceptions from one context to another. The conceptual change is context-dependent and unstable. Long-term and stable conceptual change is achieved when the student is able to perceive the commonalities across contexts and recognize the generality of the scientific conceptions across contexts.

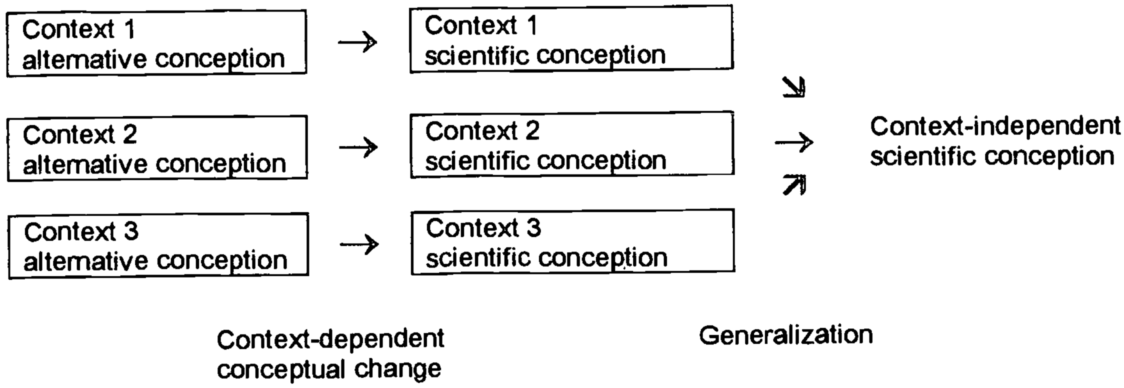


Figure 2 A tentative model of conceptual change

Implications

This research was conducted in a naturalistic setting with the intention that any findings may be used to inform classroom practices for the improvement of science teaching and learning. There are several implications for classroom practices.

1. The provision of a range of learning experiences in different contexts

This research shows that learning is contextually based. The implication is that there is a need to provide a wide range of learning experiences in different contexts to enhance learning, particularly in topics that demand conceptual understanding. A wide range of learning experiences within a context maximizes the chance of students encountering cognitive conflicts in that context. Different contexts may help students acquire contextually-based scientific conceptions from which they may be able to made generalizations across contexts. The learning experiences need not be restricted to computer-based activities, as were used in this research; other activities, e.g. experiments, can also be organized

2. Explicit instruction on transfer of learning

The research shows that students faced a major difficulty in the transfer of learning from one context to another. It is therefore suggested that when students are presented with a new context, they should be reminded of an earlier analogous context, and perhaps also taught explicitly about the commonalities across the contexts. Only then would transfer of learning be possible for the majority of students. There is already considerable support for explicit instruction on the transfer of learning in the literature (e.g. Singley & Anderson, 1989).

3. Teaching the generality of scientific conceptions.

This research argues that to achieve long-term and stable conceptual change, students need to accept the generality of scientific conceptions, that they are applicable to a wide range of contexts. Students' alternative conceptions are developed from experience and are shaped by a socially constructed "commonsense" ways of describing and explaining the world. As argued by Driver et al. (1994), commonsense reasoning is pragmatic, with ideas judged in terms of being useful for specific purposes or in specific situations, whereas scientific reasoning aims at "constructing a general and coherent picture of the world" (p.8). This research suggests that students need to be taught to appreciate the generality of scientific conceptions.

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