

Confronting students' alternative conceptions in mechanics with the Force and Motion Microworld

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This article describes the development of a suite of four computer simulation programs, collectively called the Force and Motion Microworld (FMM), that was designed to confront some high school students' alternative conceptions in mechanics. The first program, Motion Graphs, aims at facilitating students' understanding of velocity-time graphs as representations of motion. The other programs, Spaceship, Model Car, and Skydiver, provide three different contexts in which the effects of force on motion can be explored. Students work in pairs or small groups on the programs carrying out predict-observe-explain (POE) tasks from a set of worksheets. The POE tasks provide discrepant events that contradict students' alternative conceptions. FMM was originally used as a tool for a classroom study into the process of students' conceptual change. The findings show that FMM may also be offered as a supplement or alternative to other instructional tools for facilitating students' understanding in force and motion. © 1997 American Institute of Physics. [S0894-1866(97)01702-1]

INTRODUCTION

The Force and Motion Microworld (FMM)¹ is a suite of computer simulation programs that was developed to match and confront some high school students' alternative conceptions of mechanics. It was originally used as a tool for research into the process of students' conceptual changes in learning introductory mechanics and the role of collaborative learning in that process. The research was carried out in a grade 10 science class of a Melbourne (Australia) High School. The findings show that FMM may also have some instructional use and may be used as a *supplement* or *alternative* to other instructional tools for facilitating students' understanding of force and motion.

Alternative conceptions are intuitive ideas about natural phenomena that students hold that are in conflict with the orthodox scientific view. Students develop these ideas from their interactions with the natural world and with people from an early age. Research has shown that such ideas are highly resistant to change despite years of science instruction;² there are studies that show that conventional instruction produces little change in these ideas³ and that even college physics students use such ideas to solve qualitative problems.⁴ Learning is therefore seen not as an absorption of knowledge but as a process of conceptual change, from alternative conceptions to scientific conceptions.

Students' alternative conceptions have been investigated in a wide range of domains in science.⁵ Among these domains, mechanics, more specifically, force and motion, has received much attention. Based on a study of college students' alternative conceptions in this area Halloun and

Hestenes⁶ developed a "taxonomy of common sense concepts about motion." Hestenes, Wells, and Swackhamer⁷ later revised the taxonomy and developed a widely known and used instrument, the force concept inventory, for probing students' alternative conceptions. Other studies⁸ have identified similar alternative conceptions to those in the taxonomy. Studies have also found that such conceptions are common across age and culture.⁹ Table I lists those conceptions for which FMM has been designed, together with the corresponding scientific conceptions towards which conceptual change is to be directed. The list is only concerned with force and motion and may be regarded as a subset of the taxonomy. It contains conceptions that are relevant to the goals and the curriculum of the physics unit of the grade 10 science course of the school in which this research was carried out. The list does not include alternative conceptions in kinematics, action/reaction pairs, and other categories in the taxonomy; these topics are included in the grade 11 physics course of that school.

The first two statements in Table I are concerned with the notion of force-of-motion in a moving body. McCloskey calls this the naive impetus theory¹⁰ relating it to the medieval impetus theory of motion. The third and fourth statements, referred to as "motion-implies-force" by Clement,¹¹ associate motion with a force in the direction of motion. Studies have shown that many students believe that the force on a ball thrown vertically upwards is (i) upward when it is on the way up, and (ii) zero when it is momentarily at rest at the top of the flight.¹² The fifth statement is concerned with the effects of force on motion. Many students believe that an object moves with (i) a constant speed when acted on by a constant force, and (ii) an acceleration when the force is increasing.¹³ This conception conflicts with the Newtonian view, but it agrees with everyday observations of moving objects where friction impedes the

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Table I. Alternative and scientific conceptions in force and motion.

Alternative conceptions	Scientific conceptions
(1) A moving body has a force of motion in it.	A force is not something in a body; it is a push or pull that acts on a body.
(2) A body slows down and stops as its force is gradually used up.	A body slows down when the net force is in a direction opposite to the velocity.
(3) If a body is not moving, there is no net force acting on it.	If a body is at rest or moves with a constant speed in a straight line, the net force acting on it is zero.
(4) If a body is moving, there is a net force acting on it in the direction of motion.	If a body accelerates, a net force acts on it in the direction of motion. If a body decelerates, a net force acts on it in opposite direction to its motion.
(5) A constant force acting on a body produces a constant speed; an increasing force produces an acceleration.	A constant net force acting on a body produces a uniform acceleration.

motion; yet students are not aware of the existence of friction.

Phenomena involving force and motion are ubiquitous in everyday life and constantly impact on students in a great way. The alternative conceptions that students develop have served them well in providing satisfactory interpretations and predictions of motions in the world around them. This explains why they are so resistant to change. Traditional instruction is notably ineffective in fostering students' conceptual change, and special teaching strategies have been used to deal with students' alternative conceptions.¹⁴ One common approach entails eliciting students' conceptions and then presenting discrepant events that contradict those conceptions. This creates a cognitive conflict in students that hopefully will effect conceptual change as students try to resolve the conflict. Students' alternative conceptions can be elicited through class discussion or by using a test or computer program. Minstrell¹⁵ has developed a computer program called *Diagnoser*, which identifies alternative conceptions in elementary mechanics (and electric circuits) from students' responses to a number of multiple-choice questions. Hewson¹⁶ has developed a similar program for diagnosing and remediating alternative conceptions in velocity. The discrepant event for invoking cognitive conflict may be a demonstration, a phenomenon, or an event that students have to explain or make a prediction about. In a strategy called *ideational confrontation*,¹⁷ students are required to present their separate explanation/prediction to the class. Through discussion and peer interaction students become aware of the inadequacy of their conceptions. The teacher then demonstrates the phenomenon and presents a scientific explanation that students have to compare with their own explanations.

The computer (both hardware and software) can be used to provide learning experiences that promote conceptual change. Thornton's tools for scientific thinking¹⁸ are most well known. The motion sensor, in particular, which enables students to graph and interpret motion in real, time has been found to be effective in teaching motion concepts.¹⁹ Laws²⁰ has developed an introductory college physics course, *Workshop Physics*, that adopts a computer-enhanced workshop format in lieu of conventional lectures.

This course makes extensive use of Thornton's and other microcomputer-based laboratory (MBL) tools. For the present research, it would have been ideal to adopt an approach similar to *Workshop Physics*. Unfortunately the motion sensor and other MBL tools were not readily available to schools in Melbourne. The alternative was to use computer programs. However, there were no suitable local programs on the topic and many programs from the United States were not well known in Australia. Those that I knew about were not suitable for the research. For example, *Graphs and Tracks*²¹ has been shown to be effective in teaching motion concepts²² but it does not deal with force and motion. I therefore decided to develop my own simulation programs for the research and my previous experience facilitated the process.²³

Computer simulations provide "microworlds" for exploration by students. The notion of microworld was first coined by Papert²⁴ as computer representations of domains of knowledge. Papert argues that microworlds are "incubators for powerful ideas" because they provide "a discovery rich learning environment" for children. Bliss and Ogborn²⁵ also contend that microworlds provide "a well-defined yet open-ended environment in which children can experiment with and investigate rules and relationships." In exploring a microworld students interact with the underlying scientific model by freely changing the parameters and variables of the model and visualizing immediately the consequences of their manipulations. In this way, students can

- (1) interpret and reflect on the model and compare it with their own conceptions;
- (2) investigate how the variables in the model are interrelated;
- (3) formulate hypotheses about the model and test them in the microworld.

It is believed that such explorations help with facilitating students' understanding and promoting conceptual change.

It should be noted that, while computer simulations are useful instructional tools, they are not a substitute for real experiences with physical phenomena. When used in

instruction, they need to be accompanied by complementary/supplementary activities such as lab work, demonstrations, class discussion, etc. FMM was designed to match the contents of the physics unit of the grade 10 science class in which the research was carried out. It was integrated into the teaching of the physics unit with suitable activities organized prior to and after its use. The development of FMM was informed by the literature reviewed above.

This article focuses on the design and development of FMM; the research which made use of FMM will be reported in detail elsewhere,²⁶ but a brief overview is given in Sec. IV.

I. DESIGN FEATURES OF THE SOFTWARE

FMM consists of four simulation programs. The first program, Motion Graphs, is designed to facilitate students' understanding of velocity-time graphs as representations of motion. The other three programs, Spaceship, Model Car, and Skydiver, provide different contexts in which the effects of force on motion can be explored. They are loosely based on a program in an earlier project.²⁷ In that program, the effects of force on motion are considered in a frictionless, context-free situation. The FMM programs expand this into three contexts.

FMM was written in C++ to take advantage of the language's powerful features. It is a programming language with which my collaborator and I are familiar. At the time of development (mid-1994), Interactive Physics (IP)²⁸ was first made commercially available in Australia. This is a powerful tool for creating simulated motion experiments. IP could probably be used to develop the FMM programs although this has yet to be thoroughly investigated. For good performance, however, the Windows-based IP requires a 486 PC with math coprocessor. Most Melbourne schools were then equipped with 386 PCs on which IP could not run smoothly. There were additional hurdles to overcome if IP were used: funds were needed to be sought for its site license, consent by the school was needed to install it in its already overloaded network server, etc. It was therefore decided to develop FMM in C++. The DOS-based programs subsequently developed run reasonably smoothly on 386 PCs and the entire FMM only takes up 481 kilobytes of disk space.

The FMM programs were designed with the following technical and pedagogical features.

(1) The programs are designed for use on IBM PCs or compatibles (386 or 486) with SVGA monitor and mouse. They use a resolution of 600×800 with 256 colors so as to provide good quality graphics that appeal to students. They are DOS-based but make use of a "pseudo" window environment with mouse and point-and-click pull-down menus. Students can freely explore the programs and try their ideas by changing the different variables in the menu bar.

(2) The programs are all simulations that use an interface that gives students a feeling of directly operating in the simulated microworld. For example, in the Spaceship, Model Car, and Skydiver programs, forces are applied by pressing the buttons in a control panel as if students are operating a remote-control device. The programs are run by operating the mouse and no keyboard input is required.

This, and other features, are intended to enable students to use the programs with minimum help or explanation.

(3) The programs are intended to be used by students working in pairs or small groups rather than alone. Such a collaborative mode of learning offers several benefits.²⁹ In a joint activity, students have to articulate their ideas, predictions, and interpretations, and this helps them to gain greater conceptual clarity. Students can coconstruct knowledge by building on each other's ideas and arrive at a shared understanding. Collaboration enables students to carry out tasks that they cannot do by themselves alone. Conflicts sometimes arise between students holding different views. The demand for justification and accountability forces students to reflect as they try to resolve the conflict. Collaboration is conducive to students' conceptual change.

(4) Each program is accompanied by a set of worksheets. The worksheets contain predict-observe-explain (POE) tasks³⁰ that were designed to challenge students' alternative conceptions. When working on the POE tasks, students are required to negotiate with each other for a joint prediction of a certain situation; give reasons for their prediction; run the program to test their prediction; and reconcile any discrepancy between their prediction and the observation in the microworld.

(5) FMM provides three contexts (Spaceship, Model Car, and Skydiver) for students to explore the effects of force on motion. This allows them to "revisit" the various conceptions in different situations for reflection and consolidation. It is believed that revisiting is necessary since these alternative conceptions are so resistant to change.

During development, the FMM programs were tried out by four volunteer grade 10 students. Upon completion, they were tested in a grade 11 physics class in the same school where the research took place. From the feedback, some minor changes were made to the programs and the accompanying worksheets.

II. THE FMM PROGRAMS

A. Motion Graphs

This program facilitates students' understanding of velocity-time graphs as representations of motion. It is not intended to give a full treatment of kinematics and position and acceleration-time graphs are not included. Rather, it is merely intended to show that in a velocity-time graph a horizontal line represents a constant speed; a straight line (or curve) "going up" or "going down" represents a change in speed; and the steeper the straight line the greater is the rate of change of speed. In the next three programs, students have to interpret motion from the on-screen motion of the object and a velocity-time graph plotted in real time and relate the force applied to the *change in speed*. In the physics unit of the grade 10 science course students are not required to study how the position, velocity, and acceleration graphs are related to one another (this is included later in the grade 11 physics course).

This program does not deal with the effects of force on motion; it is included to facilitate use of the other FMM programs. If Graphs and Tracks were available and used prior to FMM, this program could be dispensed with.

On booting up, the program shows a truck on a level road (Fig. 1). The truck can be made to move by selecting

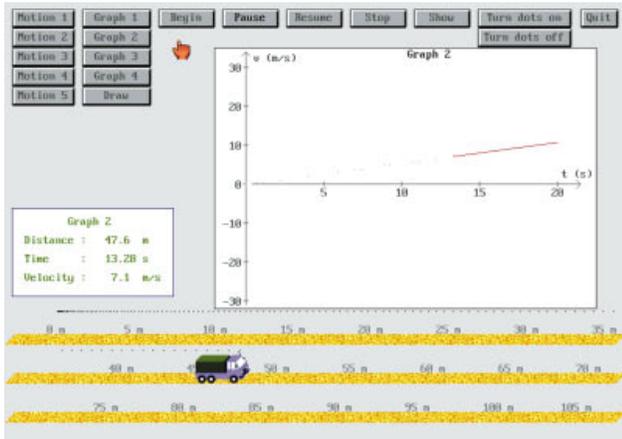


Figure 1. The Motion Graphs program. The truck can be set to move according to some preset motions or velocity-time graphs, or graphs drawn by the user.

one of the preset velocity-time graphs or motions. When a graph is selected, it is displayed and students are asked to describe the motion that it represents, then start the truck moving. As the truck moves, it leaves a trace of ticker-timer dots behind it. At the same time, a “meters window” shows the real-time values of the velocity, distance, and time, which change as the truck moves. By observation, students can determine the motion of the truck and compare it with their description. There are four preset graphs: (i) constant speed, (ii) uniform acceleration, (iii) constant speed followed by uniform deceleration to rest, and (iv) constant speed, stop, and then same constant speed in reverse.

When a motion is selected, the truck moves on the road in certain ways. Students are asked to describe the motion in words and sketch a velocity-time graph of the motion. Students then compare their graphs with those plotted in the program. There are five preset motions: (i) constant speed, (ii) uniform acceleration, (iii) higher uniform acceleration, (iv) uniform acceleration, constant speed, and then uniform deceleration to rest, and (v) constant speed, uniform deceleration to rest, uniform acceleration in reverse, and then same constant speed.

Students can also draw their own graphs on a graph pad (Fig. 2). Both line segments and curves can be drawn. After finishing the graph, the truck is set to move accordingly. This is an interesting feature since students can experiment with different kinds of graphs and try their ideas freely.

B. Spaceship

This program is concerned with linear motion with no resistance and gravity. On booting up, it shows a spaceship traveling in space at a constant speed (Fig. 3). The spaceship is powered by a pair of stern rockets for forward motion and a pair of retrorockets for backward motion. The screen display shows a control panel, a meters window, and a force diagram. On the control panel are buttons for increasing or decreasing the rocket thrust (buttons with upward and downward arrows), firing the stern and retrorock-



Figure 2. The “graph pad” in Motion Graphs: Any velocity-time graph (consisting of line segments or curves) can be drawn and the truck will move according to the graph.

ets (buttons with forward and backward arrows), and pausing and stopping the motion (buttons with symbols for pause and stop similar to those on a VCR). Thus forces of different magnitudes, in a forward or backward direction, can be applied to the spaceship at any time and for any duration, and the effect is shown by the on-screen motion of the spaceship and the plotting of a real-time velocity-time graph. When the rockets are fired, they give off a yellowish flame and emit a rocket sound. As the spaceship moves, the meters window displays the real-time values of the force, time, distance, and velocity. The force diagram shows an arrowed bar giving the magnitude and direction



Figure 3. The Spaceship program: By clicking the buttons in the remote control panel forces of different magnitudes, in the forward or backward direction, can be applied to the spaceship at any time and for any duration, and the effect is shown by the on-screen motion of the spaceship and the plotting of a real-time velocity-time graph.

of the rocket thrust. The menu bar allows the mass and initial velocity of the spaceship to be changed.

The program is designed to show that

- (1) with no force applied the spaceship moves at a constant speed;
- (2) when a constant forward force is applied, the spaceship moves with uniform acceleration;
- (3) when a backward force is applied, the spaceship slows down to rest, then reverses (it does not reverse as soon as the backward force is applied);
- (4) when the forward or backward is turned off, the spaceship continues to move with the constant speed reached.

In this and the next program, the rockets/jet engine form part of the spaceship/model car. It was recognized that this might be a source of confusion to students—that these components were not perceived as providing an external force to the vehicle. Some measures were taken to resolve this, although the measures taken may not be entirely satisfactory. Prior to running the FMM programs, students did some trolley experiments using ticker-tape timers and they applied different pushing forces to the trolley to study the effects of force. They also considered the case of a wooden block being given an impulsive push by the hand to move it on the bench top and that of a car being driven by its engine. In the former case, they learned that once the wooden block was out of contact with the hand it was no longer acted on by a force and it slowed down due to an opposing frictional force. In the latter case, they learned that chemical energy in the fuel was converted into motion energy and this provided the force to move the car. When students used Spaceship and Model Car, they were told that when they clicked the mouse on the force button they started the energy conversion process and this provided the force on the vehicle.

C. Model Car

This program is concerned with horizontal motion with friction. On booting up, it shows a jet-powered model car on a horizontal track (Fig. 4). Similar to the Spaceship, the screen display shows a control panel, a meters window, and a force diagram. By operating the buttons in the control panel, the jet engine can be turned on to apply a forward or backward force of different magnitudes at any time and for any duration. When the jet is turned on, it emits a yellowish flame and an engine sound. The effects of force on the model car is shown by the on-screen motion and the plotting of a real-time velocity-time graph. The meters window shows the real value of the force, friction, time, distance, and velocity of the motion. The force diagram shows two arrowed bars representing the applied force and the friction. Several changes can be made; they can be the mass and initial velocity of the model car, the force applied, and the friction of the track (high, medium, low, and zero).

When a small force is applied, the model car is opposed by friction of equal magnitude (shown in the force diagram and meters window) and so remains stationary. As the applied force is increased in small increments, friction also increases and the model car remains stationary. When the force is greater than the limiting friction, the model car

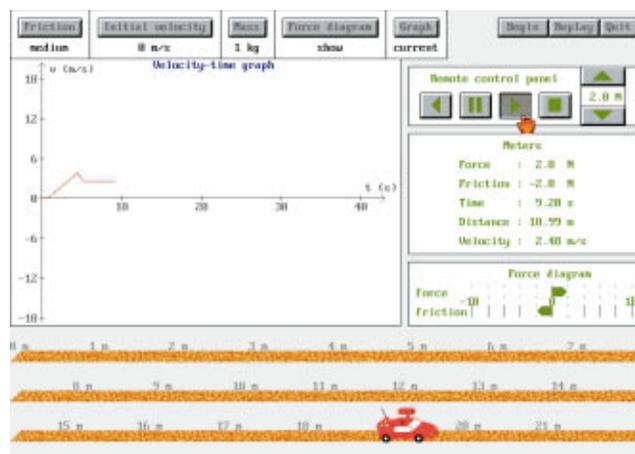


Figure 4. The Model Car program: By clicking the buttons in the remote control panel forces of different magnitudes, in the forward or backward direction, can be applied to the car at any time and for any duration, and the effect is shown by the on-screen motion of the car and the plotting of a real-time velocity-time graph; the friction of the track can be set to high, medium, low, or zero.

is acted on by a net force and moves with a uniform acceleration.

The program is designed to show that

- (1) friction acts in the opposite direction to motion or intended motion;
- (2) the model car remains at rest when the force is balanced by friction, that is, the net force is zero;
- (3) the model car moves with a uniform acceleration when the force is greater than friction, that is, there is a net force;
- (4) when the force is turned off, the model car slows down since the frictional force is in the opposite direction to its motion; the greater the friction the faster the model car slows down;
- (5) when a backward force is applied, the model car slows down to rest, then reverses (it does not reverse as soon as the backward force is applied);
- (6) when the force is balanced by friction while the model car is moving, that is, net force is zero, the model car moves at a constant speed.

D. Skydiver

This program is concerned with vertical downward motion with gravity and speed-dependent air resistance. On booting up, it shows a hovering helicopter (Fig. 5). When a button is clicked, the skydiver jumps out of the helicopter and falls vertically to the ground. The skydiver's parachute can be opened at any time during the fall. The fall is shown by the on-screen motion of the skydiver and the plotting of a real-time velocity-time graph. The mass of the skydiver and the height from which he/she jumps can be changed. During the fall, the motion can be paused. As "magical cases," the air resistance and gravity can be "turned off" before the skydiver jumps or at any time during the fall. This allows for interesting explorations.

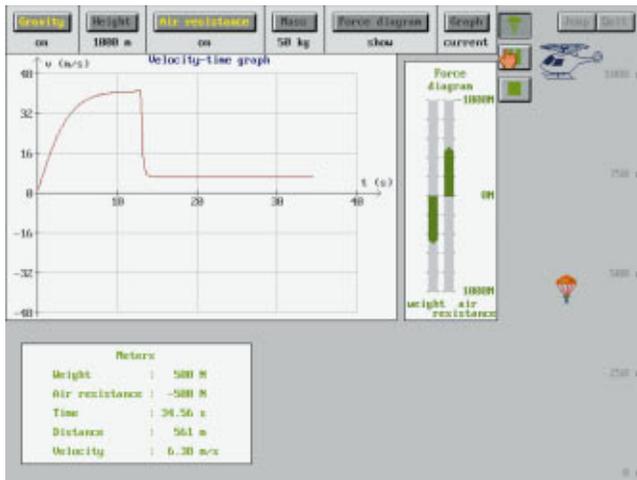


Figure 5. The Skydiver program: On clicking the <jump> button, the skydiver falls from the helicopter and the fall is shown by the on-screen motion and the plotting of a real-time velocity-time graph; the parachute can be opened at any time during the fall.

The forces on the skydiver, weight, and air resistance are shown as two vertical arrowed bars in opposite directions in the force diagram. Initially, the skydiver falls with an acceleration. As he/she gains speed, the air resistance increases. When the air resistance increases to equal to the weight of the skydiver, he/she falls with a constant (terminal) speed. When the parachute is opened, the air resistance is greatly increased and the skydiver falls with a much lower terminal speed.

The program is designed to show that

- (1) when the skydiver's weight is greater than air resistance, that is, there is a net force, he/she falls with a nonzero acceleration;
- (2) when the skydiver's weight is balanced by air resistance, that is, net force is zero, he/she falls with a constant speed;
- (3) the greater the mass of the skydiver the larger is the terminal speed, since the speed has to increase to a larger value so that a greater air resistance balances the greater weight;
- (4) under zero air resistance, the skydiver falls with a uniform acceleration;
- (5) under zero air resistance, skydivers of different masses

fall with the same uniform acceleration.

III. CONFRONTING STUDENTS' ALTERNATIVE CONCEPTIONS

The POE tasks in the worksheets are designed to match and confront students' alternative conceptions in force and motion. The tasks for Spaceship, Model Car, and Skydiver are briefly described below; those for Motion graphs are not described since they simply entail the running of the preset velocity-time graphs and motions and are not concerned with the effects of force.

A. Spaceship

There are 15 tasks in the worksheet. The first set of tasks requires students to predict the motion of the spaceship when (i) all the rockets are shut down; (ii) the stem rockets are fired for a short time, then continuously; (iii) the rocket thrust is changed; (iv) the mass of the spaceship is changed while the same forward rocket thrust is applied; (v) the retrorockets are fired for a short time, then continuously; (vi) the mass of the spaceship is changed while the same backward rocket thrust is applied; and (vii) the initial velocity of the spaceship is changed while the same backward rocket thrust is applied. The next set of tasks requires students to apply force(s) to the spaceship such that it moves according to some given velocity-time graphs. Finally, students are asked to draw their own graphs, then apply force(s) to move the spaceship according to the graphs.

As an illustration, one of the tasks is given below. All tasks consist of one instruction and a set of questions to guide students in making the prediction.

Task 1. "Do not fire any of the rockets. Predict what would happen to the spaceship." All rockets are shut down. Is there a net force on the spaceship? Would the spaceship slow down after some time? Predict what the velocity-time graph of the spaceship would look like. Sketch this graph.

This task is intended to confront the force-of-motion and motion-implies-force conceptions. Students holding these conceptions are likely to predict that the spaceship would slow down.

B. Model Car

There are 20 tasks in the worksheet. The first set of tasks requires students to predict the motion of the model car when (i) a small forward force is applied that is increased in small increments until the car starts to move; (ii) the force is applied for a short time, then continuously; (iii) there is a pause in the motion and the force is reduced to equal to the friction; (iv) the friction of the track is changed from medium to low and then to high; and (v) a backward force is applied. In the next set of tasks, students are required to set friction to zero and carry out tasks similar to those in Spaceship for consolidation. The third set of tasks requires students to reset friction to medium and initial velocity to zero and apply force(s) to move the model car (a) forwards and then backwards; (b) forwards with a constant speed; and (c) backwards with a constant speed. Finally, students are asked to apply any force they like to the car and predict the motion of the car.

As an illustration, one of the tasks is given below.

Task 5. "Apply a force to accelerate the car, then pause the motion in the middle of the run. Reduce the force to equal 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 velocity-time graph.

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

Table II. Examples of how the FMM programs match and confront students' alternative conceptions in force and motion. (SS—Spaceship; MC—Model car; SD—Skydiver.)

Alternative conceptions	Examples of how the programs confront the alternative conceptions
(1) A moving body has a force of motion in it.	SS and MC require students to press the mouse button to apply a force. The pressing of the button starts the process of converting chemical energy in the engine fuel to motion energy and this provides the force. As such, the force is "external" to the vehicle, not a force of motion contained in it.
(2) A body slows down and stops as its force is gradually used up.	SS and MC slow down when an opposing force (friction, backward force) act on them.
(3) If a body is not moving, there is no force acting on it.	SS continues at a constant speed when all its rockets are shut down; MC remains at rest if no force acts on it; MC and SD move at a constant speed when the forces acting on them are balanced, that is, net force is zero.
(4) If a body is moving, there is a force acting on it in the direction of motion.	When SS, MC, and SD accelerate, a net force acts in the direction of motion. When opposed by a force, SS and MC continue to move but slow down, stop, then reverse.
(5) A constant force acting on a body produces a constant speed; an increasing force produces an acceleration.	SS and MC accelerate if a constant net force acts on them; the SD's acceleration changes as the net force changes.

C. Skydiver

There are 10 tasks in the worksheet. The first set of tasks requires students to predict the motion when (i) the skydiver falls all the way without opening the parachute; (ii) the skydiver's mass is changed; (iii) the skydiver falls from different heights; (iv) the skydiver opens the parachute in the middle of the fall; and (v) the skydiver opens the parachute at different heights from the ground. The next set of tasks considers magical cases of zero air resistance and requires students to predict the motion when (i) the skydiver falls to the ground, (ii) the skydiver's mass is changed, and (iii) the skydiver falls from different heights. Finally, students are asked to think of some POE tasks themselves, then carry them out. Suggestions are made that they can change the air resistance and/or gravity to zero prior to and during the fall.

As an illustration, one of the tasks is given below.

Task 1. "Let the skydiver fall all the way without opening the parachute." Would the skydiver fall faster and faster all the way? What would be the force(s) acting on the skydiver? Would there be a net force on the skydiver? Predict what the velocity-time graph would look like. Sketch this graph.

This task is intended to show that initially, when the skydiver's weight is greater than the air resistance, he/she falls with an acceleration, and later, when the weight is balanced by the air resistance, he/she falls with a constant speed. Students are likely to predict that the skydiver would fall with a uniform acceleration. This task is later contrasted with one in which the air resistance is set to zero.

The above gives one example each of the programs of how students' alternative conceptions in force and motion are matched and confronted. Table II gives more examples for each of the conceptions across the programs.

IV. THE RESEARCH

The research was carried out in a naturalistic setting using an intact class. It adopted an interpretive (qualitative) research method. The FMM programs were incorporated into the ten-week physics unit of a grade 10 science class in a Melbourne high school. To assess *individual* students' conceptual change subsequent to the instruction a test was administered, in identical form, to the class before and after the instruction. The test was also administered five months later to those students who went on to do physics in grade 11; these students did not receive any instruction on force and motion between the post-test and delayed post-test. The test was primarily used for identifying students who achieved substantial conceptual change and students who achieved minimal change. The conceptual developments of these students during instruction were then compared. The test was not intended as an evaluation of the FMM programs.

The test was compiled to cover the alternative conceptions listed in Table I with most of the questions drawn from validated questions in several previous studies.³¹ In these studies, the questions were prepared for junior high or younger students. Three questions were specifically generated for the research to relate to the Spaceship program. These were also validated by a panel consisting of three physics teachers and a teacher educator. The questions in the test were not dissimilar in substance to some of those in the Force Concept Inventory.⁷ Questions in the Inventory were not used because they cater to high school physics students and college students and might not be entirely suitable to the grade 10 students in the research. Each question in the test required students to select an answer from a list of options (distracters chosen from alternative conceptions) and to explain why they made such a choice.

Students spent five lessons on the FMM programs in the middle of the physics unit. Prior to this, they were taught three lessons on speed and acceleration and they carried out trolley experiments using ticker timers. After the computer activities, they were taught about “force, inertia, and acceleration” in one lesson in a conventional, didactic way without much reference to the programs. They spent two more lessons on problem solving of force and acceleration.

While students worked in pairs on the programs, their within-group conversational interactions were audio/video taped. Transcripts of these tapes formed the primary data source of the research. A range of secondary data was also collected: responses in the worksheets and summary sheets for each computer-based lesson; open-ended responses in the pre, post-, and delayed post-tests; responses in the end-of-unit test; transcripts of interviews with some students conducted shortly after the three tests; and fieldnotes on all the lessons during the instruction. Of the 27 students in the class, 14 (7 pairs) were identified for in-depth case studies. These students took the pretest, plus the post-test and/or the delayed post-test, so their conceptual change could be assessed. All the data collected on these students were analyzed *qualitatively* to gain insight into the process of their conceptual change, the way they collaborated, and how this might facilitate conceptual change. Each student’s conceptual development during instruction was written up as a case study.

After the computer activities, students completed a questionnaire on the FMM programs. The questionnaire consisted of Likert-type items (five-point scale with 1 for strongly agree and 5 for strongly disagree) and a few open-ended questions. The results showed that students found the programs interesting (mean score 2.00) and easy to use (1.58) and the graphics well designed (1.75); they agreed that the programs facilitated their understanding of force and motion (1.46), helped them correct their prior ideas (2.00), and allowed them to freely try their ideas (1.63); they also preferred not to work on the programs by themselves (4.13). During the computer activities, there were frequent outbursts of excitement and spontaneous utterances commenting favorably on the programs. It is evident that the programs were well received and that the students very much enjoyed using them.

To take account of the variance of students’ answer scores at the pretest, conceptual change was measured in terms of the gain in score in the post-test and/or delayed post-test. The 14 students selected for in-depth case studies differed widely in their conceptual change. Five students showed substantial change (more than 20% gain) at the post-test, of whom two showed further improvement, one sustained his change, and one showed deterioration in the delayed post-test (one student was absent). One student showed some change at the delayed post-test (10% gain) (he was absent from the post-test). The other eight students showed no change in the post-test and/or the delayed post-test. The conceptual development of the students with substantial conceptual change was compared with those with no change.

The findings of the research are presented as assertions. One set of assertions is concerned with the process of

conceptual change and another with collaborative learning. These are described below.

The students who showed substantial conceptual change went through a series of conceptual progression and regression in the course of the instruction, that is, they shifted back and forth between alternative and scientific conceptions from one context to another. They achieved stable conceptual change only if they were able and willing to reflect on the different contexts and to see the commonalities across them. Two of the students accomplished this on their own; three did so after being asked to consider the different contexts together at an interview. These students actively engaged in the POE tasks. They initiated most of the predictions and articulated their explanations, and reflected when confronted with cognitive conflicts. At the interview after the delayed post-test, five months after the instruction, these students could remember the programs very well; they claimed that they were interested in physics and found the programs interesting, useful, and enjoyable. On the other hand, the students with no conceptual change showed little cognitive commitment to the tasks. Although they completed the tasks with their partner, they seldom made public their ideas and initiated very few predictions, agreeing mostly to their partners’ suggestions; some even went off task from time to time.

The collaborative mode of learning provided students with experiences of peer conflicts as well as coconstructions of shared knowledge. Peer conflicts appeared to be effective in facilitating conceptual change since they brought students’ alternative conceptions into sharp focus for criticism and justification. The students who showed conceptual change in the post-test and sustained their change or showed further improvement in the delayed post-test experienced a large number of peer conflicts.

Collaborative learning in the cases described above provided peer support and helped students complete the tasks and develop shared knowledge and understanding. Coconstruction of knowledge was important, but to achieve conceptual change, the students needed to undergo personal construction and sense making of the new understanding. This was a private process that only the individual student could decide whether or not to commit to. In four of the seven groups, one member showed conceptual change whereas the other member showed no change in the post-test and/or delayed post-test. Students in these groups developed shared understanding during the computer activities, but those who failed to achieve conceptual change appeared to not have reflected nor personally constructed a meaning of the new understanding.

V. CONCLUDING REMARKS

The research described above was an in-depth study using a small sample of students. As in all qualitative studies, the aim was not to produce generalizations but to generate rich information about the process and to formulate hypotheses for further tests on a larger scale. The present research shows that the FMM programs, when used in a collaborative learning mode by students, may be of use in facilitating conceptual change, particularly if students are cognitively engaged in the tasks. Further research is now being carried out in several high schools in Hong Kong involving about

500 students. The research adopts a “treatment-control groups” approach comparing classes that use FMM with those that are taught in the conventional way. In the “treatment” classes, particular attention is given to promote students’ cognitive task engagement and to induce them to reflect on their conceptions. The results will prove or disprove the claim that FMM is an effective instructional tool.

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