APPLYING AN iMVT PEDAGOGY TO ADDRESS STUDENT LEARNING DIFFICULTIES IN FORCES AND MOTION

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Abstract

This study is part of a project in exploring how to design, sustain, and scale up an iMVT (Modeling and Visualization Technology integrated inquiry-based Learning) pedagogy in science in Singapore schools. The paper describes the co-design process of a student workbook and research through collaboration between a school teacher and researchers on the topic of *Forces and Motion* and findings during and after the enactment of the curriculum. The study involved eighty-two secondary one students from two experimental and two control classes of an above average school. The iMVT integrated curriculum with the topic of *Forces and Motion* took one month to finish in the experimental classes (Including pre-test, intervention and post-test) in this school. Pre-test and post-test data from experimental and control classes in the school were collected. Other data included post-survey, interviews of students and the teacher about the design and enactment of the curriculum, classroom observation field notes and videos. The statistical results showed that there was improvement in the students' conceptual understanding measured by the post-test for both control and experimental groups; the improvement in the experimental group was statistically significant. Surveys about students' views of the iMVT approach showed that most of students had positive feedback on iMVT implementation in classroom and appreciated its features. Students' artefacts showed that they made their understanding of *Forces and Motion* explicit by making models from low quality to high quality. Teacher interviews showed that the teacher appreciated certain elements of the pedagogy and thought the iMVT was a systematic way to address students learning difficulties. The study contributes to the literature by providing strategies to curriculum material development and students learning in order to promote desired education change in schools.

Keywords: Forces and Motion; Modeling and visualization technology; Inquiry; Secondary school students

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Introduction

Using ICT integrated pedagogies to address student science learning difficulties has received much attention among science education researchers. Intuitive beliefs or pre-instructional conceptions have a special place among the sources of difficulties that students come across in physics (Savinainen, Scott, & Viiri, 2005), which affect student's learning of new concept. Pre-instructional conceptions can refer to preconceptions, alternative conceptions, misconceptions, scientific intuitions, children's science, common sense concepts and spontaneous knowledge based on previous studies (Eryilmaz, 2002). As a most widely discussed topic in mechanics, many evidences have shown that Forces and Motion is a topic in which students have more alternative conceptions compared to other topics. In this study, students' alternative conceptions in Forces and Motion were examined before and after they studied an iMVT (**M**odeling and **V**isualization **T**echnology integrated **i**nquiry-based Learning) curriculum. As an innovative pedagogy in science education, iMVT approach has shown some effectiveness in addressing student learning difficulties in science. It has been about six years for researchers to explore the developments and refinement of this iMVT pedagogy (B. H. Zhang, et al., 2010). iMVT pedagogy has not only improved students' conceptual understanding but also process and reasoning skills, as well as understanding of models and modeling (B. H. Zhang, et al., 2008). However, it takes time for us to develop a process model about how to integrate iMVT in curriculum development and show its efficacy. This study intends to fill in the gap in the literature by describing the process and effectiveness of how to integrate and enact ICT in inquiry-based learning. The following research questions guided the study:

1. How to integrate iMVT in a physic *Forces and Motion* unit through a co-design process?
2. How are student alternative conceptions addressed in the *Forces and Motion* unit?
3. What is the learning effectiveness of the enacted unit?

Theoretical Underpinning

The iMVT Pedagogy

iMVT pedagogy has been formed, enacted, and refined in secondary schools in Singapore for about six years (B. H. Zhang, et al., 2010). Models and modeling, visualizations, and science inquiry are the main components of iMVT pedagogy. In science, models are representations of abstract or complex science phenomenon, process, concepts, and theories (Cartier, Rudolph, & Stewart, 1999; Gilbert 1995; Hestenes, 1987; Ingham & Gilbert, 1991). Models maintain the key features or attributes of the real thing. Thus, the unique properties of objects together with their interactive relations in science phenomenon can be revealed through scientific models. *Modeling* approach allows students to present and construct understanding of science phenomenon as complex systems by elaborating on variables, relationships, and the interaction among the components of the systems. Building models not only has the potential to help students improve their understanding about natural phenomena or complex systems, but also facilitate their understanding of the nature of science as an enterprise that is largely concerned with extending and refining models (Gilbert, Boulter, & Rutherford, 1998). *Visualization* is to simulate abstract and invisible interactions through visible manipulation. This usually involves the use of *Technology*. iMVT approach in science involves computer-supported technology to facilitate student's model-based learning. Students are also provided with visual aids (such as simulations, animations, videos, virtual labs, and the like) to understand science phenomenon through various representations. Different representations with different merits are more flexible for scaffolding students' learning. Further, iMVT scaffolds students' science inquiry through several inquiry processes, such as contextualization, thinking aloud, inquiry question and hypothesis, investigation, discussion and collaboration, modeling, simulation, visualisation, reflection, and application. Such features of inquiry learning can be seen in the designed iMVT curriculum materials which will be discussed later.

Co-design Approach

In recent years, a collaborative approach to develop innovations has been explored by researchers in the learning sciences. Penuel and his colleagues (2007) defined the co-design process as a highly-facilitated, team-based process in which teachers, researchers, and developers work together in defined roles to design an educational innovation, realize the design in one or more prototypes, and evaluate each prototype's significance for addressing a concrete educational need. They described seven characteristics of co-design: 1) co-design takes on a concrete, tangible innovation challenge; 2) begins by taking stock of current practice and classroom contexts; 3) has a flexible curricular target; 4) needs a bootstrapping event or process to catalyze the team's work; 5) is timed to fit the school cycle; 6) strong facilitation with well-defined roles is a hallmark of co-design; 7) there is central accountability for the quality of the products. These seven characteristics fit our study well. The most common form of collaboration in educational research is to involve researchers and teachers or even students (Gunckel & Moore, 2005), and sometimes software developers (Penuel, et al., 2007). There are many reasons to involve teachers as co-designers in the curriculum development process (Barnett, 1991; Clayton, 2007), rather than confining teachers' role to that of transmitters of curricula developed by others (Clayton, 2007; Connelly & Ben-Peretz, 1997). In addition to being a means to develop curriculum materials and assessment tools (Edelson, 2002; Maldonado & Pea, 2010; Penuel, et al., 2007), the co-design process is also perceived as a way to build community and common language among different communities of practice such as researchers and teachers. The co-design approach seems to be more popular in Western countries than in the Asian countries, where those lower in the hierarchy are more submissive towards prescribed policy and leaders' decisions (Batliwala, 2003), and where it is less common for subordinates to be included in planning. In Asian contexts, little research has been done on the mechanism behind collaboration among different parties. The research team has explored the process of co-design in chemistry curriculum development and summarized a tripartite collaboration among researchers, teachers, and curriculum specialist (Ye, Zhang, & Chia, 2010). The case study showed that through co-designing the curriculum materials, the three parties demonstrated their expertise and learnt from each other, and the effectiveness of the tripartite model was proved by the capacity development of the teacher and his acknowledgement of co-design's role in the sustaining efforts of the innovation, as well as the students' significant improvement on content understanding and their attitude towards the pedagogy.

Alternative Conceptions in Forces and Motion

Alternative conceptions refer to those intuitive beliefs, pre-instructional conceptions or prior ideas of phenomena that are often inconsistent with or contradict those of accepted science (Osborne, Freyberg, & Education, 1996). Although students' conceptions are not consistent with scientifically accepted ones, they are deeply settled down in students' cognitive structure since they are reasonable for them. These non-scientific conceptions negatively affect students' further learning and hinder students from the new constructions which are consistent with scientifically accepted ideas (ÜNAL, Coştu, & AYAS, 2010). The field of alternative conceptions study has been a dominant area of research in science education for more than two decades (Tao & Gunstone, 1999). Based on the literature review, we aggregated alternative conceptions in *Forces and Motion* (Eryilmaz, 2002; Galili & Bar, 1992; Ozdemir & Clark, 2009; Tao & Gunstone, 1999). The concepts are required as the instructional objectives in the unit plan of the pilot school. We list the common alternative conceptions that correspond to the instructional objectives and test questions. See Table 1 (The test paper is shown in Appendix 1).

Table 1. Construct map of "*Forces and Motion*" test

Question	Instructional Objectives	Alternative concepts
MCQ-1	• Identify some examples of forces in our daily life, including gravitational force	(1c) Heavier objects fall faster
MCQ-2	• Demonstrate understanding of Newton's 1st law.	(2a) Velocity proportional to applied force (2b,d) Motion when force overcomes resistance (2e) Resistance opposes force/impetus
MCQ-3	• Identify some examples of forces in our daily life, including frictional and gravitational forces • Describe the effects of a force. • Friction opposes motion. • Forces can change speed and direction of an object. • Demonstrate understanding of Newton's 1st law.	(3a) Motion implies active force (3a,e) Mass makes things stop (3b) Impetus supplied by "hit" (3d) Gradual/delayed impetus build-up (3e) Impetus dissipation
MCQ-4	• Identify some examples of forces in our daily life, including gravitational force. • Demonstrate understanding of Newton's 1st law.	(4b,c,d) Impetus dissipation (4d) Gravity increases as objects fall (4d) Gravity acts after impetus wears down (4e) Gravity intrinsic to mass
MCQ-5	• Identify some examples of forces in our daily life, including gravitational force. • Describe the effects of a force (gravitational force). • Forces can change speed and direction of an object.	(5b) Gravity intrinsic to mass (5c) Force causes acceleration to terminal velocity (5d) Air pressure-assisted gravity (5e) Gravity increases as objects fall (5e) Acceleration implies increasing force
OEQ-1	• Identify some examples of forces in our daily life, including gravitational force. • Forces can change speed and direction of an object.	• Bigger acceleration will be caused by a heavier weight
OEQ-2	• Demonstrate understanding of Newton's 1st law.	• Motion implies active force (all objects immediately stop moving when the force is removed)
OEQ-3	• Demonstrate understanding of Newton's 1st law. • Identify some examples of forces in our daily life, including gravitational force. • Describe the effects of a force. • Forces can change speed and direction of an object.	• If an object has a motion, it must have force acting upon this object

Methodology

Procedures

There are two stages in our research: 1) Co-design of workbook on *Forces and Motion*. The duration of workbook development was about two months. We adopted similar structure and features of student workbook in chemistry (Ye, et al., submitted) to be aligned with the iMVT pedagogy. The participants of this co-design were mainly a physics teacher and researchers. 2) Implementation of iMVT approach. In this study, identical pre- and post-tests were conducted immediately before and after the teaching intervention. Below are the procedures: Firstly, diagnosing students' alternative conceptions by pre-test before teaching intervention. The administration of the pre-test took 20 minutes in four classes. Secondly, in order to understand the normal teaching and learning process, one researcher observed one of the two control classes for six hours (six sessions) before the enactment of the co-designed unit and discussed the instructional process after the session when necessary. Students finished the post-test after learning the topic. Thirdly, three months after teaching the control class, the same teacher taught the two experimental classes for four hours (four sessions) using the co-designed iMVT workbook. The topic taught for the experimental and control classes were the same, i.e. "*Forces and Motion*". Fourthly, at the end of the teaching intervention, students did the same post-test as the control class. Meanwhile, a questionnaire about students' feedback on the iMVT approach and iMVT curriculum features was administered in the two experimental classes. Besides these instruments, teacher's post survey and interview were also conducted to collect the teacher's feedback of iMVT approach.

The Co-design Process of Workbook on Forces and Motion

The co-design process and approach

The co-design process was presented in Table 2. In order to make the pedagogy more sustainable in schools, the researchers decided to observe the lessons before embarking on the design work so as to better integrate the iMVT pedagogy into the teacher's current teaching. To initiate the curriculum design process, the researchers shared with the teacher a general template for the iMVT integrated curriculum material (with the student workbook as the main product) to frame up the main curriculum features which constitute contextualization, asking questions/making hypotheses, investigation, modeling, visualization, simulation, reflection, application, and the like. This was followed by working sessions where the teacher and the researchers exchanged ideas from their different perspectives. The depth of the content was determined by the school's special syllabus and discussed by two parties over several rounds of communication. Afterwards, the researchers completed the first draft of the workbook and engaged the teacher in several cycles of discussion and revision. After intensive working sessions and revisions of workbooks, the teacher conducted the lessons while the researchers observed, provided on-site support and gave quick feedback after the lessons. Multiple communication modes: emails, SMS messages, phone calls, and face-to-face working sessions were utilized during the collaboration. Emails were used to exchange ideas on curriculum feedback, acquire students' information and updates on project progress, while SMS messages and phone calls were used more for the logistic matters, such as arrangement of observations and reminders of meetings. Face to face working sessions usually focused on the discussion of content structure, scope and cognitive domain of subject matter knowledge.

Table 2. Major tasks and participants in different phases during co-design process

Time	Major Task	Participants
Early Apr'10	Discussion on the topics and schedules	Teachers* and researchers
Apr'10	Observing the current teaching on the same topic as intervention	Teacher K, researchers, and students
End April	Sharing of general template to get familiar with the curriculum features	Teacher K and researchers
Early May	Searching for suitable simulations to be used in the curriculum	Teacher K and researchers
Jul'10	Continuously co-designing and revision of the workbook	Teacher K and researchers
End Jul' 10 - Early Aug'10	Implementation of the curriculum	Teacher K, researchers, and students

* The initial meetings involved teachers from all subjects (chemistry, biology, and physics).

The features of workbook on Forces and Motion

In this workbook, we decomposed the overall iMVT framework into three levels (Kwan, et al., 2010). Four inquiry activities that featured the student-centred learning from low levels to high levels were developed. The activity unit was defined as the first level of the book structure. In the workbook, Activities 1-3 were assigned for students to do in sequence while activity 4 was optional. In each activity, we integrated inquiry components to scaffold students learning process. The form of inquiry process was the second level of the structure. It consisted of several components: contextualization, thinking aloud, inquiry question, investigation[1], discussion and collaboration, modeling, simulation, visualisation, reflection, application, and assessment. Each component was labelled as an icon with implication. Take Activity 2 for instance, students conducted inquiry activities according to the fixed learning process. Two *Inquiry Questions* were presented before students' do their investigation. They were required to draw initial models of the relationship between forces and motion guided by some questions (*Modeling*). After that, an existing model with instructional content was provided for students to do simulation and make observation, as well as to answer some questions (*Simulation*). They were required to answer a series of questions when and after they manipulated the parameters of the model. Subsequently, several questions were also designed as application and assessment instrument (*Application and Assessment*). Finally, students summarized what they had done and rise above their observation to indicate what they have learned by filling words in the blank line (*Reflection*). In this learning process, different supportive curriculum features such as questions, instructional measures, guidelines, and supplementary readings and resources were also provided. We defined these components as the third level.

Participants

The study was undertaken in one secondary school which featured ICT integration in teaching and learning. Student achievement level in this school is above the average across Singapore. They are also more science and technology oriented in terms of their learning interests. There were a total of 82 students with 41 in two control classes and 41 in two experimental classes randomly provided by the pilot school. The teaching intervention was

[1] In the revised workbook, Investigation is added as another feature of iMVT curriculum materials.

conducted by the physics teacher, K., who had 9.5 years of teaching experience and had been teaching in the school for 1.5 years. This teacher also took part in the co-design of workbook with researchers.

Data Collection and Analysis

In this study, identical pre- and post-tests comprising 5 multiple-choice questions (MCQs) and 3 open-ended questions (OEQs) designed by researchers were conducted in both of control and experimental classes (See Appendix 1). The OEQ were also used to better assess how students performed on modeling skills, because we designed these questions which allowed students to draw their models using paper-pencil. (See OEQ-1, OEQ-2 and OEQ-3 in Appendix 1). The durations for the pre- and post-test were 20 minutes. The test was constructed based on the instructional objectives in the unit plan shared by the physics teacher and common alternative conceptions found based on literature review as Table 1 has showed. The instrument was reviewed and revised by researchers and the teacher. For the experimental class, a questionnaire was also asking the students to rank four statements (on the iMVT approach) and 11 statements (on the iMVT curriculum components) provided as 'strongly agree', 'agree', 'neutral', 'disagree', and 'strongly disagree'. In order to probe the reasons behind their responses to each item, they were given spaces to give comments to their MCQs. In the open response part they were asked to provide suggestions for improvement of the activities and questions or comments on the workbook. The content of teacher's post survey and interview was about teacher's understanding of, comments on, and attitude towards iMVT pedagogy. Teacher's responses would have implications in the sustaining and scaling up of this teaching and learning approach. Videos and audios were collected in the experimental classes and teacher interview. The verbal protocols were transcribed to be used as the evidence for our assertions. We mainly uses quantitative methods to analyze data we collect in this study. The methods will be described in next session.

Results and Discussion

Students' Post- test Performance

The data provides plenty of information about students' conceptual understanding on *Forces and Motion* after being exposed to an iMVT integrated teaching intervention. A one-way analysis of covariance (ANCOVA) was conducted in this study. In this analysis, we defined the conditions which contained common teaching method and iMVT teaching approach as the independent variables, so common teaching method and iMVT approach were the independent variables. Post-test performance of control group and experimental group was defined as dependant variable. The covariant was included in the analysis to control the differences on the independent variable, so pre-test of this two groups was adopted to be as the covariant to consider the effect of pre-test on post-test performance, the pre-test scores were used as a covariate to allow us a more accurate measure of post-test differences between the control and experimental groups. The priori alpha level was set at .01. Table 3 shows basic information of post-test of experimental group and control group. The mean score of post-test is 1.84 with 2.29 of experimental class and 1.39 of control class.

Table 3. Descriptive Statistics

Condition	N	Mean	Std. Deviation
Experimental group	41	2.2927	1.05461
Control group	41	1.3902	1.09266
Total	82	1.8415	1.15971

From the Table 4 output, we attain that the underlying assumption of homogeneity of variance for the one-way ANCOVA has been met – as evidenced by F (1, 80) = 0.079, p=0.779, that is p> a (.01).

Table 4. Levene's Test of Equality of Error Variances

F	df1	df2	Sig.
.079	1	80	.779

The results shown below are as follows (see Table 5). In the current study, this relationship between covariant and dependent variable is not significant, F (1, 80) = 0.193, $p=0.662$ > .01.

Additionally, what this shows us is that there is not a relationship (effect) between the covariate and the dependent variable. The results of the analysis indicate that the null hypothesis should be rejected, F (1, 16.7) = 14.37, p =*.000* < .01. The test assesses the significant differences among the adjusted means for the two groups, which are reported in the Estimated Marginal Means box as 2.293 (experimental group), 1.390 (control group). In summary, there was a statistically significant difference found between the control group and the experimental group.

Table 5. Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16.920	2	8.460	7.263	.001
Intercept	84.370	1	84.370	72.433	.000
Pre-test	.225	1	.225	.193	.662
Condition	**16.746**	**1**	**16.746**	**14.376**	**.000**
Error	92.019	79	1.165		
Total	387.000	82			
Corrected Total	108.939	81			

Students' Alternative Conceptions in Forces and Motion

Below are the results of distracter response analysis of MCQs of the control class and the experimental class. See figure 1a (the control class) and figure 1b (the experimental class). The choice percentages of option A, B, C, D, E and omits are listed from the top to the bottom of bar chart (right options are marked with bold font; others are the students' distracters). Figure 1 reveals student alternative conceptions through the percentages of distracters, as well as the changes of distracters in pre-test and post-test.

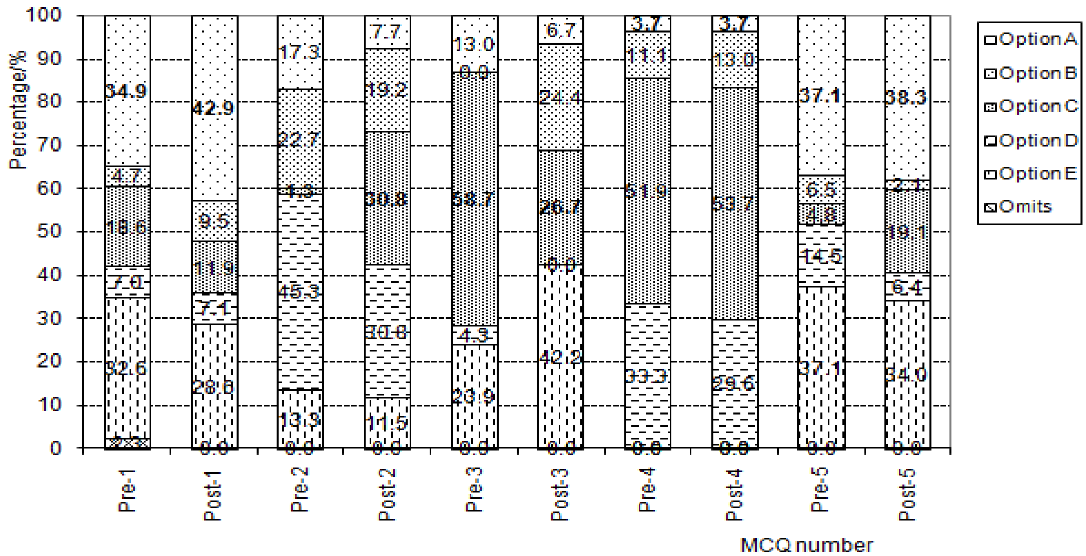


Figure 1a. The distracter response analysis of MCQs for the control class

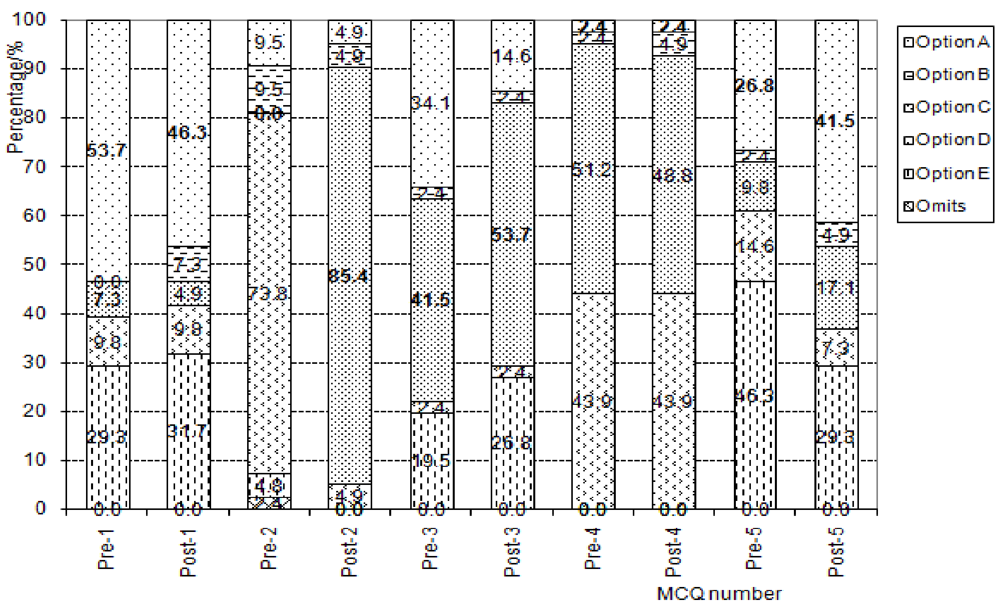


Figure 1b. The distracter response analysis of MCQs for the experimental class

Student answers varied among the five choices of MCQ-1, but the most popular distracter was option (e), see Figure 1a. The percentage of students who chose this distracter was 32.6% (pre-test) and 28.6% (post-test) in control group, 29.3% (pre-test) and 31.7% (post-test) in experimental group. This answer suggested that many of the students held an alternative concept that heavier falls faster. It was evident from the pre- and post- tests that students of the experimental group encountered the same difficulties and held the same alternative conceptions as those of the control group. For MCQ-2, students in both groups initially had a great deal of difficulty in answering the question. As shown in Figure 1a and 1b, more than 40% and 70% students in pre-test chose the option (d) whereas almost none of the students of each group chose the right answer option (c). In the post-test, the experimental groups' performance indicated significant improvement. On the other hand, many students in the control group did not significantly improve. Option (d) remains the strongest distracter and option (b) remains the second strongest one in the pre- and post- tests for the control group. The finding revealed that the experimental instruction was effective in helping students understand the basic concepts of Newton's 1st law. For MCQ-3, the correct answer option(c) was chosen by about 54% of the experimental students in the post-test, an increase of 12% over the pre-test. On the other hand, the performance of the control students dropped from 59% (pre-test) to 27% (post-test). More than 42% of the students chose option (e), see Figure 1a. It indicated that the students held alternative conception of impetus dissipation. As depicted in Figure 1, students of both control and experimental groups had difficulties to answer the question of MCQ-4, even after instruction. Option (c) was the strongest distracter for both groups during the pre- and post- tests. Again, it was evident that the students held misconception of impetus dissipation. Option (e) of MCQ-5 was the strongest distracter for both groups during the pre- and post- tests (see Figure 1). The students might think that acceleration implies increasing force. This alternative concept is aligned with students' answer on OEQ-1.

Students' Concept Changes in Forces and Motion

Below is the line chart which shows changes of correct answer percentages of pre-test and post-test in control class and experimental class respectively. We distinguish the pre- and post-test with dotted line and solid line, the control group and experimental group with square dot and round dot. See figure 2.

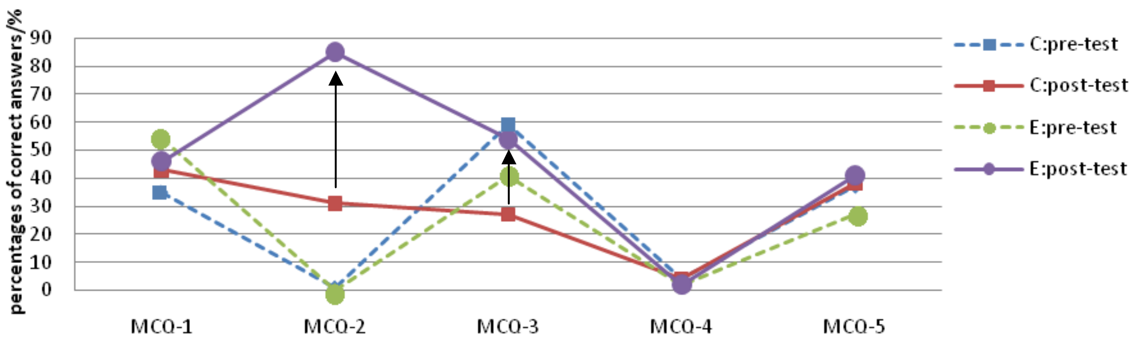


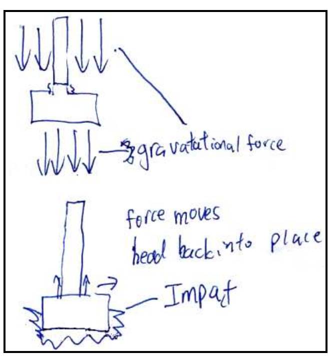
Figure 2. The correct answer percentage of pre-test and post test of two groups

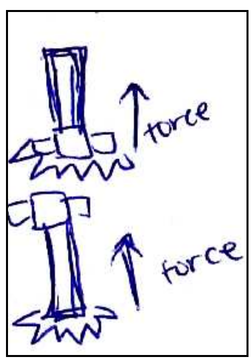
In figure 2, percentage of students who answered the clicker items correctly changed after teaching intervention. Figure 2 presents that the average percentages of right answers in post-test of experimental class is higher than that of the control class, which indicates students' improvements in concepts understanding through iMVT approach. The data from Figure 1b also demonstrated that students' main alternative conceptions in experimental class had decreased much more than students in control class, this was reflected by the percentage of distracters of MCQ-2 (main distracter percentage reduces from 9.5% to 4.9%), MCQ-3 (main distracter percentage reduces from 34.1% to 14.6%), MCQ-4 (main distracter percentage reduces from 51.2% to 48.8%) and MCQ-5 (main distracter percentage reduces from 46.3 to 29.3%). For the control class, although the percentage of alternative conceptions had been decreased in the post-test, the rates were still keeping on the high level (main distracter percentages were 28.8%, 30%, 42.4%, 29.6%, 34% respectively). Specially, there were large gap of correct answer percentage of MCQ-2 and MCQ-3 between experimental class and control class in post-test. It reflected that students got benefits from iMVT approach on the learning of New 1st law and the abstract concept of friction opposes motion.

Besides of five MCQs, there were three OEQs to be another assessment. In the pre-test, only 12% students of the control group and 15% students of the experimental group could answer correctly that the acceleration of the two marbles were the same in OEQ-1. During the post-test, only 17% of each the control and experimental groups, respectively, could answer correctly. Two (out of 41) students of the experimental group could provide the correct explanation in the post-test. During the pre-test, only 27% students of the control group and 5% students of the experimental group could answer correctly that they should tap the hammer with the handle end down in OEQ-2. In the post-test, only 10% students of the control group and 7% students of the experimental one could answer correctly. In the pre-test, there was only one student of the control group could link his answer to Newton's 1st law. OEQ-3 was about the combination between the application of the Newton's 1st law and gravitational force. In the pre-test, only 17% students of the control group and 5% students of the experimental group could answer correctly that it was possible. There were two students from each of the control and experimental groups could give correct explanation. In the post-test, only 20% students of the control group and 24% students of the experimental one could answer correctly. There was only one student from the control group and five students from the experimental one could provide correct explanation during the post-test.

Students' Performance on Models

The above analysis provides information that students end with lower score of OEQ compared to MCQ. While, the experimental group performed better in OEQ answer. In this paper, we use model performance to assess students' understanding of scientific models and the application in problem solving (Adbo & Taber, 2009; Cheng & Brown, 2010; Ergazaki, Komis, & Zogza, 2005). Based on literature review, the models performance in students' OEQs were classified into three levels (Ergazaki, et al., 2005; Grosslight, Unger, Jay, & Smith, 1991; Halloum, 1997; Harrison & Treagust, 2000; B. H Zhang, Wong, Chew, Jacobson, & Looi, 2006): High quality models (HQM) which have accurate description of science concepts or phenomenon that involve objects with basic properties, reflect interaction between objects. They usually use abstract scientific symbols to express models); Medium quality models (MQM) are the models featuring partially exact description that taking into account of some of modelling components, the expression is in the more concrete level; While Low quality models (LQM) refer to that models which have inaccurate description of all modelling components, it usually in the level of scribble drawing). Below are the scanned pictures of models of OEQ-2 in the test, see figure 3a, 3b, and 3c. Three representations are used to be as assessment indicators: symbols, verbal description, and the abstract level of models. As we can see from the scanned pictures, students who drew the HQM had full understanding of what models looked like, and they used simple symbols and brief words to describe the components. Compared to the HQM, the MQM is more concrete. Although students knew the applications of force symbols, the force had not been defined exactly. In regarding to the LQM, which was difficult for teachers to understand students' LQM without common symbols and some verbal description.





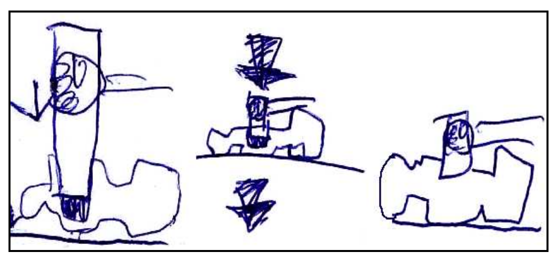


Figure 3a. HQM Figure 3b. MQM Figure3c. LQM

The sum of models was also collected based on students' answers of OEQ. In the pre-test and post-test, both of students from experimental class and control class revealed positive attitudes on models in problem-solving. Most of students used models to express their ideas and give explanation of their concepts understanding. The total number of models was 70 and 75 in pre- and pro-test of experimental class, 65 and 69 in pre-and pro-test of control class. The proportion of each type of models was accounted, see Figure 4. From the top of bar to the bottom of bar, the percentages of each models level (from the low level to the high level) are listed. Figure 4 indicates that the disproportion of models performance scattered in each test. In the pre-test, both of groups' modeling activities had low performance on HQM, which were only 20% and 15%. Most of students' could not use models effectively. The LQM occupied 50% in the experimental class and 40% in the control class. After instructional intervention, students of control group still had some difficulties in drawing HQM (17% in post-test). On the contrary, students in experimental group had achieved better performance on HQM application in test (43% in post-test), as well as decreasing rate of LQM (from 50% to 28%). Therefore, it had been verified that students could make improvements on the understanding of models and modeling through iMVT teaching approach. The iMVT could enhance their modeling skills and develop their expert-oriented models (Wu, 2010; B. Zhang, Liu, & Krajcik, 2006).

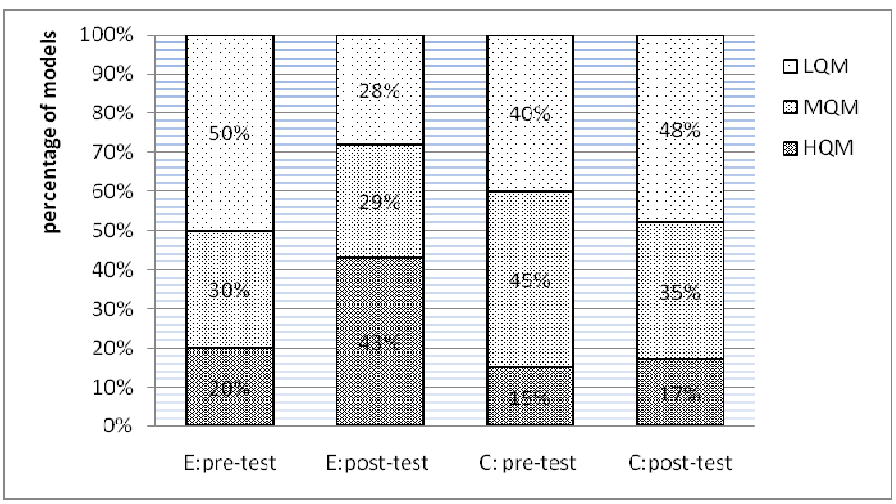


Figure 4. Students performance on model of control class and experimental class

Feedback on the iMVT approach

Students' Responses and Comments

In this section, the questionnaire included items to collect data of students' feedback on iMVT teaching approach and curriculum material features. A typical five-level Likert item was used to design the questionnaire. The content of each items involved student's response on interests, motivations, and features of iMVT approach. Students were required to explain their choices. Stacked column as shown in figures 5a and figure 5b visualize the analysis of students' feedback on the iMVT approach. In general, more than 50% students showed the positive response on iMVT approach. 86% students liked lessons and activities designed by iMVT pedagogy (Item a) (From the top to the bottom of the bar chart, it is the percentage of strongly disagree, disagree, neutral, agree and strong agree). And most of students agreed with that iMVT was different from previous methods and they would like to continue to learn science through iMVT approach. While, there were still about 30% students revealed neutral attitude in item b, c and d. (Item a: the interests in the lessons and activities using iMVT approach; Item b: the willingness to continue to learn using iMVT approach; Item c: the difference between the iMVT approach as compared to the normal physics lessons; Item d: the attention paid to the physics lesson using iMVT approach.)

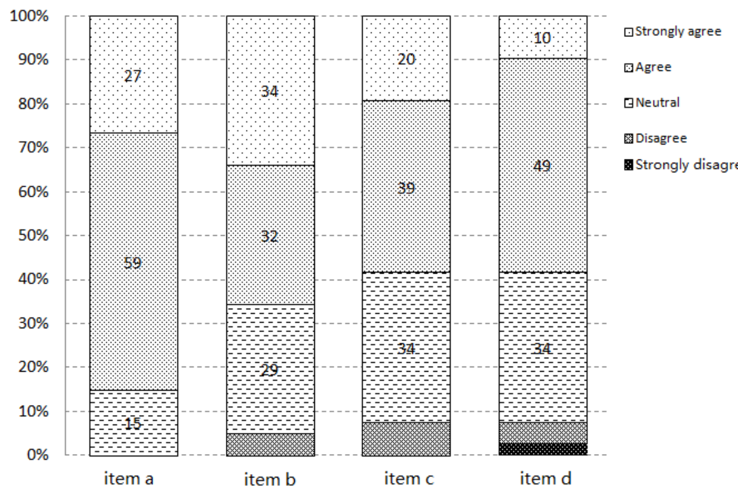


Figure 5a. Students' response on iMVT approach

Overall, students wrote that they benefited from the iMVT approach and the curriculum features. Students took the opportunity to provide open comments on iMVT approach in item e. We examined the suggestions on iMVT proposed by these students and concluded them. In the following, we present four interview segments to show the typical examples.

S1: In order to make the lessons more interesting, we can have inter-group competition about lessons and topics. That way, more people will be interested in learning science.

S2: Give more in-depth topics or deep insight into the topics and more outdoor activities and experiments.

S3: User easier terms for questions so that it is easier to understand.

S4: Give concepts at the start of the activities. And show examples before learning activities.

The comments illustrated student's response on the iMVT learning activities. More outdoor activities were required to conduct. And students would like to deep insight of some topics and proposed activity competition to make learning more interesting. They also need some more basic knowledge for the inquiry activities, such as concepts, inquiry skills and scientific methods. These suggestions and comments gave us hints and enlightenments that more flexible learning activities need to design for students with different learning levels and learning styles. The activities should not only be limited to the inside investigation, outdoor investigations need to be considered in the further design.

Date collection of students' impression on 11 components of iMVT students workbook (1.contextualtion, 2.talking aloud, 3.inquiry question, 4.discussion and collaboration, 5.modeling, 6.simulation, 7.visuliaztion, 8.application, 9.assessment, 10.reflection, 11.supplementary readings and resources) was conducted as figure 5b show. In this section, students also kept positive attitude on these features. The percentages of agreed with (including strongly agree with) were increasing from about 60% to 90%. In particular, students had great interest in "discussion and collaboration", which featured students' collaborative learning and peer discussion. "Simulation" also attracted students' strong interests with 51% strongly agreement. Several students showed strongly disagreement on the feature 7, 10 and 11. However, there were some comments reflected that such features not very applicable.

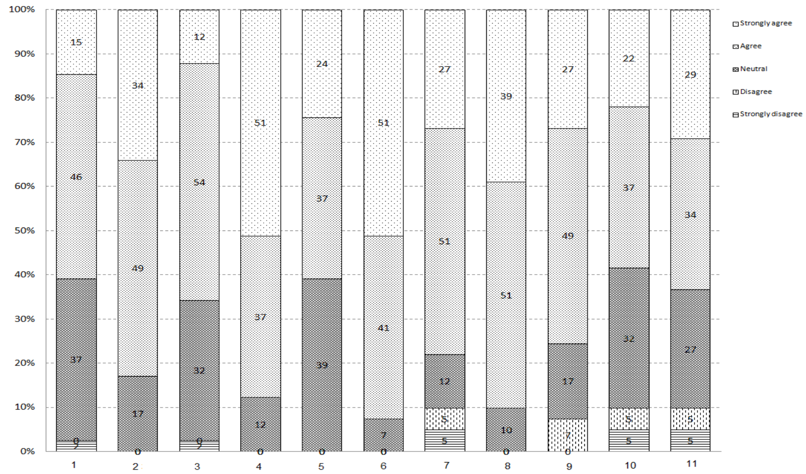


Figure5b. Students' response on iMVT curriculum material

Teacher's Comments on iMVT Approach

Post survey and structured interview were administered to better inform the research community, school policy-makers and teachers on the journey to sustain and scale the iMVT pedagogy as well as address the challenges we have encountered. The survey and interview comprised three parts: 1) the feedback on iMVT approach. 2) teachers' practices in iMVT community. 3) research design principles for sustaining and scaling iMVT. As the core member of co-design iMVT curriculum, the teacher showed his understanding of the iMVT curriculum development, and proposed his suggestions on the improvement of iMVT approach. Below are excerpts we quoted some important comments from the physics teacher.

Comments: *I feel that the iMVT package is comprehensive and gives sufficient coverage to the knowledge and skills that need to be covered for their learning. iMVT approach is pretty similar to what I preach. And small group and collaborative learning with student using the IT simulations can help students understand more difficult concepts. What is different is probably the design of the material used, in which I would not have included all the icons found in the workbook. I also do not quite know if they preferred the inquiry method of* *learning. I guess some will still prefer teachers to tell them the answers straight away but I am quite sure that they like to do small group activities.*

Suggestions: *I think we can separate the assessment portion from the activities portion. Given that there were only 4 hours to cover the whole topic (including pre- and post- tests), there isn't quite sufficient time to cover the assessment portion. It would be good if the whole worksheet can be on an e-platform with interactive features. This should further engage students in the learning and allows them to explore further on their own.*

On the survey, the teacher showed his positive attitude on iMVT approach implemented in the science teaching. He though it would enhance students' conceptual understanding and also build their critical thinking skills. There were still some challenges such as completing activities within the class periods, deep understanding of how to implement iMVT integrated lessons. We still need to pay more attention on the assessment part. On the aspect of iMVT community communication, there were not very frequent for teachers who belonged to this community to discuss with teachers in the same community or the other communities, as well as shared experience with administrators. In the co-design process, the teacher appreciated the co-design approach of curriculum development. And he found it was still tough for him to co-design the assessment, such as pre-test, and post-test. The teacher asked for more theoretical backgrounds of relevant pedagogy design and iMVT approach.

Discussion and Implications

Despite the limitations, the analysis presented in this paper showed that students' conceptual understanding in "Forces and Motion" was improved after the iMVT integrated instruction. The iMVT approach, when implemented appropriately, is potentially effective in transforming the classroom into a learning environment where students actively construct knowledge and build integrated scientific conceptual understanding. In this study, we applied iMVT pedagogy to address students' learning difficulties in a frequently discussed topic:

Forces and Motion. We developed curriculum materials, implemented teaching intervention, and conducted pre- and post-test, post surveys and interviews. Date collection was concentrated on four main aspects: 1) Students' concepts changes after iMVT teaching intervention. 2) Students modeling performance through different teaching approaches. 3) Students and teacher's attitudes on iMVT approach. 4) Comments and suggestions on the improvement, sustaining and scaling up iMVT approach. In summary, students have had benefits from this approach. From ANCOVA, significant difference of means existed between control and experimental group. Students had less alternative conceptions after iMVT teaching intervention based on the distracter response and correct answers analysis. On the other hand, modeling skills were emphasized on during iMVT integrated teaching (Gilbert & Rutherford, 1998). And iMVT also seeks to encourage students to apply models and modeling approach in problem-solving, use models to express their mental models of science phenomena. Students were provided more chances to build models, execute models and simulations, and observe models compared to students in control group (Schwarz, et al., 2009). The difference of modeling performance reveals these effects: students in experimental group performed modeling task better; they had higher proportion of high quality models, which was most closely similar with conceptual level. An initial conclusion could be drawn that students kept positive attitudes on this teaching and learning approach. They performed interests in some of learning process and inquiry activities, and gave good satisfaction measurements of iMVT approach. Regarding to teachers interview and survey, positive comments and suggestions would improve iMVT pedagogy on aspects of curriculum materials design, teaching approach, and also could be the support for the sustaining and scaling up in science education.

Because sustaining and scaling up the iMVT pedagogy is a long journey, we would like to share our experience in this iMVT implementation in physics topic. A proposed research framework is created through this iMVT endeavour. See figure 6. The content with the dotted border was the general research methods adopted by researchers in this research. The major procedures includes teacher-researcher working sessions of iMVT pedagogy → co-design iMVT curriculum materials → students' hands on session of computer technology and modeling skills, as well as teacher-researcher working sessions of iMVT implementation → iMVT curriculum implementation. The teachers and students' survey (questionnaire, interview, etc), students' test are conducted before and after teaching intervention. During teaching intervention, researchers will collect more evidence through classroom observation. Data analysis on the test, survey and classroom observation provides feedbacks for improvement iMVT pedagogy research and curriculum implementation. The feedbacks are labelled as the dotted arrows.

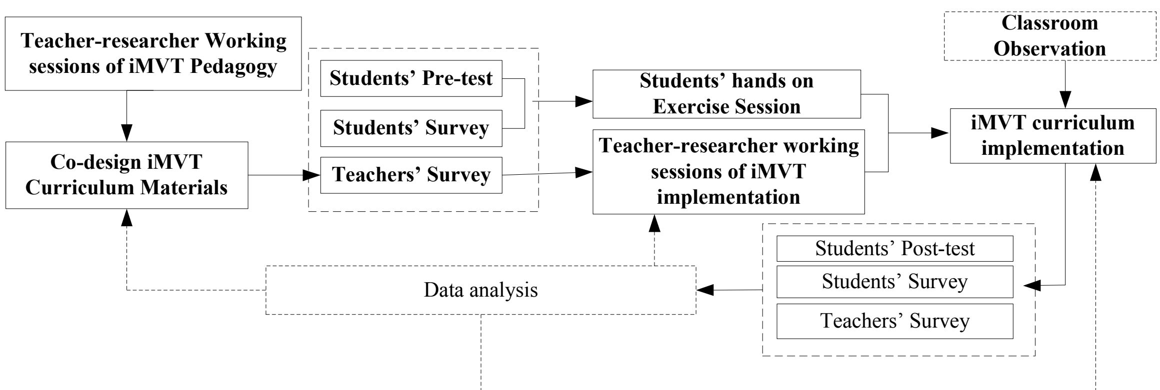


Figure 6. A proposed research framework of iMVT pedagogy

Further Work

In this study, there are mainly multiple factors affected the result and analysis; it is difficult to clearly determine which factor has bigger influence on the results. Below we highlight possible relationships to be as reference of our further work on the study of iMVT pedagogy and its application in real learning context. We refine several aspects on the further work of iMVT implementation:

1) The teacher education of iMVT pedagogy

The workshop includes deep understanding of iMVT pedagogy, the iMVT lesson plan, hand on exercise of simulations, visualizations and modeling tools, co-design approach and iMVT curriculum structure and features. During this workshop, teachers will get more familiar with the theoretical backgrounds of iMVT pedagogy, the rationale and procedures of co-design process as well as the manipulation of existing models and other visualization technologies.

2) The hands-on sessions for developing students' modeling skills

In iMVT teaching intervention, varied modeling practices were not provided for students by considering limited class periods. In further study, there will be more chances for students to take part into the modeling activities which involve making physical models, drawing scientific models, manipulating simulations, and building models by computer-supported modeling tools. These hans-on activities seek to help students to develop basic modeling skills and sophisticated understanding of models and modeling. In the further work, we will concentrate on students' concept of models and modeling, and make in-depth study of students modeling performance after long-term iMVT teaching intervention.

3) The in-depth study of students' cognitive ability

In general, it was found that there was significant improvement of students in experimental class. We also had some preliminary results of the correlation between iMVT approach and quality of models. Further study will be paid more attention on the effectiveness of the iMVT approach in fostering students who have different levels of cognition based on the data from our process videos.

4) Large scale of iMVT teaching intervention

In our study, there are many issues to be covered. Such as curriculum material development and implementation, teaching intervention, instruments design and test, teacher's survey and interview. However, there was limited manpower and research timeslot, we just chose one physics teacher as the co-designer of curriculum material and the teaching intervention executer. In the further study, more participants from larger scale will be chosen to address to find the effectiveness of iMVT approach and get more feedbacks to improve this pedagogy.

5) The improvement of instruments

On the analysis, we assigned only 5 MCQ and 3 OEQ for students pre- and post-test. Although experimental group had better performance, it was not significant in some questions, such as MCQ-1 and MCQ-5. We also had not enough evidence to support why students in experimental class had higher percentage of distracters in MCQ-1 after teaching intervention. Further discussion will be conducted to explain why students get lower scores of OEQs. We will do further study of correlations between characters of concepts and iMVT features. It will tell us whether iMVT is appropriate for all of topics, or it is better suitable for some specific topics and concepts.

At present, a network-based system called WiMVT (A Web-based Modeling and Visualization Technology Integrated Inquiry-based Science Learning Environment) is under the development by our research team (B. Zhang, Sun, Mous, & Koh, 2011). With features of model-based inquiry cycle, WiMVT system will integrate iMVT pedagogy into curriculum materials development and implementation. It is proposed to realize iMVT approach through this collaborative learning platform. Scaffolds that support students' quick feedback, synchronous co-constructive modeling, synchronous writing and asynchronous editing are developed. The application of WiMVT platform is expected to improve students' concepts understanding, inquiry skills, reasoning skills, self-regulated learning, and collaborative learning skills. In summary, lessons from teachers' professional developments, empirical studies and the new web-based application will support iMVT research with varied experience in the future. We will make more efforts on sustaining and scaling up iMVT approach in science education.

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Appendix 1: Forces and Motion Quiz

- This quiz consists of 5 multiple-choice questions and 3 open-ended questions.
- Please answer all the questions in 20 mins.
- For all multiple-choice and open-ended questions, consider all situations in the gravitational field of the earth and ignore the air resistance.
- For multiple-choice questions, read the five possible answers carefully and please circle the appropriate answer(s).

If time permits, provide explanations (in drawings and/or words) to support your answers in the spaces provided below each question.

Personal details

Name: _______________Class/number: _______________Age: _______________

Gender: _______________Date: ________________

A. Multiple-Choice Questions

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:
   a. the same time for both balls. b. half as long for the lighter ball.
   c. half as long for the heavier ball. d. considerably less for the lighter ball, but not necessarily half as long.
   e. considerably less for the heavier ball, but not necessarily half as long.
2. A large box is being pushed across the floor at a <u>constant speed</u> of 4.0 m/s. What can you conclude about the forces acting on the box?
   a. If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
   b. The amount of force applied to move the box at a constant speed must be more than its weight.
   c. The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
   d. The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
   e. There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces. The external forces just resist motion.
3. If the force being applied to the box in the preceding question (question number 2) is suddenly discontinued, the box will;
   a. stop immediately. b. continue at a constant velocity.
   c. immediately start slowing to a stop.
   d. increase its speed for a period of time, then start slowing to a stop.
   e. continue at a constant speed for a period of time and then slow to a stop.
4. A boy throws a steel ball straight up. The force(s) acting on the ball until it returns to the ground is (are):
   a. a constant downward force of gravity only.
   b. its weight vertically downward along with a steadily decreasing upward force.
   c. a constant downward force of gravity along with an upward force that steadily decreases until the ball reaches its highest point, after which there is only the constant downward force of gravity.
   d. a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing downward force of gravity as the object gets closer to the earth.

e. none of the above, the ball falls back down to the earth simply because that is its natural action.

5. A stone falling from the roof of a single story building to the surface of the earth;
   a. speeds up because of the constant gravitational force acting on it.
   b. falls because of the intrinsic tendency of all objects to fall towards the earth.
   c. reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
   d. falls because of a combination of the gravitational force and the air pressure pushing it downward.
   e. speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.

B. Open-Ended Questions

1. Student 1 throws a red marble horizontally from the top of a roof; student 2 throws a white marble straight down. Once in flight, is the acceleration of white marble greater than, less than, or equal to the acceleration of red marble? Explain your answer in words and drawing.
2. The metal head of a hammer is loose. To tighten it, you tap the hammer on a floor. Should you
   (a) tap the hammer with the handle end down (the handle is made of wood), as shown in the picture on the right,
   (b) tap the hammer with the head end down, as shown in the picture on the left, or
   (c) do you get the same result either way?
   Explain your answer in words and drawing.

(a) (b)

3. Is it possible for an object to be moving in one direction while the net force acting on it is in another direction? Explain your answer in words and drawing, and provide an example to support your answer.