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A comparison of the effectiveness of two teaching strategies in the remediation of misconceptions of force and gravity among students

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ABSTRACT
In this paper an attempt is made to explore the efficacy of a teaching strategy which not only factors the misconceptions of students but also employs the Generative Leaming Model. This is compared with the traditional didactic approach, which serves as a control. The topics of force and gravity were selected because we have found that these are areas where Singaporean students generally harbour misconceptions. This allows us to make comparisons with other reported misconceptions in these areas in the literature as well as assess the effectiveness of the Generative Leaming Model in these areas, domains where the Model has so far not been addressed in the literature.

Introduction

There is presently greater awareness of the challenges facing educators in teaching scientific concepts to students. This stems mainly from the recognition that any pedagogical approach will have to contend with the preconceived notions of students.

The preconceived notions may often be misconceptions and be a stumbling block in assimilating scientifically correct knowledge since the notions are entrenched in the student's cognitive psyche. Ausubel (1968) observed that "The most single factor influencing learning is what the learner already knows: ascertain this and teach him accordingly". The works of Viennot (1979), Driver & Erickson (1983), Dawson & Rowell (1984), Osborne (1984) and Watts (1983) indicate that students do not relinquish concepts which they have found to be satisfactory in explaining their perception of the world.

It is a challenge to devise an instructional strategy to overcome specific misconceptions. Methods such as activation of prior knowledge (Alverman & Hynd, 1989), the use of refutation text (Alverman & Hague, 1989), creating cognitive conflict (Posner et al., 1982), and using microcomputer simulations (Weller, 1995) are some of the approaches that have been tried and found to be successful in the circumstances in which they have been used.

Understanding of the complexities of the learning process can aid the teaching process. In this aspect, the constructivists seem to be most promising in offering an answer. Kelly (1969), Wittrock (1974) and more recently, Driver (1981, 1991), West and Pines (1984) have all argued for a case in which learning is not a simple internalising of new knowledge but involves the construction of meaning by the child when confronted with sensory input. Wittrock (1974) has combined his ideas about generating meaning with those of information processing and proposed the Generative Leaming Model in which a learner's memory store and processing strategies collaborate to sieve and select any incoming sensory input. The input is then linked with relevant parts of the memory and the learner then generates meaning before subsuming or accommodating the constructed meaning into memory. Together with Osborne (1983), he proposed the relevance of this model to the learning of science.

In this paper an attempt is made to explore the efficacy of a teaching strategy which not only factors the misconceptions of students but also employs the Generative Leaming Model. This is compared with the traditional didactic approach, which serves as a control. The topics of force and gravity were selected because we have found that these are areas where Singaporean students generally harbour misconceptions. This allows us to make comparisons with other reported misconceptions in these areas in the literature as well as assess the effectiveness of the Generative Leaming Model in these areas, domains where the Model has so far not been addressed in the literature.

Research design

The research design was quasi-experimental based and follows the approach described by Campbell and Stanley (1966). The teaching strategies were implemented with two different groups over a period of six weeks. Group I received instruction using Teaching Strategy I (TS I), which was the traditional teaching method, while Group II received instruction using Teaching Strategy II (TS II), an approach which took into consideration the students' misconceptions and employed the Generative Learning Model. The students from the two groups underwent the same amount of instruction and had the same teacher taking the lessons; the teacher was a Physics graduate and had 8 years of teaching experience in this subject. In order not to disrupt the curriculum time, the lessons were conducted after school for both the groups.

The effectiveness of the two teaching strategies was evaluated by the performance of the two groups on validated tests before and after instruction. A pre-test and post-test were also given. A delayed post-test was administered four weeks later to determine which of the teaching strategies was more effective in helping students retain what they had learnt. The period of four weeks was considered sufficient to test maintenance of effect. The post-tests were identical to the pre-test.

Subjects

The students chosen for the two groups undergoing the instruction were from the secondary three (grade 9) *express stream* of a co-educational secondary school in Singapore. The school is an average government secondary school in terms of its academic performance in the G.C.E. Ordinary Level Examinations (percentage of three Ordinary Level passes is around 70%). To ensure randomness in sampling and equivalent ability prior to instruction, the two groups were selected as discussed below.

The school had six secondary three classes in the *express stream* in which the students were placed according to their examination results for the previous year. The students from the first class and the last class were chosen so as to obtain a group of students of mixed ability for the different treatments. The students were then randomly divided into two groups. One half from the best class was combined with one half of the last class to form Group I (26 students: 10 boys and 16 girls) and the others were combined to form Group II (2 7 students: 13 boys and 14 girls). Group I was subjected to TSI while Group II was subjected to TSII.

Description of instrument

The Misconception Questionnaire for Force and Gravity (MQFG) was used to determine the common misconceptions of students. It consisted of 24 questions, which testing 16 common misconceptions.

Each question had two parts; the first part was essentially a multiple choice question, while the second part required the student to write down reasons for selection of the answer in the first part. A student obtained a full score for a question for a correct answer to the multiple choice problem as well as the correct explanation for the selection. The percentage of correctly answered questions was termed the Conception Score of the student. A poor score meant that the student still had a number of misconceptions concerning force and gravity.

The MQFG was developed through the following steps:

- Based on research previously done on misconceptions in the areas of force and gravity (Watts & Zylberstajn, 1981; Gunstone & White, 1981; Minstrell 1982; Osborne 1984; and Treagust and Smith, 1989) and based on the curriculum for students in this study, propositional knowledge statements were listed using the approach of Treagust and Smith (1989). These propositional statements became the basis for the development of interview cards.
- In order to obtain a broad spectrum of ideas and misconceptions of students at secondary level, sixteen students with different abilities were selected from different levels of the same secondary school for the interview.
- Using interview cards depicting situations, the students were asked to predict the outcome of the situations. They were then asked to give an explanation of the predictions. Their answers were probed to discover their understanding of the concepts of force and gravity. (For interview about instances see, Osborne and Gilbert, 1980).
- The information gathered was used to construct the 24 questions of the instrument plus the options and distractors for each question. The two-tiered diagnostic question format was chosen as it gave a complete picture of the students' understanding of a particular concept.

Validation of the instrument (MQFG) was performed with the help of 12 experts who included lecturers of student teachers in science education, senior science school teachers, Physics teachers, and science inspectors from the Ministry of Education in Singapore. Their feedback was used to make relevant revisions.

A total of 89 students sat for the pilot test. The students were from 3 classes of the secondary three express stream from an average government co-educational secondary school.

Item analysis was performed for each of the test questions. Generally, all the facility indices (F.I.) of the items fell within the range of 0.25 and 0.75 except for one item which required students to identify the direction of the force acting on the ball which is on the way down to the ground. Although this item has a F.I. of 0.86 which is rather high, it was decided that it should be kept after careful consideration of the nature of this item. The discrimination indices (D.I.) of the items fell within the range of 0.20 and 0.75 except for the item mentioned above with a D.I. of 0.13. Its low D.I. could be due to the F.I. of this item. The Kuder-Richardson-20 value of the instrument was 0.75. This value is considered acceptable to ensure internal consistency and reliability of the instrument (Salvia & Ysseldyke, 1988).

Teaching strategies

Teaching strategy I was basically didactic in nature. Although this approach is educationally outdated, it is still widely practised in the science classroom. Teaching Strategy II took into account the students' misconceptions and employed the Generative Leaming Model. However, a number of adaptations were made as follows.

Firstly, the lesson was not divided into 3 clear progressive phases of focus, challenge and application, but rather the cycle of the 3 phases was repeated over and over again, both through the development of the lesson and as freely as the students consciously or unconsciously did it. This is believed to be necessary and reasonable as the learning process takes place continuously within the students' mind. It would be too controlled and unrealistic to compel and expect all students to follow a fixed programme of proceedings to fit the 3 phases. As Osborne and Wittrock (1985: 73) have noted, the construction and reconstruction of meaning are complex and are most likely to be more than a simple *single-path single-loop process.* Rather it is a *multitude of linking* between the sensory inputs and existing ideas taking place continuously.

Secondly, the teaching strategy involved the use of a *learning diary.* In the teaching strategy suggested by Cosgrove et. el. (1982) they explained the need for, and the benefits of, students being able to voice and share their personal concepts and predictions publicly. The teacher will then be able to detect inadequacies of the students' preconceptions and at the same time allowing students to compare their views with classmates. In the context of students in Singapore, being required to publicly reveal and defend a personal idea may be rather threatening, both socially as well as one which may be too demanding on one's language ability. Thus, students in the teaching strategy designed used the learning diary to articulate their perceptions and predictions. A sample entry from the Leaming Diary is shown on the next page.

The Leaming Diary does not just act as a preparation and focussing tool to enable the student to start attending to and selecting the relevant sensory input, but also as a guide, and gently coerces the student to generate links relevant to the existing ideas as other students go through the questions and statements in the Diary. The Leaming Diary thus enhances the implementation of the Generative Leaming Model. However, the use of the learning diary does not mean that students are not encouraged to discuss and contribute in class, but rather its use will enable academically poorer or shy students to benefit from the implementation of the learning model.

A sample of a learning diary

A 1 kg mass is placed and lightly strapped to a weighing machine. The reading is 10N.

The whole machine together with the weight is dropped.

What is the reading on the scale?

The treatment

The planning of the lessons was made in accordance with the misconceptions to be modified for the day. The objectives, exercises, examples and experiments were the same for both the teaching strategies. In line with the teaching strategies spelt out earlier, the way the lessons were executed and developed were different. Transparencies and audiovisual aids were different, both in quantity and method of employment, depending on the teaching strategy used. For each lesson in the two teaching strategies, lesson plans were developed to show how the lesson should progress. Each lesson lasted for about an hour and a half.

To check how the teacher proceeded with the lessons an independent observer, using an observation checklist, was invited into the classes at her convenience. The observer, a senior science teacher, who is also the head of the science department in the school, was briefed on what to look for and how to complete the checklist, but was not told which class was the control and which class was the experimental group. The observation exercise was to ascertain whether the teacher had taught faithfully according to the postulates of the particular teaching strategy.

Results and discussions

Quantitative data relating to the appraisal of the two teaching strategies are tabulated below:

	Pre-test		Post-test		Delayed Post-test	
Teaching Strategy	TSI	TSII	TSI	TSII	TSI	TSII
N	26	27	26	27	26	27
Mean	8.5	8.7	11.46	18.15	10.62	17.37
Standard Deviation	3.15	4.06	4.09	3.59	3.53	3.58
t value	0.20		6.33		6.80	
alpha	0.05		0.05		0.05	
df	51		51		51	

The pre-test results show there were no significant differences between the treatment groups before the treatment. The post-test scores, show significant differences between the Conception Scores of the two treatment groups. For the delayed post-test, the group undergoing TS II again scored significantly higher than the group undergoing TSI.

It is interesting to note there is a drop in Conception Score for the delayed post-test and not an increase as would be expected of students who are continuing in a Physics course. The drop not only shows how strongly students held on to their misconceptions but also how easily students reverted to their old misconceptions even though attempts had been made to modify them by instructional intervention. This is in agreement with research findings that unless there is sufficient reinforcement and unless the student finds that the new concept is plausible, useful and relevant, he/she will revert to what he/she has been most comfortable with all these years (Osborne and Freyberg 1985). Even though there is a drop in the Conception Score, the net gain in mean for the delayed post-test as against the pre-test for the experimental group (8 .67) is still larger than for the controlled group (2.1 2). Despite the drop in Conception Score, the treatment is still effective.

The results of the delayed post-test show that although TS II was effective in enabling students to modify their misconceptions, however, more is still needed to help them not to revert to previous misconceptions.

The record of the checklist showed that the different aspects demanded of the two strategies had been faithfully followed. Students in the experimental group enjoyed the experiments which they had no opportunity of doing in their normal lessons. This implies the need to let students enjoy discovering truths in the process of learning. Although in most of the experiments, the equipment required had to be specially designed and constructed, it is worth the while to invest time and effort to set up adequate numbers for use, especially if such experiments are effective in helping students overcome stubborn misconceptions.

During the lessons using TS II, which was to help students articulate their understanding, it was observed that discussion was limited to a few more vocal ones who dominated the development of the discussion. This implies that in order for all students to benefit from the teaching strategy, both the teacher and the students themselves must learn to get used to the new style of learning. The more vocal students must allow and encourage the rest to contribute. The teacher must acquire the skills to make the discussion more lively, with more students participating, while at the same time directing the discussions purposefully and not leaving students more confused. In the study, it is fortunate that the above mentioned shortcoming was compensated by means of the Learning

Diary. The Learning Diary was popular and the students were pleased and enjoyed the cartoons used in the diary. The students, in their feedback, mentioned that learning using the diary helped because it was fun and systematic, made them think, and gave them the satisfaction that they could, by reasoning out on their own, come to the correct conclusion.

When the teacher sought to determine whether the students' responses were adequate in terms of being able to correctly explain and consistently predict the outcome of a situation, two problems arose:

- With the help of the students, the teacher explained the shortcoming of each common misconception and why it was not acceptable. In doing so, there had been several occasions where the mere highlighting of a misconception caused more confusion than understanding. In this case, the teacher had to be not only very certain of his/her own understanding, but also very articulate, because some misconceptions are very counterintuitive.
- In an attempt to make sure that students would not acquire a particular misconception, the teacher's emphasis on the error of the misconception could give rise to misunderstanding. For example, some students often memorised the fact that a particular misconception was wrong, but could not understand what the correct concept actually was. Therefore, it was crucial for the teacher to be aware that the highlighting of the correct concept is also very important.

When using TSII in the normal class lesson, the teacher must bear in mind the following. In the strategy employed, the researcher planned the lessons using the misconceptions that were common to students. Though this process may be effective in terms of helping students to overcome their misconceptions, to a great extent, it turned the lessons into sessions with the purpose of eliminating misconceptions rather than teaching students new concepts. The teacher's time spent, in preparing the lesson plan and the learning diary, will help to envisage pit-falls that may arise. This is useful as the teacher, while thinking through the possible problems and misconceptions that the students may face, will be prepared to guide the discussion and learning.

Implications for science teaching

This study does have its limitations. For example, the sample size, the choice of subjects and instructor effect are factors which may introduce an element of bias in the findings. However, the results show that misconceptions exist, are hard to eradicate, and even if they are modified, some students may revert to the previous misconceptions. Moreover, knowing these misconceptions exist is insufficient; the teacher must make a effort to help the students, failing which learning will be greatly reduced.

There is definitely a need for a change of methodology and teaching strategy to help students modify their misconceptions. The didactic approach was shown to be relatively ineffective in this study. The Generative Leaming Model proved to be effective. Information and *spoon-fed* knowledge is not sufficient to make a student abandon what he or she has found to be adequately useful, even though the teacher may have explained otherwise. Care is needed to help students express their personal understanding and use their concepts to explain, solve or predict a situational problem. Only when their misconceptions are challenged will they see a need to change. A conducive learning environment makes a difference to accelerate this process.

Although the conventional teaching methodology is not particularly effective in helping students to overcome their misconceptions, this method of supplying information with the expectation that the students will learn by way of passive reception is, however, practised by a significant proportion of local teachers. These teachers are either not aware of the inadequacy of their teaching methodology or are not convinced that a particular strategy can help their students overcome misconceptions. In some cases, as researchers have shown, the teachers themselves might contribute to their students' misconceptions (Hewson 1981). There is therefore a need to reach out to such teachers and provide them with in-service training so that they become aware of such misconceptions and are equipped with the skills to handle the misconceptions. Students teachers, in their pre-service training, could also be appropriately trained before they are sent to schools. Teachers should be made to realise that they have to take on a new role from that of a knowledge dispenser if the teaching strategy 1s to be effective. The teacher becomes a diagnostician, a facilitator, a guide and a sounding board, asking more leading and relevant questions to arouse discussion rather than just dispensing the facts. He or she has to challenge and encourage students to appreciate and see the relevance of the new evidence confronted them. This implies that the teacher must be trained in the necessary skills to guide discussions and to use questions effectively. Mastery of subject, especially in handling subtle misconceptions, must be a part of the training given to teachers.

In the class, the students will need some help. They will no longer be allowed to sit passively, hoping to absorb as much information as possible but will be required to participate actively in discussions, question critically, and be bold enough to express their own ideas and understanding of problems. Most Singaporean students have grown quite accustomed to sitting back and letting the teacher do the talking. The learning diary can help in that students will have to write down their understanding of the problem, their predictions or their ideas. Questions in the learning diary will have to be designed in such a way as to lead the students first to express their ideas/concepts and then to see the conflicting evidence found during the experiments or discussions before finally expressing their conclusions.

Experiments will have to be carried out in a way not just to confirm a law or a principle, but to allow students to discover the principles for themselves. The students need to gather data to test their hypothesis and this will provide them with conflicting evidence to challenge their misconceptions.

Textbooks can be written to make both students and teachers aware of common misconceptions. The history of the development of the topic, how previous scientists grappled with the difficulties, and how they, too, sometimes held misconceptions until proven wrong, can be very helpful. Some researchers have recommended a change in teaching methodology to include historical anecdotes as part of the constructive approach to help students learn (Gil-Perez and Carrascosa, 1990; Sequeira and Leite, 1991). Textbook writers can include materials in the form of remedial exercises and examples in order to help students apply difficult concepts that are especially prone to misconceptions. Features similar to the presentation in the learning diary may be incorporated in textbooks.

To enable students to overcome misconceptions is not a simple task, but one that needs preparation and time, in comparison with a lecture or lesson that employs the chalk and talk approach. Special experiments and demonstrations that will help the students grapple with their inadequate understanding of certain concepts take time and effort to prepare. The process through which students are led by confronting and providing conflicting evidence to their concepts is sometimes arduous. Many teachers will be hard pressed to complete the syllabus. There will be nothing more alarming than to have completed the syllabus to find that, other than memorised answers, students had hardly learnt.

Teachers thus need to spend more time and effort in the preparation of teaching materials. To make the task easier, team teaching could be encouraged. Teachers can sit down together to discuss how best to handle stubborn misconceptions and to share resources in their classrooms. It is heartening to note that apparatus and models prepared for demonstrations can be kept for use in the following year.

The fact that students have the tendency to revert back to their previous misconceptions, as reflected by the results of the delayed post-test, requires special attention. Reversion to previous misconceptions implies that there has not been any replacement or displacement. The old concept had not disappeared after learning a new one. It could mean that the new concept has not been internalised due to insufficient reinforcement. This reveals a need to put more emphasis on the application stage of the Generative Leaming Model. Students have to be provided with opportunities to practise and apply the accepted concept. It is a challenge for the teacher to make this stage adequate and overcome those stubborn misconceptions.

Conclusions

In spite of the limitations mentioned above, the results of the study do show the effectiveness of Teaching Strategy II over Teaching Strategy I. If a teacher takes into consideration the students' misconceptions and adopts the Generative Leaming Model, a greater percentage of the students can overcome their misconceptions. The teaching strategy is not ideal, but it is an important step forward to move beyond knowing what the students' misconceptions are to actually having a teaching strategy that gives significantly positive results. The findings have important implications not only for teachers but also for school administrators, curriculum specialists and textbook writers.

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