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Abstract

This study examines the impact of inquiry based learning on Science. Using mixed method research methodology, it assesses the effect on both cognitive and affective domains of Secondary Two (aged 14 years of age) students in the sub-topic of Electricity.

This research will be conducted in a government girls' school in Singapore. The participants are Secondary Two Express stream students. The students will be divided into two groups: the inquiry-based group (N=80) and the control group (N=80). Students in the inquiry-based group will use the guided inquiry approach to understand & apply basic Physics concepts. Students in the control group will use the traditional learning approach.

Analysis will be conducted to find out if there is a significant difference in both cognitive and affective domains after the 5-week intervention. Quantitative instruments used to measure the students' Science achievement and attitude towards the subject include The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS). The same instruments will be used as the pre-test and post-test. There would also be follow-up interviews to elicit students' major misconceptions and focus group discussions to analyse the students' perception towards the Physics-by-inquiry approach.

Introduction

Area and Topic

This assignment examines the impact of inquiry based learning on Science achievement. More specifically, it aims to find out if the Physics-by-Inquiry (McDermott, 1996) approach will significantly affect Secondary Two students (aged 14 years old) on both their Physics achievement scores and attitudes towards the subject. Using mixed method research methodology, this study focuses on both the cognitive and affective effects of inquiry based learning.

Many research topics have been done on the impact of inquiry based learning on Science achievement (Hofstein, Navon, Kipnis & Mamlok-Naaman, 2005; Volkmann & Zgagacz, 2004; Bianchini & Colburn, 2000), but few have investigated on the impact of inquiry-based learning on Science achievement in an Asian context. Hence it is the aim of this assignment to find out if established research findings on the positive impact of inquiry-based learning are echoed in the Asian context as well.

Inquiry-based learning is not a new idea. Jerome Bruner (1961) viewed inquiry as an intellectual process. Through discovery, the learner becomes more engaged in learning. It also requires the learner to be a collaborator and thus is more likely to pursue learning for intrinsic reasons there after. In inquiry-based learning, teachers now act as facilitators while the students take over the ownership of their own learning. It is essentially a form of active student-centred learning, where they investigate phenomenon, cultivate deeper understanding towards the subject after a question is posed about the natural world. As observed by Llwellyn (2002), the process of inquiry involves linking previous information to the new experience in an attempt to make sense of the new experience. Such a learning mode helps one to be open-minded, utilizes habits of mind and builds up self-reliance and self-confidence in the students.

Background and Context

The Lower Secondary Science Syllabus The *Lower Secondary Science Syllabus* in Singapore is divided into two parts, one for the more academically inclined students in Special/Express/Normal (Academic) stream and one for the more technically inclined students in Normal (Technical) stream. Students are categorized into the different streams at the end of their six years of primary education, where all students will sit for a nationwide Primary School Leaving Examination. (Ministry of Education, 2003).

On average, about 85% of the primary school cohort move on to Special/Express/Normal (Academic) stream. Pupils who are within the top 10% in the Primary School Leaving Examination can choose to go to the Special stream. Other pupils are placed in either the Express course or the Normal (Academic) course based on their Primary School Leaving Examination results. Students in these three streams can proceed to higher education in either polytechnics or junior colleges, and thereafter the university, depending on their eligibility.

Another 15% of the cohort would qualify for the Normal (Technical) stream. This course provides students an opportunity to complete 10 years of basic education and prepares them for The Institute of Technical Education, an institution that provides pre-employment technical training to secondary school leavers.

The Lower Secondary Science Education in both Special/Express/Normal (Academic) stream and Normal (Technical) stream emphasises on the ability to access, generate and process information. Lesser emphasis is placed on the acquisition of scientific knowledge and understanding since the ever-expanding scientific knowledge makes it impossible for the student to acquire all. To build up on acquisition of lifelong skills, from discrete process skills, thinking skills to processes such as decision-making and problem solving, the Lower Secondary Science Syllabus uses the Science as an Inquiry framework (Ministry of Education, 2003).

Although the same Science as an Inquiry framework is adopted by both Special/Express/Normal (Academic) stream and Normal (Technical) stream, the content knowledge differs substantially. In Special/Express/Normal (Academic) stream, emphasis is placed on building a bridge to, and a foundation for, the pursuit of scientific studies at higher levels whereas in the Normal (Technical) stream, emphasis is placed on acquiring knowledge and skills that have direct relevance to technical courses.

Teach Less, Learn More Initiative The Singapore Ministry of Education's vision of "Thinking Schools, Learning Nation" was first announced by then Prime Minister Mr Goh Chok Tong in 1997. The vision describes a nation of thinking and committed citizens capable of meeting the challenges of the future, and an education system geared to the needs of the 21st century. Thinking schools will constantly challenge assumptions and seek better ways of doing things through participation, creativity and innovation. A Learning Nation envisions a national culture and social environment that promotes lifelong learning in its people (Ministry of Education, 2004).

"The Teach Less, Learn More Initiative" was implemented in 2004 and it continues the journey to improve the quality of interaction between teachers and learners. This initiative helps educators focus on the quality of classroom interaction and learning of life-long skills through innovative and effective teaching pedagogies. It tries to take away the emphasis on rote-learning, repetitive tests and prescribed answers, all of which are part and parcel of the education scene in Singapore.

In 2006, Crescent Girls' School was selected as one of the prototype schools for the "The Teach Less, Learn More Initiative". Through the years, there has been a lot of positive review on the use of inquiry-based learning in classrooms, both internationally and locally (Hofstein & Navon, 2005; Volkmann & Zgagacz, 2003; Bianchini & Colburn, 1999; Ng, 2004). Encouraged by the positive research findings and coupled with the support from the Ministry and school, a project to investigate the impact of inquiry-based learning on achievement scores and attitudes is initiated.

Physics-by-Inquiry There are many reports that document the difficulties for an inquiry-based lesson. Among them, lesson planning is thought to be time-consuming and tedious (Appleton, 1977; Gibson, 1998).

Physics-by-Inquiry (McDermott, 1996), is a set of laboratory-based instructional modules that resulted from more than 25 years of research by the Physics Education Group in the Physics Department at the University of Washington.

Through a series of experiments involving observation, hypothesis making and sound reasoning, students construct physical concepts and simple scientific models. Teachers, approximately one for every 20 students, act as facilitators to help the students gain understanding through good questioning techniques. With carefully prepared worksheets, the emphasis is on discovering rather than on memorizing. Students are recommended to work in pairs and feedback is in the form of worksheets and “checkouts”.

In “checkouts”, students are encouraged to articulate their reasoning to a given problem and reflect on their progress. Individual questions are brought up and diagnose in small group discussions. Conceptual misunderstandings are cleared, under the guidance of the facilitator. “Checkouts” usually occur after an hour of activity and lasts around five minutes. Such small group checkouts are possible only if the teacher-student ratio is kept small.

Hence, the Physics-by-Inquiry approach developed by Dr Lillian McDermott, University of Washington, is adopted for this study. However, the worksheets in the modules were intended for pre-service teachers and university students and need to be redesigned for secondary school students. The five worksheets that were adapted from Physics-by-Inquiry (McDermott, 1996) have been included in the appendix.

Statement of Purpose

The main goal of this assignment is to study the impact of Inquiry-based learning on Physics achievement scores and attitude towards the subject. More specifically, it assesses if the Physics-by-Inquiry (McDermott, 1996) approach will significantly affect Secondary Two (aged 14 years of age) students in a Singapore government girls' school in the following areas:

i) performance in Physics achievement in the sub-topic of electrical circuits,

ii) attitudes towards the learning of Physics,

iii) perception towards in inquiry-based learning.

Significance

The Singapore Ministry of Education has adopted Science as an Inquiry framework for both Special/Express/Normal (Academic) stream and Normal (Technical) stream in all secondary schools since 2001. Positive research results have also been published in abundance on the impact of inquiry based learning on achievement scores and attitudes (Haury, 1993; Gibson, 1998). However, in a bid to complete the school syllabus on time and the reluctance by some teacher to change, many of the classroom lessons are still conducted using the didactic traditional chalk-and-talk method.

In addition, these researches are mostly confined to schools in the western context. Would the same positive impact be reaped in the Asian context? Although increasingly challenged in the education literature in recent years (Kember & Gow, 1991; Cheng, 2000), Asian students have been thought to be reticent and rely heavily on rote-learning. Would this make a difference to the results? International assessments on Mathematics and Science have consistently reported that Asian students outperformed their peers. This can be seen in the results of 2003 Programme for International Student Assessment and 2003 Trends in International Mathematics and Science Study. Could this be partly due to rote-learning?

On the other hand, studies have shown that Asian students do not fare as well when faced with relatively novel tasks that requires problem solving (Cai, 2000). Could this be partly due to rote-learning as well? Would Asian students respond well with the inquiry approach, which encourages open discussions, creative problem solving and a spirit of discovery?

Hence, this research project is initiated with the support of the school and the Singapore Ministry of Education. A Curriculum Planning and Development Officer from the Curriculum Planning and Development Division and a School Research Activist are also available for consultation with regards to pedagogy and statistical methodology respectively.

Research Questions

The general and specific research questions are as follows:

General Research Questions

1) How does the use of Physics-by-Inquiry affect the students' cognitive domain?
2) How does the use of Physics-by-Inquiry affect the students' affective domain?

Specific Research Questions

(a) How does the use of Physics-by-Inquiry affect the results of the Electrical concept test?
(b) How does the use of Physics-by-Inquiry affect the students' misconceptions in electrical circuits?

(c) How does the use of Physics-by-Inquiry affect the students' attitudes towards Physics?

(d) What are students' perspectives on the impact of Physics-by-Inquiry on their learning?

Literature Review

As mentioned earlier, advocating inquiry is not new. Efforts have been made as early as the 1930s to develop science curriculum that emphasises on inquiry as an approach to teaching and learning (Yager, 1977). Throughout the past few decades, ample research papers have also been published to advocate a shift from a process approach to an inquiry approach to learning (Deboer, 1991). In fact, there has been a dramatic increase in the number of research articles on inquiry-based learning in Science teaching in the past decade (Zhang, 2003). This shows the increasing importance of inquiry-based learning among educator researchers.

While there is an abundance of literature supporting the use of inquiry based learning in classrooms (Hofstein et al, 2005; Volkmann et al, 2003; Bianchini et al, 1999), there is a lack of related literature in the Asian context. Hence, there will be an emphasis on literature review in the Asian context in this assignment.

In Ng (2004), the Alice Heim AH4 General Ability Test (Heim, 1970) was used to study the effects of general ability and inquiry based learning on acquisition of scientific reasoning in Singapore. The Alice Heim AH4 General Ability Test consists of two parts. Part I comprises of 65 questions which have a verbal or numerical bias. Part II comprises of 65 questions which have a diagrammatic bias and which exemplify five types of principles: analogies, sames, subtractions, series and superimpositions. This test was last reviewed in the Seventh Mental Measurements Yearbook (1972) and was designed as a group test of general intelligence. Based on their scores, students are grouped into three levels of general ability.

While it is a thorough test, the number of questions given to students can be further cut down to ensure that all items are carefully read through and attempted. Students can be turned off by long questionnaires, and responses compiled in this manner might not be authentic. One possible way to reduce its length is to divide the survey into two questionnaires, each with a different focus. This approach was adopted by Zhang (2003) in his study of opportunities and challenges of China's inquiry-based education reform in secondary schools. In the study, the questionnaire (Pomeroy, 1993) was divided into two sections, each designed to take no more than 20 minutes to ensure the greatest level of participation (Zhang, 2003).

In this study by Ng (2004), it was found that students achieved higher scores in their scientific reasoning test after the inquiry-based lessons. In addition, this applied to students for all the three different levels of general ability, based on the Alice Heim AH4 General Ability Test. Although a small sample size of 38 was used, the results provided a good platform for continuing work in inquiry-based approach in Singapore.

In Zhang (2003), it was pointed that resources for inquiry-based learning are limited. Resources that are available in the market were primarily for test preparation under the traditional approach. He also observed that the larger society, in general, has not recognized the importance of inquiry-based learning.

In addition, it was observed that many teachers do recognize the value in inquiry-based approaches. However, many find it difficult to change the long-held tradition of teaching in the way that they have been taught. Furthermore, the assessment for university entry does not evaluate the results of inquiry-based approach. With these, it is difficult to justify a change in the teaching approach as schools are answerable to parents and society's expectations as well. This difficulty is also reflected in the Singapore education system (Ng, 2004). Fortunately, all these might change for the better in the near future. This is because the Singapore Ministry of Education is adjusting the assessment scheme for the General Certificate of Education (Ordinary Level), a major examination that the majority of secondary school students will take after their 4-year course in Singapore.

Starting in 2007, the Singapore Ministry of Education will introduce more critical thinking components in existing examinations. There will be a change in weighting of assessment objective "Knowledge with Understanding" from 60% to 55% and for "Handling Information and Solving Problems" from 40% to 45%. This implies a greater emphasis on application of concepts. In addition, there will be a compulsory data-based question, which involves interpreting, evaluating or solving problems using a stem of information. With such a move by the Singapore Ministry of Education, it is hoped that more student and parents will support and welcome the use of inquiry-based approach in classrooms.

In Zhang (2003), it was identified that a large class size is one of the major challenges to adopting inquiry-based learning. This observation was based on a study on secondary students in China, with a class size of 50. However, in Scherr (2003), it was observed that a large enrolment class at university level does not make a significant difference to the quality of inquiry-based learning. “Checkouts” in classes of 70 students were strikingly similar to small group “checkouts”. Although it is true that only students who spoke up had their issues addressed in big enrolment classes, it was observed that the conceptual issues raised were very similar to the classes of small enrolment.

This is an important consideration for Singapore where the general class size is 40. Government schools generally do not have the extra resources to engage an additional teacher assistant in the classroom.

Method

Strategy and Design

This study will be conducted at Crescent Girls’ School in Singapore. The participants are Secondary Two Express stream students, with an average age of 14. The students will be divided into four classes: two classes in the experimental inquiry-based learning group and the other two classes as control group. Two teachers will take one class each from the experimental inquiry-based learning group and the control group. Students in the experimental inquiry-based learning group will use the guided inquiry approach to understand & apply basic Physics concepts. Students in the control group will use the traditional learning approach.

An achievement pre-test will be administered to the four classes of Secondary Two students. To ensure that a standard diagnostic test is used, The Determining and Interpreting Resistive Electric Test Circuit Concepts Test (DIRECT) is adopted for this study. It is designed to evaluate the students' understanding of a variety of direct current resistive electric current circuit concepts. The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) will be used as it is more qualitative, and is more suitable for secondary school students with minimum prior knowledge on electric circuits.

In addition to using The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) to quantify the Science achievement scores of students, another standard diagnostic, the Colorado Learning Attitudes about Science Survey (CLASS), will be used to study and measure students' attitude about Physics.

In order to ensure that The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS) are equally applicable to secondary students in Singapore, the items were carefully reviewed and assessed. Items which are not included in the Singapore scheme of work were removed. Care was also taken to ensure that the questions were pitched at the correct academic level.

In addition, the test will be administered to a pilot group of 30 random students. Interviews with students taking The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS) will also be done to further ensure the clarity of instructions and questions given. Students will also be asked to verbalise some of their answers to the questions and why they have chosen that way.

At the end of a five-week intervention, the Secondary Two students will take the same The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS). Analysis will be performed to assess if there is any significant difference in the results after the intervention.

Attempts will be made to ensure that all conditions are similar for the experimental inquiry-based learning group and control group; this includes the academic and teaching background of teachers, classrooms used, number of periods of lessons, worksheets and homework given. However, as pointed out by Zhang (2003), one of the major challenges to the successful implementation of inquiry-based learning in China was the large enrolment in class. This is equivalent to a class size of approximately 50 students. The average class size in Singapore is 40 students. Although it has been pointed out by Scherr (2003) that large enrolment classes does not make a significant difference to the quality of inquiry-based learning in classrooms, it is crucial to note that these lessons are conducted at university level in the United States.

Firstly, students in this study are at a secondary level and might require more scaffolding in their newly given tasks. In addition, they might not be equipped with the necessary questioning techniques required to run through the new learning approach. Secondly, the research performed by Scherr (2003) was conducted in the United States where students are believed to be more out-spoken. In Singapore, there is a difference is schooling and cultural traditions which might lead to a difference in learning behaviour in classrooms.

Hence, it is with this consideration that a teacher assistant is attached to the experimental inquiry-based learning group. With a class of 40 students, this will cut down the teacher-student ratio to one teacher for every 20 students. This is the recommended teacher-student ratio in Physics-by-Inquiry (McDermott, 1996). This teacher assistant will facilitate the discussions in the classrooms and help in the management of off-task behaviour.

Sample and Sampling

The participants are 160 Secondary Two Express stream mixed-ability students from four separate classes, with an average age of 14. Each class has 40 students. There will be two classes each in the experimental inquiry-based learning group and the control group. The four classes are selected at random.

Data Collection

Quantitative instruments Over the years, many diagnostic tests have been developed to test students' understanding of Physics concepts. Some of these tests include the Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992) and the Test of Understanding Graphs in Kinematics (Beichner, 1994). Through these tests, many misconceptions have been discovered.

In recent years, many more standard diagnostic tests have been developed and one of them is The Determining and Interpreting Resistive Electric Test Circuit Concepts Test (DIRECT) designed to evaluate the students' understanding of a variety of direct current resistive circuit concepts. This test has been developed by Engelhardt and Beichner from the North Carolina State University (Engelhardt & Beichner, 2004). It has been designed for use with secondary school and university students. To test on the students' understanding of key circuit concepts, distractors such as misconceptions have been incorporated into the test items.

Though many tests on resistive electric circuits do exits (Cohen, Eylon, & Ganiel, 1983; Millar & King, 1993), they have been mostly developed as a research tool or curriculum assessment tool, not as a general assessment tool. The Determining and Interpreting Resistive Electric Test Circuit Concepts Test (DIRECT) (Engelhardt & Beichner, 2003), is developed as a tool for general assessment. It covers a wide content base and includes two to three questions for each assessment objective. This allows additional statistical studies in future.

The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) was administered to 1135 students from secondary school (N=454) and universities (N=681) across the United States. There are 29 multiple-choice test items and it takes half an hour to complete. The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1) was developed after an analysis of The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) results to improve its reliability and clarity of questions. The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1) was administered to 692 students from secondary school (N=251) and universities (N=441) in Canada, Germany and the United States.

One main critic of the paper was the significant difference in sample size (40%) for the test administration of The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1). In addition, while The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) was administrated solely in the United States, The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1) was administered in three countries, two in North America and one in Europe. Though the age of students taking the test might be similar, they might have undergone different curricula in schools, taught in different approaches or have different emphasis on Physics in schools. Hence, for a fair and just reliability and validity comparison between the two tests, sample size and target audience should be kept similar.

In summary, The Determining and Interpreting Resistive Electric Test Circuit Concepts Test (DIRECT) has been proven to be a reliable and valid test through a series of rigorous and thorough testing. Results indicate that either version could be used in evaluating curriculum or instructional methods as well as providing insights into students' conceptual understanding of direct circuits. Depending on the tester's area of interest, The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) or The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1) could be used. Since The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) is more qualitative, it can be used to elicit misconceptions more directly while The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.1 (DIRECT 1.1) can be used if students' mathematical abilities, together with Physics conceptual understanding, are of greater interest.

Apart from measuring the achievement scores in Physics, emphasis also has to be placed on measuring the affective domains of students. The department of Physics, from the University of Colorado, published a paper named "A new instrument for measuring student beliefs about physics and learning physics: the Colorado Learning Attitudes about

Science Survey" (Adams, Perkins, Podolefsky, Dubson, Finkelstein & Wiemen, 2004) to assess students' beliefs on Physics.

Since Fall 2003, the Colorado Learning Attitudes about Science Survey (CLASS) has been administered to over 4200 students in 35 Physics classes in the United States. A series of rigorous validation and reliability studies that involved several iterations to revise and refine the survey statements have been performed. Care has been taken to ensure the clarity of the statements and to keep the survey short such that the students can complete within 30 minutes.

There are many ways to analyse and apply Colorado Learning Attitudes about Science Survey (CLASS). Correlation studies can be performed with student learning, course selection, gender, age and many others. Shifts in beliefs over a semester can also be analysed to determine correlations between various teaching practices. It is highly suited for widespread use and serves as a valuable tool for research.

Qualitative instruments Follow-up interviews will be conducted after analysing the results for The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0). The interview is to allow a better understanding on the students' misconceptions towards the topic.

The top five questions from The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) that were incorrectly answered were extracted and analysed. It was found that the major misconceptions that the students have fall into three general categories of difficulties that Dr McDermott point out after years of extensive research in the area (McDermott, 1992). The three categories are: *an inability to apply formal concepts to an electric circuit*, *an inability to use and interpret formal representations of an electric circuit* and *an inability to reason qualitatively about the behaviour of an electric circuit*. These general categories are further divided into specific difficulties. Due to time and resource constraint, the follow-up interview will focused on eliciting major misconceptions for two of the categories; *an inability to apply formal concepts to an electric circuit* and *an inability to reason qualitatively about the behaviour of an electric circuit*.

A structured questionnaire is developed for this discussion based on the common misconceptions highlighted by Dr McDermott. This questionnaire is attached in the appendix. Purposive sampling will be used and eight students will be selected to verbalise their response. From each of the experimental and control group, the top two students who have achieved the most significant improvement in the Science achievement scores will be chosen. In addition, for maximum variation, two students from each of the two groups, who have achieved the lowest in the Science achievement scores will also be chosen. The discussions will filter prominent misconceptions that the weak students have and to find out if the academically strong students do indeed reason the correct way.

Since the purpose of the focus group is to elicit students' spontaneous conceptions and not to recall facts and knowledge from classroom lessons, students are encouraged to write down what comes to their mind instantly and verbalise their thoughts in words as they come up with the solution. They are told that the analysers would look through the workings in much more detail than the final answer.

Apart from follow-up interviews to elicit major misconceptions, focus group discussions are also in place to investigate the students' perception of inquiry-based learning as a new pedagogy tool.

The Colorado Learning Attitudes about Science Survey (CLASS) has focused primarily on the attitudes towards Physics as a subject, including their confidence, interest and problem solving skills. However, as the main teacher facilitator for this course, it was observed that some students exhibit intense emotions during the execution of the course. For example, some students will be bog down by frustration because they cannot get any direct answers from the teacher facilitator. Hence, it is hoped that a focus group discussion will capture some of the students' perception towards the inquiry-based learning, which is important for the study of this approach.

As highlighted in Punch (2005), well-facilitated group interaction can assist in bringing out aspects of a situation that might not surface previously. The discussions will be semi-structured. Students will be started off with a series of pre-determined questions and open-ended questions would follow where students are free to interact and respond.

The questions in the semi-structured interview are as follows:

1. Do you enjoy Physics-by-inquiry lessons?
2. What are some of the problems you encounter?

12 students from the experimental group will be included in this focus group discussion. These include 4 students who have improved the most in the Science achievement scores, 5 students with scores closest to the mean of the experimental group and 3 students who have achieved the lowest in the Science achievement scores. As the sample size is small, sampling is purposive rather than random and care is taken to include students for maximum variation. Semi-structured interview was used, leaving space for probing beyond the answers.

The aim of the focus group discussion is kept simple. It is to elicit common attitudes of the group towards the new Physics-by-inquiry approach and not to identify individual differences. In addition, we will find out if the attitude of the experimental group is common with a class undergoing Physics-by-inquiry in the United States, to find out if attitude towards the new approach is common across different cultures. This case study in the United States will be used as our frame of reference.

Procedures

Both The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS) will be used as pre-tests for the four randomly selected classes of Secondary Two students. This is to test their prior knowledge of direct current electric circuits and beliefs about Physics before the start of the lessons.

In the next phase of the experiment, the two groups will begin with a five-week programme on the topic of Electricity. Different curriculum packages will be developed for the two groups by the teachers with the advice of the Curriculum Planning and Development Consultant. All students in the same group will be taught using the same curriculum design.

A typical Physics-by-Inquiry lesson will start with a simple test to surface any prior misconceptions. This also sets the context for the class and helps the students to focus on key ideas on look out for during the lesson. The students then worked in groups of four on carefully structured worksheets, adapted from Physics-by-Inquiry (McDermott, 1996). With teachers acting as facilitators, students are expected to come up with their own models and conclusions at each "checkouts" as described earlier. They are encouraged to clarify their doubts within their group and explain to one another how they arrive at their own predictions.

Both The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS) are administered on the last day of the programme on the same groups of students to study if there has been any quantitative change in Science achievement scores and attitudes in Physics after the five-week programme. This will be followed by a follow-up interview with students to elicit common circuit misconceptions and a focus group discussion to bring out important perceptions towards the inquiry-based learning approach.

Data Analysis

Quantitative data analysis Analysis of covariance (ANCOVA) is used in the analysis of the results. The independent variable is the method of instruction and the dependent variables is the student achievement and attitudes towards Physics. In this method, the post-test mean of the experimental group is compared with the post-test mean of the control group with the pre-test mean used as a covariate. The level of confidence will be set at 0.05. ANCOVA adjusts the post-test achievement scores based on the pre-test scores and in turn increases the internal validity. Only students who took both pre-test and post-test surveys are included in the analysis of data. This is to ensure that any calculated change measures the actual shift in achievement scores or attitude rather than a difference in student population.

Separate ANCOVA analyses were run for both The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) and Colorado Learning Attitudes about Science Survey (CLASS) on the standard statistical software, Statistical Package for Social Sciences (SPSS).

Analysis was performed to determine the following:

(a) Is there any significant difference in the post-test results of The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0) between the experimental and control group?

(b) Is there any significant difference in the post-test results of the Colorado Learning Attitudes about Science Survey (CLASS) between the experimental and control group?

For the analysis for the Colorado Learning Attitudes about Science Survey (CLASS), separate ANCOVAs were performed for each for the different dimensions.

(a) Real world connections

(b) Personal interest

(c) Sense making and effort

(d) Conceptual connection

(e) Applied conceptual understanding

(f) Problem solving general

(g) Problem solving confidence

(h) Problem solving sophistication

Qualitative data analysis To begin this analysis, a general analytical strategy has to be decided and adopted. In this project, *relying on theoretical proposition* is used, where findings are compared with a frame of reference for similarities (Yin, 2004). Within-case analysis is used in this study, with Miles and Huberman framework (Miles & Huberman, 1994) as the analysis technique.

The frame of reference chosen is a study on undergraduate students' perception of an Inquiry-based Physics course in Northwestern Ohio, United States (Duran, McArthur & Van Hook, 2004).

The laboratory-based Physics-by-inquiry modules have been originally designed for the Physics and Physical Science pre-service teachers. However, they have also been used with other student population with great success (McDermott, 1992). In this study, the perception of undergraduate pre-service teachers is chosen as the frame of reference as they are the original target audience of the newly designed modules. The modules in this study have been altered to match the cognitive ability of Secondary school students. It would be interesting to match the response of 14 year-old students and undergraduates to see if similar perceptions surface.

Four major themes were pointed out in the findings for the frame of reference. They are:

1. Personal Conflict in a Constructivist Atmosphere
2. Appreciate for Inquiry-Based Methodology
3. Workload Perceptions
4. Need for Relevant General Education Science Courses

The fourth theme, *Need for Relevant General Education Science Courses,* which refers to the need of courses to enable the pre-service teachers to teach Science concepts to students in schools is not applicable in this study.

Using the Miles and Huberman framework, data in the form of words will be analysed with three concurrent flows of activities, namely: (1) Data reduction, (2) data display, and (3) conclusion drawing/verification.

Data reduction, as the name suggests, refers to the reduction in data that helps to sort, focus, discard and organise the data. Miles and Huberman (1994) stated that data can be reduced and transformed through means such as summary, paraphrasing or through being subsumed in larger patterns. Data display is a concurrent event where reduced data is displayed and organised compressed manner such that conclusions can be reached easily and systematically. In the conclusion drawing/verification, coherent initial meaning is drawn from a display that involves noting regularities, looking at contrasts, clarifying relationships, possible configurations, causal flows, and propositions. It was emphasised that these data reduction and data display should not be separate from analysis but should be part of it.

In qualitative analysis, key elements in the data are called *themes* (Ayres, Kavanaugh & Knafl, 2003). There are many ways to define themes; it can be entered before the analysis is developed or during the study (Patton, 2002). Themes might apply to all members of the group or only to specific individuals, depending on the data and the approach used.

Since the purpose of the focus group is to elicit common attitudes of the experimental group towards the new approach, the interview transcripts were carefully analysed and significant statements that forms the primary focus of a respondent’s input are highlighted. The aim of this process is to draw out important and crucial experience for each individual. Following this, similarities around *themes* are identified across individual students in experimental group. Pattern matching, or pattern coding, is then used to compare an empirically-based pattern with the frame of reference. This lays the groundwork for within-case analysis. A table summarising the analysis strategy for this focus group is given below.

Comparison	Purpose	Strategy	Product
Within individual students in experimental group	Identify important aspects of the experience	Extraction of individual interview	Coding category, themes
Across individual students in experimental group	Identify similarities around themes	Data coding and display	Subthemes
Within experimental group in this project	Identify configurations of themes within group	Close reading of individual interview and summary	Reorganise themes based on within group discrepancy
Across experimental group in other projects (frame of reference)	Compare configurations of themes across groups	Relational database display, interviews and summaries	Refined comparison and summary

Results and Discussion

Effects on Cognitive Domain

Quantitative results The Science achievement scores were determined using *The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0).* Table 1 shows the ANOVA results on the post-test after offsetting the effect of their performance in the pre-test, $F(1, 129) = 8.034$, $p < .005$.

Table 1
Analysis of Covariance Results for DIRECT

	N	Adjusted Mean (Std. Error)	df	Mean Square	F	Sig
Control	63	44.56 (16.06)				
Experimental	69	51.64 (11.40)				
DIRECT Posttest	132		1	1478.70	8.034	<.005

Qualitative Results The examples below show the major misconceptions or missing concepts that were identified in the follow-up interviews. Since it is not likely to compile an exhaustive list of misconceptions that surfaced during the interview, only the key misconception is highlighted. It is hoped that these key misconceptions will be emphasised and clarified in more detail during the delivery of Physics-by-inquiry to the next batch of students.

A) General Category: An inability to apply formal concepts to electric circuits.

Specific Difficulty: Difficulties with concepts related to electric current;

- belief that current is “used up” in a circuit.

Students are asked to rank the relative brightness of the 4 identical bulbs (A, B, C and D) in the following diagram.

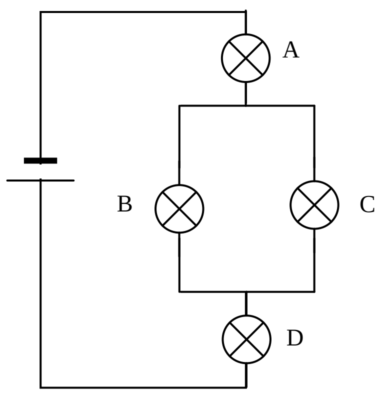
<table>
<tr>
<td>


Figure 1
</td>
<td>
Typical Response:

<u>Response 1:</u>
A=D>B=C

I figured that light bulbs A and D would be equally bright because whatever current that will flow through A will also flow through D to return to the batteries.

However, light bulbs B and C would have lesser current running through them because the wire splits into two, so the current is also halved.

<u>Response 2:</u>

At bulb A, the electric current is completely flowing through. However after the electric current passes through bulb A, it came to a point where the electric current is split equally into two, then each passing through Bulb B and Bulb C respectively. After that, the electric current came back together into one electric current and then passing through bulb D.

Hence, my answer is:

A=D > B=C.
</td>
</tr>
</table>

Five out of eight students answered this question correctly. They were able to use words like “split” and “come together again” to describe the correct behaviour of the current flowing through. For the three students who did not give the correct answer, they reflected deep rooted conception that the current at bulb D is lesser than the current at bulb A, since the current has been "used up by the wires" as they flow through.

B) General Category: An inability to apply formal concepts to electric circuits.

Specific Difficulty: Difficulties with concepts related to potential difference;

- failure to distinguish between branches connected in parallel.
- failure to distinguish between potential and potential difference.

Specific Difficulty: Difficulties with concepts related to electric current;

- belief that battery is a constant current source.

Students were asked to relative brightness of the 5 identical bulbs (A, B, C, D and E) in the setup as shown below.

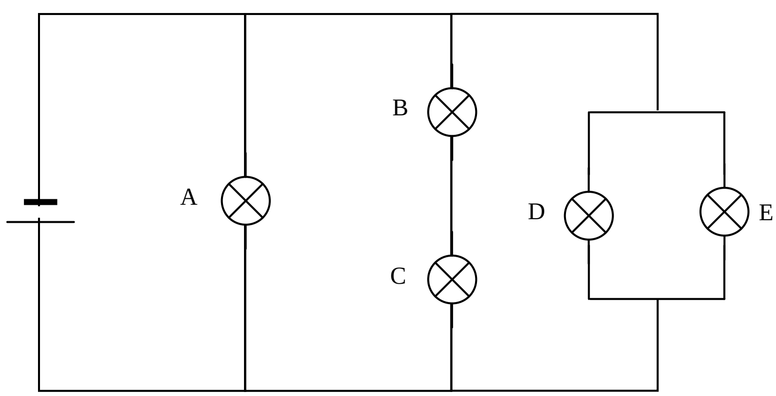


Figure 2

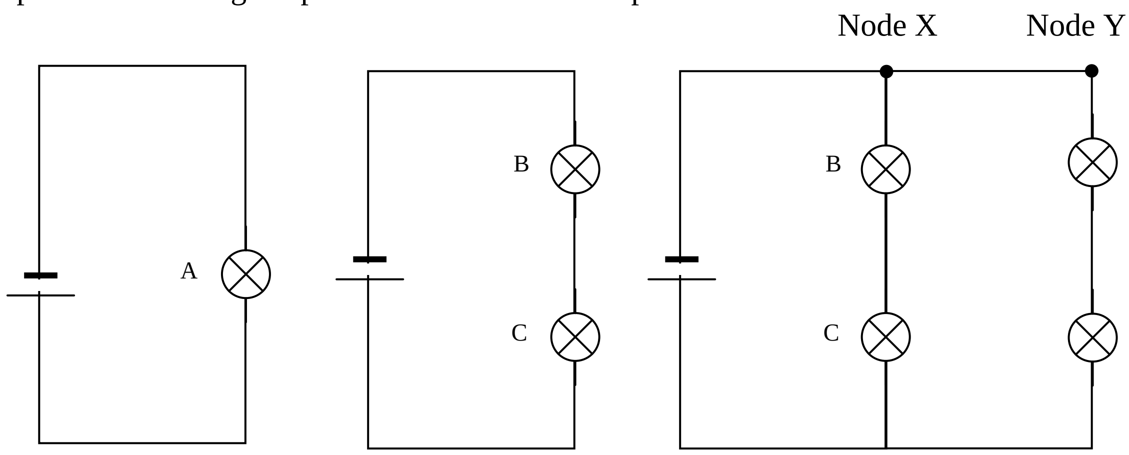
<u>Response 1:</u>

A=B=C>D=E
For A, B and C, the current doesn't split so they are the same but the current splits for D and E so they are less bright.

<u>Response 2:</u>

A>D=E>B=C
Bulbs B and C are not very bright because they are on the same piece of wire, one after the other. I think that bulbs D and E would be brighter because of the way they are arranged, parallel to each other.

This proved to be the hardest of all the questions and none of the students answered this correctly. It was observed that students do not recognise that the setup in figure 2 is made up of the following simpler circuits connected in parallel.



When students are asked on the current flowing through bulb A and bulb B, many do not realised that the current through bulb B is lower. They held on to the notion that current from the same battery should be the same, regardless of what is connected to it. Some strong students, however, do not have difficulty with this concept.

They also do not fully understand the concept of parallel circuits as by typical statements by students, “For A, B and C, the current doesn’t split so they are the same but the current splits for D and E so they are less bright.”

Common misconceptions involving potential and potential difference were also surfaced. Students typically reflected, upon probing, that node X and node Y are at different potential since “node Y are further away from the battery”. They also made typical statements like “potential at B and potential at C are the same, hence both bulbs should carry the same current.” Such statements reflect the confusion between potential and potential difference. Hence, much has to be done to build up concepts of parallel circuits and to distinguish the difference between potential and potential difference.

C) General Category: An inability to apply formal concepts to electric circuits.

Specific Difficulty: Difficulties with concepts related to resistance;

- tendency to focus on number of elements or branches.
- failure to distinguish between the equivalent resistance of a network and the resistance of an individual element.

General Category: An inability to reason qualitatively about the behaviour of electric circuits.

Specific Difficulty: Lack of a conceptual model for predicting and explaining the behaviour of simple dc circuits.

$R_A = R_B = R_C = R_D = R_E = 6$ ohms

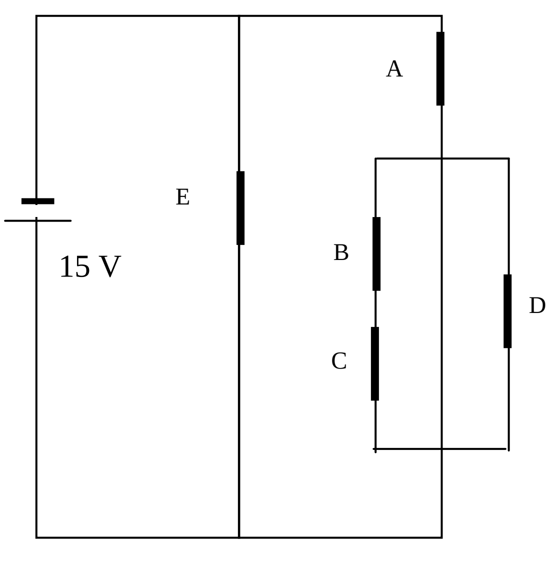


Figure 3

<u>Response 1:</u>
$1/R = 1/12 + 1/6$
$= 1/4$
Total resistance of R_B, R_C and R_D
= 4 ohms
Total resistance of R_A, R_B, R_C and R_D
= 4 + 6 = 10 ohms

$1/R = 1/6 + 1/10$
$= 4/15$
Total resistance in the circuit
= 3.75 ohms

I, current that flows in the circuit
= V/R
= 15/3.75
= 4 A
Current through R_A, R_B, R_C and R_D = 2 A (incorrect!)
Since they are arranged in series, current through resistor A = 2 A

Students are asked to calculate the current flowing through Resistor A, assuming that the battery is ideal. They are told to use the values of the battery and resistance shown in the figure 3.

Students have generally no problems calculating the total resistance of Resistor A, B, C and D, which is 10Ω. However, a lot of misconceptions were uncovered as they moved on to solve the rest of the problem. One student, after calculating the total resistance of the whole circuit, concluded that the current through resistor A must be the same as resistor E since they are in parallel connection. This is incorrect. This is a failure to distinguish between the equivalent resistance of a network and the resistance of an individual element. Another student went on to conclude that the current through resistor A and resistor E should be the same as they have the same resistance. This is incorrect as well since she has ignored the adjacent resistors connected to resistor A. This is the tendency to focus on number of elements or branches. Students often focus on the number of circuit elements rather than on the configuration. They reasoned that if two identical resistors are connected in a circuit with a battery, the results would be the same regardless of their electrical connection, which is incorrect (McDermott, 1992).

Discussion One of the main motivations of this major paper is to find out if the positive impact of inquiry-based learning in the Western context is echoed in the Asian schools as well. Based on the post-test results of The Determining and Interpreting Resistive Electric Test Circuit Concepts Test (DIRECT), there is an adjusted post-test mean of

51.6% for the experimental group and 44.6% for the control group, with a significant difference in the results for both groups with $p < 0.005$.

This result has been encouraging as it has replicated the success of Physics-by-inquiry in the Asian countries. Asian students are often thought to be reticent and reserved (Chang & Mao, 1999). Hence, it was feared in the initial stages of this project that Physics-by-inquiry, which requires students to openly discuss their thoughts and mental models, might not work in Singapore. However, the results have shown otherwise. In fact, as a teacher in the Physics-by-Inquiry class, I observed that students are able to speak up when they are given the opportunity to do so. They can articulate their thoughts and clarify their doubts confidently. Although the students do not speak up often in classroom settings, I observed that they are able to challenge their group mates on their understanding and mental models in small group discussions. In addition, the more academically inclined students would often act as the “teacher” of the group, explicitly addressing the different views of the groups. Students are observed to enjoy this form of peer teaching.

Another step in the study is to examine if the misconceptions of the students are similar across students of different cultures. The follow-up interviews of specially selected students from both the experimental and control group show that misconceptions or missing conceptions are alike; they fall into the three general categories pointed out by Dr McDermott (1992) during her research.

A comparison was done on the relative ability of the top four students in the experimental and control group. In this aspect, the students in both groups perform equally well in solving quantitative circuit problems. However, the students from the experimental group were better in analysing circuits qualitatively. Studies have shown that the ability to solve a circuit problem quantitatively does not imply a corresponding level of qualitative understanding (McDermott, 1992). Many were able to do so by seeing concepts of current, potential difference and resistance as variables in an equation. To solve complex situations requiring only qualitative analyse, many fail to integrate concepts and apply appropriately. Hence, both the Science achievement scores and follow-up interviews have shown the Physics-by-inquiry approach to be more effective in problem solving of electrical circuits. This is despite the fact that more time is needed in the Physics-by-inquiry approach, thus leaving lesser time for problem solving questions in class. Therefore, this is a truly encouraging result.

Dr McDermott (1992), stated that an emphasis on conceptual development does not adversely affect, and may even improve quantitative problem solving. This is also true of this study in Singapore. The only two students who answered the third question, a quantitative problem, correctly are both from the experimental group. This is truly encouraging, as these students do not see formulas as blind application of numbers into the equation. They could see a relationship between the variables in the problem and realised that it is not a simple one-to-one relationship between them.

Comparison of the response from the weaker students in the class showed that the new approach did not make any significant difference in their quantitative and qualitative understanding of electrical circuits. The focus group discussions, however, did elicit some serious misconceptions as highlighted in previous section. This would definitely be useful for the revised curriculum development. Stronger emphasis can be placed on these misconceptions for the next cycle.

Effects on Affective Domain

Quantitative results The scores for attitude towards Physics were determined using The Colorado Learning Attitudes about Science Survey (CLASS). Out of the eight dimensions in the survey, three showed a significant difference in the adjusted post-test between the experimental and control group. The three dimensions are: Problem Solving Confidence, $F(1, 117) = 5.26$, $p < .05$; Problem Solving Sophistication, $F(1, 117) = 4.38$, $p < .05$; SenseMaking effort, $F(1, 117) = 6.39$, $p < .05$.

In addition, an additional variable that measures the affect of All Categories also showed a significant difference in the results. Table 2 shows the results for these categories.

Table 2
Analysis of Covariance Results for CLASS

(a) **All Categories**

Source	N	Adjusted Mean (Std. Error)	Df	Mean Square	F	Sig
Control	55	42.27 (2.38)				
Experimental	63	50.64 (2.22)				
All Cat	118		1	2047.53	6.62	< .05

(b) **Personal Interest**

Source	N	Adjusted Mean (Std. Error)	Df	Mean Square	F	Sig
Control	57	44.17 (3.42)				
Experimental	63	50.46 (3.25)				
Personal Interest	120		1	1185.18	1.78	ns

(c) **Real World Connections**

Source	N	Adjusted Mean (Std. Error)	df	Mean Square	F	Sig
Control	56	43.32 (4.46)				
Experimental	63	50.25 (4.20)				
Real World Connections	119		1	1424.12	1.28	ns

(d) **Problem Solving General**

Source	N	Adjusted Mean (Std. Error)	df	Mean Square	F	Sig
Control	57	47.68 (3.30)				
Experimental	63	62.33 (3.13)				
Problem Solving (G)	120		1	6348.86	10.32	< .01

(e) **Problem Solving Confidence**

Source	N	Adjusted Mean (Std. Error)	df	Mean Square	F	Sig
Control	57	53.80 (4.07)				
Experimental	63	66.67 (3.87)				
Problem Solving (C)	120		1	4953.39	5.26	< .05

(f) **Problem Solving Sophistication**

Source	N	Adjusted Mean (Std. Error)	df	Mean Square	F	Sig
Control	57	32.97 (3.30)				
Experimental	63	42.50 (3.14)				
Problem Solving (S)	120		1	2721.64	4.38	< .05

(g) **Sense Making Effort**

Source	N	Adjusted Mean (Std. Error)	Df	Mean Square	F	Sig
Control	57	54.49 (3.21)				
Experimental	63	65.78 (3.06)				
Sense Making	120		1	3724.98	6.39	< .05

(h) **Conceptual Understanding**

Source	N	Adjusted Mean (Std. Error)	Df	Mean Square	F	Sig
Control	56	30.90 (3.45)				
Experimental	63	38.14 (3.25)				
Conceptual Understanding	119		1	1547.98	2.33	ns

(i) **Applied Conceptual Understanding**

Source	N	Adjusted Mean (Std. Error)	Df	Mean Square	F	Sig
Control	56	24.35 (2.64)				
Experimental	63	31.31 (2.49)				
Applied Conceptual Understanding	119		1	1434.84	3.67	ns

From Table 2, it can be seen that students from the experimental group scored consistently higher in all dimensions than those in the control group. However, only 3 dimensions are significantly different.

The first dimension is “Problem Solving Confidence”. Typical items in this category are:

15. If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works.

16. Nearly everyone is capable of understanding physics if they work at it.

34. I can usually figure out a way to solve physics problems.

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

The second dimension is “Problem Solving Sophistication”, which is closely related. In fact, some of the items are banded in both “Problem Solving Confidence” and “Problem Solving Sophistication”. Items in this category include:

5. After I study a topic in physics and feel that I understand it, I have difficulty solving problems on the same topic.

21. If I don't remember a particular equation needed to solve a problem on an exam, there's nothing much I can do (legally!) to come up with it.

22. If I want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations.

25. I enjoy solving physics problems.

34. I can usually figure out a way to solve physics problems.

40. If I get stuck on a physics problem, there is no chance I'll figure it out on my own.

The third dimension is “Sense Making/Effort”. Typical items are:

11. I am not satisfied until I understand why something works the way it does.

24. In physics, it is important for me to make sense out of formulas before I can use them correctly.

39. When I solve a physics problem, I explicitly think about which physics ideas apply to the problem.

42. When studying physics, I relate the important information to what I already know rather than just memorizing it the way it is presented.

Qualitative results The table below shows the significant statements that were extracted from each individual for the focus group discussions to elicit perceptions towards the inquiry approach.

Students	Significant Statements	Themes	Sub-themes
A1$^+$	Enjoy project work but not enough time to try practice questions.	Personal conflict in constructivist atmosphere	Frustration
		Workload perceptions	NA
	Finds the summary at the end of lesson useful.	Personal conflict in constructivist atmosphere	Prefers some traditional lecturing
A2$^+$	Teachers do not give answers, just roundabout way which adds to frustration and confusion. At the end, can deepen understanding of concept though.	Personal conflict in constructivist atmosphere	Frustration
A3$^+$	Enjoys the new approach, something new.	Appreciation for Inquiry-based methodology	NA
	Stressful, as there is extra workload of understanding on your own, in addition to trying out textbook questions.	Workload perceptions	NA
A4$^+$	Teachers doing checkout should be clear on what the question is targeting at.	Frustration	NA
	Prefers to be given answers instead of exploring on her own.	Frustration	NA
B1*	Transition from tradition note-taking classroom to Physics-by-inquiry frustrating, as she had to think of her own explanations.	Personal conflict in constructivist atmosphere	Frustration

	At the end, realise the new approach is helpful for understanding.		
		Frustration	NA
B2*	Too rushed, too much time needed to come up with models	Workload perceptions	NA
	Beneficial, but more traditional lessons can be sandwiched in between	Personal conflict in constructivist atmosphere	Prefers some traditional lecturing
B3*	Likes hands-on experience, but some traditional lecturing is still needed to understand what she is doing	Appreciation for Inquiry-based methodology	NA
		Personal conflict in constructivist atmosphere	Prefers some traditional lecturing
B4*	It is helpful but can be time-consuming and tiring to come up with models and explanation on your own every time	Personal conflict in constructivist atmosphere	Frustration
B5*	Prefers to be given formula, but admits that she can remember better this way	Personal conflict in constructivist atmosphere	Frustration
C1#	Too much work, very tiring and prefers to sit and receive information	Frustration	NA
C2#	Very confusing, cannot come up with models on her own, depends on teammates	Frustration	NA
C3#	Very fun, likes project work and hands-on experience	Appreciation for Inquiry-based methodology	NA

+ = students in experimental group who have improved the most in the Science achievement scores

* = students in experimental group with scores closest to the mean of the experimental group

= students in experimental group who have achieved the lowest in the Science achievement scores

The individual responses were coded and the data were sorted to track themes across the cases. The following summary table is generated after making comparison and noting patterns with the frame of reference.

	Themes				
Student	Personal conflict in constructivist atmosphere		Appreciation for Inquiry-based methodology	Frustration	Workload perceptions
	Beneficial, but frustrating	Beneficial but prefers some traditional lecturing			
A1[+]	+	+			+
A2[+]	+				
A3[+]			+		+
A4[+]				++	
B1[*]	+			+	
B2[*]		+			+
B3[*]		+	+		
B4[*]	+				
B5[*]	+				
C1[#]				+	
C2[#]				+	
C3[#]			+		
Frame of reference	*		*		*

+ = Number of significant statements that belong to assigned theme

* = Themes that were evident in frame of reference

Discussion From the post-test results of The Colorado Learning Attitudes about Science Survey (CLASS), there has been an increased in problem solving confidence, problem solving sophistication and sense-making effort.

This is not surprising as the Physics-by-inquiry approach emphasises on the use of simple mental models that takes on increasing complexity as the lessons progressed. With Socratic learning, where the teacher facilitator and the students engaged in active dialogue, students discover principles by themselves. By going through rounds of problem solving and self-inquiry in class, students are more equipped with necessary exposure and skills to make sense of what is happening around them. This might, in some ways, contribute to the increased in “Sense Making/Effort” dimension.

In Physics-by-inquiry, the learner constructs hypotheses, makes decisions, selects and organizes given information. This cognitive experience allows the learner to go beyond blind application of formulas to given situations. They understand that there are alternative approaches to a given problem and application of formulas is just one of the many approaches. Through logical reasoning, the same conclusion can also be reached without the use of formulas. This increases their level of problem solving confidence and problem solving sophistication.

Furthermore, an additional variable that measures the effect of all categories also showed a significant difference in the results. This shows that the inquiry approach has improved the students’ attitude towards Physics as a subject in general. This is truly encouraging.

Apart from investigating the change in attitude towards the Physics subject, there is also an interest on students' perception towards the inquiry approach as a new pedagogy.

Within-case analysis was employed for the examination of the focus group discussion. In this study, data from the focus group interview was compared with a study on undergraduate students' perception of an Inquiry-based Physics course (Duran, McArthur & Van Hook, 2004).

Four major themes were pointed out in the findings for the frame of reference. They are:

1. Personal Conflict in a Constructivist Atmosphere
2. Appreciate for Inquiry-Based Methodology
3. Workload Perceptions
4. Need for Relevant General Education Science Courses

The fourth theme, *Need for Relevant General Education Science Courses*, was removed as it was not applicable.

Through the analysis of the focus group interview, it was observed that there was a pronounced theme, *Frustration*, from the data. This theme was a subset under *Personal Conflict In Constructivist Atmosphere* in the frame of reference. However, in this study on the perceptions of secondary school students, the key statements eliciting the theme were prominent and distinct. Hence, it was added as a main theme in this study. The four revised major themes are:

1. Frustration
2. Personal Conflict in a Constructivist Atmosphere
3. Appreciate for Inquiry-Based Methodology
4. Workload Perceptions

Theme 1: Frustration

One of the major theme that was elicited was “Frustration”, either as a sub-theme “Beneficial, but frustrating” under “Personal conflict in constructivist atmosphere” or under the main theme “Frustration”. Most of them were used to traditional note-taking lectures, where answers and formulas were given to them. A transition to the inquiry approach proved annoying to many of them, as they have to put on their thinking caps and conceptualise models on their own. Students feel they were left to fend for themselves and teachers were not telling the answers; they advised by asking more questions, which makes the whole situation even more confusing.

This type of frustration with the new approach should not be a surprise to educators engaged in science education reform. There are many studies that have shown students’ frustration with new inquiry-based pedagogy (Duran, McArthur & Van Hook, 2004, Hartland, 2006). In fact, a certain level of discomfort is inevitable and sometimes desirable to shake students from their passive learning styles. (Apedoe, Walker & Reeves, 2006).

Theme 2: Appreciation for Inquiry-based methodology

Although many find the new approach uncomfortable, there were some who appreciate the constructivist methods that allowed them to investigate topics in depth and develop greater conceptual understanding. Others found the hands-on nature of inquiry-based learning appealing as it provides them with a concrete start to their understanding.

Theme 3: Personal conflict in constructivist atmosphere

Students who were used to passive learning environments may show the most resistance to the inquiry-based approach. Inquiry-based learning requires students to take charge of their own learning, build up their own models and collaborate with others to complete authentic tasks. They have to get used to a different teacher-student interaction where answers are not provided directly. When the rules of interaction change, students may become resistant. Resistance to this approach may be especially strong for students who have excel with high achievement scores within the traditional teacher-centered approach (Apedoe, Walker & Reeves, 2006). However, many students do reveal their appreciation for the different learning experience at the end of the course and many admit that it was the challenging and stimulating nature that makes it so enjoyable.

Indeed, this personal conflict towards inquiry-based pedagogy is not uncommon. In the study by Duran (2004), the undergraduates' response to the new approach proved equally frustrating. They were impatient and anxious during the development of the Physics concepts and wanted the instructors to give them answers rather than spend time constructing their own models. They were only able to appreciate the new active learning experiences and embrace the new approach at the end of the course. It is interesting to note that the perceptions are not only common cross-culturally, but at different educational levels as well. Both secondary and undergraduate students had to deal with the emotional hurdle before embracing the new pedagogy.

Theme 4: Workload perceptions

Many of the students find it tiring to go through the five-week intervention, with little traditional lecturing along the way. They feel that traditional "drill and practice" sessions are still necessary for high achievement scores and they are losing out to the traditional classes that have more free time for practice questions compared to them. Apart from figuring the mental models on their own, they need to spend additional time on standard workbook questions which might not be inquiry-based. Furthermore, most of the items in tests and examinations are not inquiry-based, reducing the motivation for students to embrace the new learning pedagogy.

Hence, the perceptions of secondary and undergraduate pre-service teachers towards the new inquiry-based pedagogy are similar in many ways. This is so despite their cultural and cognitive difference. Secondary school students are observed to be more easily frustrated. This might be due to their inability to work through emotional hurdles, as they are not used to being challenged. They might not be able to see the end in mind, and appreciate the meaning of inquiry-based learning.

Limitations and Delimitations

In Physics-by-Inquiry, students learn a few topics deeply (McDermott, 1996). It is designed for students to develop a deep understanding of the topics rather than cover a large number of topics superficially. In the Singapore education system, where an overwhelming scheme of work has to be fulfilled each semester, this poses a great challenge to the teachers.

In addition, students adopting the Physics-by-Inquiry approach require more time to fulfil an instructional objective. This is because the traditional method uses the didactic approach, where the students learn by “listening” and teachers teach by “telling”. Students using the Physics-by-Inquiry approach need time to construct a hypothesis, question their observation and reason out their own conclusion, with the aid of the teachers. Hence, the approach would naturally require more time than the traditional method. In view of this, not all the lessons in the experiment group are conducted using the inquiry approach. Some direct teaching would have to be included in order to complete the scheme of work on time.

Lastly, this study is conducted in a school in the Express stream. Hence, it does not represent the general school population in Singapore as they are many other students in the Special, Normal (Academic) and Normal (Technical) stream as well.

In addition, it is noted that students’ usually learn in the way that they will be assessed (citation). Although there is a change to introduce more critical thinking components in examinations from 2007, the mode of assessment still requires a high level of rote-learning and drill-and-practise for the learner. It would be easier to engage the students if assessments adopt the same approach.

Students are divided into groups of four. This is a comfortable size as the class is now divided into ten groups, where each teacher goes round five groups for “checkouts”. With four members in a group, each student is also given ample opportunities to clarify their doubts and participate in active discussions. However, as a teacher, I have observed that some academically inclined students tend to dominate the discussions while the weaker students listen passively, occasionally jotting down notes. The teacher needs to elicit response from these students, to ensure that they participate and learn as well.

Physics-by-Inquiry is a set of instructional modules that have been specially designed for pre-service Physics teachers, but have been used successfully with student from high school levels as well (McDermott & Shaffer, 1992). However, there is a need to improve the instrument used to measure the students’ achievement scores. The instrument used in this small scale project is The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0). It was administered to 1135 students from secondary school (N=454) and universities (N=681) across the United States. The average difficulty index for university and high school is 0.49. A value of 0.49 indicates that for every 1 student, 0.49 student in the sample will chose the correct response. An ideal value for the average difficulty index ranges from 0.40 to 0.60.

However, university students tend to do much better than the secondary school students. This can be elicited from the university mean of 52%$\pm$0.56% and secondary school mean of 41%$\pm$0.65%, with a standard error of the mean of 0.45. The overall mean was 48%$\pm$0.45%, with an ideal value of 50% for maximum spread of scores. With this difficulty level for The Determining and Interpreting Resistive Electric Test Circuit Concepts Test 1.0 (DIRECT 1.0), especially for secondary school students, it is worrying that the students might feel demoralised after attempting the first few sets of test items, and subsequently completing the test without truly attempting the items. This would invariably contaminate the results of the test.

Although deliberate attempts have been made to remove higher order thinking questions in this small scale school project, the adjusted mean is still low. The mean is 44.56% for control group and 51.64% for the experimental group. Hence, it might be worthwhile to construct two different tests for secondary school and university levels.

Conclusion

(To be continued)

Consent, access and human participant's protection

Before the start of the programme, students involved will be notify the objective of this study. They would be informed that their responses will be kept strictly confidential and the student's choice to withdraw from the programme will be respected. (to elaborate)

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