Investigative work in school science: A comparative study of student performance in open and closed investigations.

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One of the aims of science education is to enable students to obtain an appreciation of the process of knowledge development through experience and understanding. This led to the initial introduction of practical work in the school curriculum. Over the years, the aims of practical work in promoting the process of science have been neglected. Practical work in school science has changed to the concentration on development of manual skills and techniques of measurement, and on the use of equipment. It is also being used as an alternative to the daily mundane rigours of classroom theoretical work. Investigative work in science is being encouraged as an alternative to provide opportunities for pupils to use conceptual knowledge and skills, and to obtain an understanding of the processes of science.

Practical work was introduced into the science curriculum during the mid nineteenth century (DeBoer, 1991). In its early stage practical work was limited to demonstrations. The lecture demonstration method was then widely used to teach science. This is still popularly used in large lecture groups. By 1902, it was generally accepted that school science should be based on laboratory work. Though the "laboratory approach" was the favored pedagogy of educational theorists, there were disagreements about the variety of ways that the laboratory work could be structured and used. There are various types of practical work carried out in school laboratories. Investigations are generally classified as a type of practical work. The Oxford English Dictionary defines investigations as a making of a search or inquiry; a systematic examination; careful and minute research. From this it can be gathered that investigative work involves examining systematically and in detail. Gott and Duggan (1995) mention investigative work as providing opportunities for pupils to use concepts, cognitive processes and skills to solve a problem. Woolnough (1994) classifies investigative work as consisting of hypothesis testing to reinforce theoretical understanding and problem solving to enable students to learn the ways of working as a problem-solving scientist.

Investigative work is a compulsory component in the school science curriculum in practically most countries. The tasks which constitute investigative work differ a great deal, ranging from closed and highly structured experiments termed practicals to open and somewhat exploratory oriented investigations. Whatever the form of the investigative work, the global aims of including it in the curriculum are common to a large extent. Apart from complementing theoretical class instruction in science, the essential aim being to teach the processes of science. These processes include skills such as planning, asking suitable questions, making measurements and observations, recording, predicting through the use of evidence, interpreting, analysing, providing explanations, drawing conclusions, and inferring relationships. These skills can be encompassed within the four major
categories of formulation, implementation, evidence and explanation (Dhillon, 1996). Formulation includes identification of the problem, refinement of it for study through the writing of an appropriate hypothesis for study, prediction of the outcome of the hypothesis informed through related conceptual knowledge, and planning of the study. Implementation entails the actual performance of the investigation and collection of data. This includes such skills as observing, making measurements and recording. Evidence involves analysing and interpreting the data to infer relationships and drawing conclusions. Explanation entails providing the link between theory and the findings or evidence. It should help to clarify the findings in the wider scientific knowledge by building on what is known and that which is found.

Principally, investigations are characterised by their lack of instructions to the student. Wellington (1994) classifies investigative work on a continuum of dimensions ranging from closed to open, directed and structured to undirected and unstructured, and pupil led to teacher led. A closed investigation involves a specific path for conducting the investigation while an open investigation involves many possible solutions with many routes. The directed and structured investigation provides guidance to the students at all stages. The steps of the investigation are specified and there is little if any leeway for the students to deviate or to use their initiative. The undirected and unstructured end of the continuum provides minimal guidance without procedural constraints. In the totally pupil led investigation the pupils ask questions and no restrictions are imposed on the students. In the teacher led investigation the question or problem is posed by the teacher. An open investigation is contrasted with a closed investigation by the degree of variation that it is possible to generate within the problem. The wording of the question used to generate the investigation is responsible for the degree of freedom given to the students with respect to how they handle the problem (Lock, 1990). As the degree of openness of a question increases, so too do the number of decisions that the student is required to make. A closed investigation directs the student to easily definable variables requiring a set route be followed and leading to a single correct outcome. In contrast, an open investigation allows the student to decide on an aspect of the question they wish to investigate and to proceed as they wish. It provides the possibility of a variety of routes and a specific outcome is not sought.

The study

Aims

In this study 50 New Zealand and 90 Singapore high school students of 16 to 17 years of age have been surveyed to identify the skills acquired through traditional practicals versus exploratory investigative work. For the purposes of this study the traditional practicals performed in Singapore schools are termed closed investigations while the exploratory investigations performed in New
Zealand schools are termed open investigations. The skills students acquire are related to the type of investigative work they experience in the science classroom.

Background
In Singapore schools, the science practical work which students perform can be termed closed investigative work. The aim, the apparatus, and the method are provided to the students. In some cases, tables and graphical axes are provided for the students to record and present the data (Figure 1). It is standard practice for the students to write a conclusion based on the findings. Practical work is usually performed individually or in pairs dependent on the amount of equipment available. The 90 Singapore students surveyed had undergone four years of such practical work during their secondary education.

Springs and Hooke's Law
1. Arrange the apparatus as shown in the diagram. Make sure you have put the ruler upside down and at the right height.
2. The ruler should be fastened so that its '0' mark is at the bottom of the spring when there is no weight on the spring. Then it will measure the extension.
3. Put weights on gently starting with the hanger alone and then adding 1, 2, 3, 4, 5, 6 and 7 extra weights.
4. For every extra weight, write down the position on the ruler. This is the extension of the spring. Put your results in a table.
5. Draw a graph using axes as shown below.

Figure 1: A closed investigative task.

In New Zealand schools, students used to perform similar practical work until 1994 when the new curriculum initiatives were effected. Now, teachers are encouraged to involve students in a variety of investigative work. This can range from closed to open, structured to unstructured, and directed to undirected. The level and experience of the students is taken into account in determining the type of investigative work. In the lower age groups the students are provided with short tasks requiring the practice of specific skills such as measurement and observation. As the students graduate to advanced levels the tasks are made less structured and directed as well as more open. The 50 students surveyed in a single school had performed open investigative work. An example of an open task the students performed is provided in figure 2.

Scenario: Sharon has a part time job after school in a supermarket. She restocks the shelves and packs at the checkout. Yesterday she had to restock the sugar shelves. She was amazed at all the different types of sugar that was available. On the shelves she found white sugar, sugar cubes, soft brown sugar, coffee sugar, icing sugar, and castor
sugar. At school Sharon's science class had been talking about dissolving. They had to do an investigation about it for homework. Sharon decided she would find out about dissolving sugar.

Task: Investigate the factors that affect dissolving of sugar in water.

Figure 2: An open investigative task.
The task in figure 2 allows the students choice as to the aspects of dissolving which they wish to investigate. They could for example investigate the effect of temperature on the rate at which white sugar dissolves in water; amount of each type of sugar required for saturation; and time taken for the different sugars to dissolve in water. In all these cases they would have to identify the variables they were measuring, varying and controlling. Students initially embarking on such tasks would be provided with a planning sheet. Once they had performed a few such investigations then not much direction or structure was provided.
In both types of investigations the students encounter hypotheses or aims, have to identify the factors or variables they are measuring or studying, have to predict or have a notion of the outcome, perform a plan or implement the method, report the results using tables and graphs, report a conclusion based on the evidence gathered, and are required to provide an explanation for the conclusion using their knowledge of science.

Method
A post test (see appendix) was used to determine the skills which students learn through the type of investigation which they perform. Question 1 is an example of a somewhat open investigation while questions 2 and 3 are of the closed variety. In question 1 a scenario was presented to determine whether the student: (a) was able to ask a suitable question to investigate; (b) could write a suitable hypothesis; © could make a prediction of the possible outcome; (d) was able to suggest a plan or a suitable method to test the hypothesis suggested; and (e) used a table to record the data and used a graph to present the results. In question 2, the student was provided with data and required to (a) identify the factor or variable being investigated; (b) identify the variable being measured; © suggest variables requiring control for a fair test; (d) suggest other possible factors for investigation; (e) suggest a suitable method for reporting and presenting the results; (f) write a conclusion based on the evidence provided; and (g) provide an explanation for the conclusion suggested. In question 3, graphical presentation of evidence was provided and the student was required to: (a) write a conclusion based on the evidence; and (b) predict the outcome of a variable from the evidence. In both cases the student was required to furnish supportive explanation as
well.
For question 2c and 2d the students were accorded a score of 1 for every variable suggested. Questions 1d and 2g were graded using a scale of 0 to 3; and questions 1e, 2b, 2e and 3a were graded using a scale of 0 and 1. The rest of the questions were graded over a range of 0 to 2. The criteria for the basis of the scores are mentioned at the beginning of the analysis for each question.
In the ensuing discussion the results of the post test are presented and analysed by question. The findings are used to highlight the weaknesses and strengths of closed versus open (exploratory) investigations, providing implications for the use of the different types of investigative work. The percentage scores of both the groups by question are given in the appendix.

Results and analysis
1a. Able to ask a suitable question to investigate: For this question students were provided a score of 1 if they were able to suggest 1 question to investigate and 2 if they were able to suggest 2 or more questions for investigation. Every student was able to suggest at least one question for investigation. Eighty six percent of the New Zealand group and 47.8% of the Singapore group were able to suggest more than 1 question for investigation. This shows that the Singapore group were less capable in suggesting questions for investigation. This can be attributed to the fact that the aim of the experiment is usually provided in a closed investigation. In open investigations students are required to identify and suggest questions.
1b. Could write a suitable hypothesis: The students were given a score of 0 if they could not write a suitable hypothesis; 1 if they could write it to an extent; and 2 if they could accurately write a relevant hypothesis. Twenty eight percent of the New Zealand group could not write a proper hypothesis while only 11.1% of the Singapore group failed to write it. In contrast, 56.7% of the Singapore group accurately presented a hypothesis while only 32% of the NZ group did so. This implies that the closed investigation where the aim of the experiment is given might help the students to learn how to write a relevant and testable hypothesis.
1c. Could make a prediction of the possible outcome: A similar scoring to that used for question 1b was used. Both groups performed well in being able to predict an outcome. This could be attributed to the fact that they did not have to predict the correct outcome. They were given a score of 2 as long as they made a viable prediction. The very fact that both groups could word a prediction shows that both closed and open investigations might aid the students in acquiring this skill.
1d. Able to suggest a plan or a suitable method: In this case the students were given 0 if they were unable to suggest a method; 1 if the method was somewhat mentioned without much detail; 2 if an applicable method was suggested with some detail; and 3 if they were able to outline the method in detail taking into account various aspects. No student in the two groups provided the method with sufficient detail. However, 43.2% of the Singapore group and 44% of the NZ group scored 2 by providing a method with some detail. This can be attributed to the
lack of attention students tend to pay to the finer details. This skill area is of concern since approximately half the students in both the groups could not provide an acceptable method or plan with sufficient detail.

1e and 2e Used a table to record the data and used a graph to present the results: The students were given a score of 0 if they did not use a table to record the data and 1 if they used a table. A similar scoring was used for the graph. The table in the appendix shows that both groups used tables to present the data and there was not much difference in this aspect. The Singapore group was less prone to using graphs to present the information. This could be attributed to the fact that students were not specifically asked to draw a graph. The question merely requested the students to show how they would record and present the results. It could be that the Singapore students assumed recording and presenting to be the same. However, 15.6% and 20% of the Singapore students used a graph to present the results for questions 1e and 2e respectively. Another reason for this group not using graphs could be attributed to the fact that in closed investigations students are usually requested to draw graphs and in the post test this was not explicitly done. In comparison, 64% and 80% of the NZ group performed graphical presentation of information. This is a skill which is stressed to the students when they embark on investigative work.

2a. Able to identify the factor or variable being investigated: The students were given a score of 0 if they could not identify the variable; 1 if they identified it to some extent through indirect indication; and 2 if they were able to do so accurately. The Singapore group performed much better than the NZ group in this task. In the closed investigations students are usually given the variable being investigated and in the question the data was provided. In open investigations students are not given the variables to investigate but identify the variables they wish to study. This could be the reason for the difference in the scores for this aspect. This can be seen as the weakness of open investigations where the students select their own variables and do not have to identify those suggested by others.

2b. Able to identify the variable being measured: The students were given a score of 0 if they could not identify the variable and 1 if they were able to make the identification. Due to reasons stated for question 2a the Singapore group performed better at this task.

2c. Able to suggest variables requiring control: The students were given a score of 1 for every control variable they were able to suggest. There was not much difference between the groups for this task. Eighty eight percent of the NZ group and 96.7% of the Singapore group were able to suggest at least 2 control variables. The concern here is that the students should have suggested at least 4 control variables. The fact that only 2% of the NZ group and 5.6% of the Singapore group were able to suggest 4 control variables shows that students are not able to identify variables which need control thereby affecting the accuracy and applicability of their investigations. Both
groups showed lack of attention to detail. They were able to suggest some controls but not a sufficient amount not to confound the investigation.

2d. Able to suggest other possible factors for investigation: This question was scored similar to 2c. The students did not realise that the variables requiring control were in turn variables which they could use for investigation. A much lower percentage mentioned 2 or more variables which could be investigated. In the closed investigation the variables for investigation are provided, while in the open investigations students seem to pursue the obvious variables. This could account for the lack of factors mentioned. In both cases brainstorming of possible factors would help the students to address other variables.

2f. Able to write a conclusion based on the evidence provided: The students were given a score of 0 if they were unable to provide a conclusion; 1 if they merely stated a general trend; and 2 if they provided a description of the relationship. The fact that no student in the NZ group and only 6.7% of the Singapore group provided a description of the relationship shows that students tend to provide brief and rather superficial information as conclusion from evidence. Most students merely stated that the rate of the reaction increases with increasing temperature. Only a small percentage provided an accurate and detailed description of the relationship. Again the lack of consideration to detail emerged as an area of concern for both groups.

2g. Able to provide an explanation for the conclusion suggested: The students were given a score of 0 if they were unable to explain; 1 if they provided some relevant information; 2 if they provided a viable but incomplete explanation; and 3 if they were able to accurately provide a detailed explanation. None of the students in both the groups scored 3. This shows that students are not able to accurately relate conceptual knowledge to support their conclusion where required. Only 24% of the NZ group and 28.9% of the Singapore group provided a viable but incomplete explanation. This shows that for both the closed and open investigations students are not able to bring conceptual knowledge to bear on the investigation. Students are unable to make links between the investigation and relevant conceptual knowledge. This is an area of extreme concern and needs to be addressed.

3a. Able to write a conclusion based on graphical evidence and provide an explanation: The students were accorded a score of 1 if they could draw a viable conclusion and 0 otherwise. The students were separately scored for the explanation as well. Students in both the groups were able to perform these tasks well showing that they are able to obtain information and provide explanations from graphically represented information. In daily life students are often exposed to this skill. They often encounter graphical information and acquire experience in making sense of it to reach a conclusion.

3b. Able to predict the outcome of a variable from the evidence and
provide an explanation: The students were accorded a score of 2 if they correctly predicted both the flasks; 1 if they were correct for only one; and 0 if they could not do it. They were separately accorded a score of 2 if they were able to provide an accurate explanation; 1 if they provided an incomplete explanation; and 0 if they failed to provide an explanation. The NZ group showed to be poor in this task. Even the Singapore group did not perform well at this task. The task required students to predict or provide viable readings for a variable tending to a certain limiting value. They had to use the graphical information and relate practical considerations and constraints to arrive at an answer. Most students merely used the graphical information and failed to consider the practical constraints.

Summary
The students exposed to more open investigations seemed to be better able to formulate a question for investigation.; and seemed to more readily use graphical presentation of information. The students who perform closed investigations seemed better able to write an appropriate hypothesis; and to identify the variable being investigated as well as the variable being measured. Irrespective of the type of investigation to which they were exposed, students were able to effectively write a prediction; use tables to record the data; to come to a conclusion from graphical representation of information; and to infer graphical evidence to support the conclusion reached. Irrespective of the type of investigation both groups showed weakness in being able to adequately identify variables for control and for study; to infer information for limiting conditions and to identify the constraints; and to supply an adequate explanation when the required to link theory to evidence obtained or presented. These are areas which both types of investigations need to address so that students can acquire the requisite skills.
The findings in this paper have implications for teachers and students who respectively use and perform closed or open investigative work for skill inculcation. The data shows that both types of investigative work have their benefits as well as weak points. The implication of this is that students should be exposed to both types of investigative work. The variety will also act as a motivator and in turn reduce any mundane aspects. Further data collection needs to be performed to isolate the variety of skills which each type of investigative work helps students to learn.

Appendix
Post test
This is not a test. It is part of a research project to determine student learning through investigations or laboratory work in science. Answer the questions in the spaces provided. Do not obtain help from anyone. The questions can be answered using the information provided.
1. The school canteen is purchasing disposable cups to serve soup. They have a choice of three types of cups: i polystyrene
A student is doing a science investigation (experiment) and wants to find out which cup is best.

(a) What factors can the student investigate?
(b) Write a hypothesis (aim) for what you wish to investigate.
(c) Write a prediction of what you think will be the outcome of your experiment or investigation.
(d) Briefly describe how you would find an answer to your investigation or experiment in part (b). Use your knowledge of science to help you.
(e) Show how you would record and present your results.

2. Jena and Paka decided to study the effect of temperature on the rate at which magnesium ribbon reacted with hydrochloric acid.

(a) What is the factor that they are investigating?
(b) What is the factor that they are measuring?
(c) What factors would they have to control (keep the same) to make it a fair test?
(d) What other factors could they have measured?
(e) Show how you would record and present this data if it was your investigation or experiment?
(f) Write a conclusion based on the evidence that Paka collected.
(g) Provide an explanation for the conclusion in (f).

3. Hayley wanted to know which thermos flask would be the best to keep her coffee hot. She carried out an investigation (experiment) and plotted a graph of her results.

(a) Write a conclusion for Hayley’s investigation (experiment). Explain.
(b) What do you predict the temperature of the coffee would be in each flask in another 6 hours? Explain.

Tables of results
New Zealand students (Open group)

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* Scores of the explanation component.

References