



## Development of an Experimental Science Module to Improve Middle School Students' Integrated Science Process Skills

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**Abstract:** A 7-week learning module was developed intended mainly for Grade 7 and 8 students who need a beginning knowledge of scientific writing. This module puts Inquiry as the heart of learning sciences and aims to support students' understanding of sciences by providing them with opportunities to independently investigate through both research and experimentation. The use of open, student-led investigations alongside scaffolded teaching of research skills and the integration of science process skills allowed students to learn what it means to do science, solve problems and develop thinking skills. This experimental science module emphasized the use of the scientific method in performing an investigation by experimentation (inquiry-based learning) to develop critical thinking and science process skills. The students were given the opportunity to design and execute experiments in a strategic and unified manner. As they go through their investigations they were expected to master different Integrated Science Process Skills. To culminate their learning in this module, the students were required to write a full science report. This study utilized a research-validated paper-and-pencil test for assessing integrated science process skills developed by Kazeni (2005). The test is consist of 30 multiple choice items that are content independent; and gender, race, school type and location neutral. Comparing pre-test and post-test scores, 66% of the students learned positively from the module. Item analysis of the test scores showed improvement in the different integrated science process skills: 8% in identifying variables, 11% in stating hypothesis, 16% in operationally defining variables, 8% in graphing and interpreting data, and 14% in designing experiments. *T-test* for paired samples further revealed that students' scored significantly improved after going through the module.

**Key Words:** Inquiry-based Learning; Science Process Skills; Science Investigations

### 1. INTRODUCTION

A holistic view of 21st century teaching and learning focuses on the discrete combination of 21st century student outcomes (a blending of specific skills, content knowledge, expertise and literacies) with innovative support systems to help students master the multi-dimensional abilities required of them in the 21st century and beyond (Pacific Policy Research Center, 2010).

The purpose of science education today should be aligned to produce a support system that produces

21st century outcomes for today's students (Center for 21st Century Skills). Science education should focus on the development of scientific literacy to enable understanding of the Nature of Science and its relationship to society, rather than a focus that is heavily weighted in content knowledge. This new approach should enable students to engage in thinking creatively, critically and constructively around complex real world problems (Office of the Prime Minister's Science Advisory Committee, 2011; International Baccalaureate Organization, 2014).



Learning sciences should develop students as inquirers, scientifically literate, caring and responsible individuals who will think critically and creatively when solving problems and making decisions about aspects affecting themselves, others and their social and natural environments - it is more than simply learning technical scientific terminology. As student learns science they should become competent and confident in accessing, using and communicating scientific information. Students are expected to use scientific language correctly and select appropriate communication formats for oral and written communication. They are also expected to demonstrate critical-thinking skills to analyse and evaluate information in order to make informed judgments in a variety of contexts (Office of the Prime Minister's Science Advisory Committee, 2011; Jugar, R., 2013).

This 21st century purpose of science must be relevant to the interests of students, providing them with opportunities to explore the connections between science and everyday life. Students are encouraged to be interested in and engaged with the role of science in the world. Through the investigation of real examples of the application of science, students gain insight into the tensions and dependencies between science and societal, environmental and ethical factors (Office of the Prime Minister's Science Advisory Committee, 2011).

This simply puts Inquiry as the heart of learning sciences and aims to support students' understanding of sciences by providing them with opportunities to independently investigate relevant issues through both research and experimentation.

The use of open, student-led investigations alongside scaffolded teaching of research skills and the integration of science process skills allows students at all levels to learn what it means to do science, solve problems and develop thinking skills[3]. Notably, these foundations are important for students who are going to continue in science, as well as for those who will not continue beyond secondary school (International Baccalaureate Organization, 2014).

The cognitive ability of creating meaning and structure from new information and experience are referred as science process skills. These skills are an important and necessary means by which the learner engages with the world and gains intellectual control of it through the formation of concepts and development of scientific thinking (Jugar, R., 2013).

Science - A Process Approach (SAPA), defined science process skills as a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behavior of scientists. SAPA grouped process skills into two types-basic and integrated. The basic (simpler) process skills provide a foundation for learning the integrated (more complex) skills.

The Basic Science Process Skills are:

Observing. The use of the senses to gather information about an object or event.

Inferring. The making an "educated guess" about an object or event based on previously gathered data or information.

Measuring. The use of both standard and nonstandard measures or estimates to describe the dimensions of an object or event.

Communicating. The use of words or graphic symbols to describe an action, object or event.

Classifying. The grouping or ordering objects or events into categories based on properties or criteria.

Predicting. Stating the outcome of a future event based on a pattern of evidence.

The different Integrated Science Process Skills are:

Controlling variables. Being able to identify variables that can affect an experimental outcome, keeping most constant while manipulating only the independent variable.

Defining operationally. Stating how to measure a variable in an experiment.

Formulating hypotheses. Stating the expected outcome of an experiment.

Interpreting data. Organizing data and drawing conclusions from it.

Experimenting. Being able to conduct an experiment, including asking an appropriate question, stating a hypothesis, identifying and controlling variables, operationally defining those variables, designing a "fair" experiment, conducting the experiment, and interpreting the results of the experiment.

Formulating models. Creating a mental or physical model of a process or event.

Science process skills can be learned if taught in a formally in the classroom with the use of proven teaching methods. Furthermore, these skills can be retained for future use if lessons are based on science investigations and practiced over a long period of time.



A science investigation emphasizes the use of the scientific method in performing an investigation by experimentation (inquiry-based learning) to develop critical thinking and science process skills of the student. This scientific method allows scientists to collect and analyze data in a strategic and unified manner and this is the same method that students use to design and execute their project - they use the same steps professional researchers use to gather new information. The different science process skills can be integrated in the conduct of science investigations (Kazeni, 2005). Thus, science investigations are giving students an opportunity to undergo the process of conducting an investigation using the scientific method making them gain a considerable understanding of the nature of obtaining solutions to problems or answers to questions in a systematic and scientific way.

A 7-week learning module was developed intended mainly for Grade 7 and 8 students who need a beginning knowledge of scientific writing. This module aims to support students' understanding of sciences by providing them with opportunities to independently investigate through both research and experimentation. The effect of this module to students' integrated science process skills was investigated.

## 2. METHODOLOGY

### *Development of the Experimental Science Module*

This experimental science module was developed to help students understand the basic aspects of scientific inquiry and to provide students with an opportunity to practice and refine their critical-thinking skills. Middle school science class offer an ideal setting for integrating many areas of student interest. This module enables students to participate in activities that integrate inquiry science, physics, chemistry and biology. The context of the module's classroom lessons is engaging, and the science process skills gained can be applied immediately to students' courseworks and laboratory practicals.

### *Experimental Science Module Contents*

- I. The Scientific Method and Science Process Skills
  - a. Steps of the Scientific Method
    1. Steps in the Research Process
    2. Searching Scientific Literature
    3. Evaluating Web Sources

4. Citing Sources (APA Format)
- b. The Integrated Science Process Skills
  1. Identifying and Controlling Variables
  2. Stating Hypotheses
  3. Operational Definitions
  4. Graphing and Interpreting Data
  5. Experimental Design
- II. Measurement and Laboratory Techniques
  - a. Safety in the Laboratory
  - b. Different Laboratory Apparatus and their Uses
  - c. Measurement and Uncertainties
    1. Principles of Experimentation
    2. Measures of Central Tendencies
    3. Systematic Errors
- III. Writing the Science Investigation Report
  - a. Title and Research Question
  - b. Abstract
  - c. Introduction
  - d. Methods
  - e. Conclusion
  - f. References

### *Subjects*

Two experimental science classes consisted of 41 students were exposed to various science investigations chosen by the teacher. Each class followed a 7-week researcher-developed curriculum and meets 7 periods in week. This experimental science module emphasizes the use of the scientific method in performing an investigation by experimentation (inquiry-based learning) to develop critical thinking and science process skills of the student. The students are given the opportunity to design and execute varied experiments in a strategic and unified manner. As students go through their investigations they are expected to master different Science Process Skills such as Identifying and Controlling Variables, Stating Hypotheses, Operational Definitions, Graphing and Interpreting Data, and Experimental Design. Students were required to submit a comprehensive written report for each science investigation they performed.

### *Integrated Science Process Skills Test*

This study utilized a research-validated paper-and-pencil test for assessing integrated science process skills developed by Kazeni (2005). The science process skills tested by the instrument are: identifying and controlling variables, stating hypotheses, experimental design, graphing and interpreting data and operational definitions. The test is consist of 30 multiple choice items that are

content independent; and gender, race, school type and location neutral. For this study, some proper nouns were changed to a more locally family names to make the test more culturally valid.

### Test Administration and Analysis

The integrated science process test was administered to students before and after they finish the 7-week module. To identify students' mastery of each science process skill, an item analysis was carried out for each item in the test.

Mastery for each item was determined by:

$$M = \%Post - \%Pre \quad (\text{Eq. 1})$$

where:

- $M$  = Percentage of Mastery; Learning occurred
- $\%Post$  = Percentage of students who are correct in the post-test
- $\%Pre$  = Percentage of students who are wrong in the pre-test

Students' proficiency levels were also interpreted as follows:

- ≤50% beginner,
- 51-60% developing proficiency,
- 61-75% proficient, and
- ≥76% advanced proficiency.

Positive learning was determined by computing the percentage of students who improved their integrated science process test after they underwent through the module.

The mean of students' pre-test and post-test scores were compared using t-Test for paired two samples of means to determine if students significantly improved their integrated science process skills.

## 3. RESULTS AND DISCUSSION

### Integrated Science Process Skills

Figure 1 shows the performance of the students in each skill tested through the Integrated Science Process Skills Test. Science process skills are defined as a set of broadly transferrable abilities that reflect the behavior of scientists.

Even before the students went through the module, they already have at least proficient level of the integrated science process skills except for

stating hypotheses where they only have skill level of developing proficiency. It can be noted that 8% of the students learned the skill of identifying variables, 11% acquired the skill of stating hypotheses, 16% learned skill of operationally defining variables, 8% acquired the skill of graphing and interpreting data, and 14% learned the skill of designing experiments.

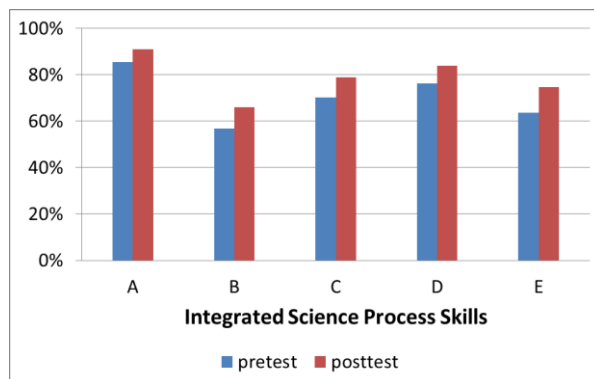


Fig. 1. Mean percentage of students' performance for each science process skills

After 7-weeks of learning the module, the students reached an advanced proficiency level of almost all the integrated science process skills except for stating hypotheses in where they only reached the proficiency level. Statistical analyses through t-Test for paired two samples of means reveal that students significantly improved their stating hypotheses, graphing and interpreting data and designing experiment skills but did not significantly improved their identifying and operationally defining variables skills.

Students' moderate mastery and high proficiency levels can be attributed to the fact that they already have the opportunities to learn about science process skills through some courses and subjects that cover some of the skills without teaching them under the concept of science process skills (Al-Rabaani, 2014).

### Overall Integrated Science Process Skills Proficiency Levels

Overall Analyses of students' proficiency level reveal that more students after going through the 7-week module reached advanced proficiency. Comparing pre-test and post-test scores, 66% of the students learned positively from the module. Statistical analysis of students' overall scores showed that students of the experimental science module significantly improved their scores in the integrated



science process skills test. It can be inferred that students exposed to the experimental science module had the opportunity to identify variables, state hypotheses, operationally define variables, graph and interpret data and design experiments as they involve themselves in the science investigation activities.

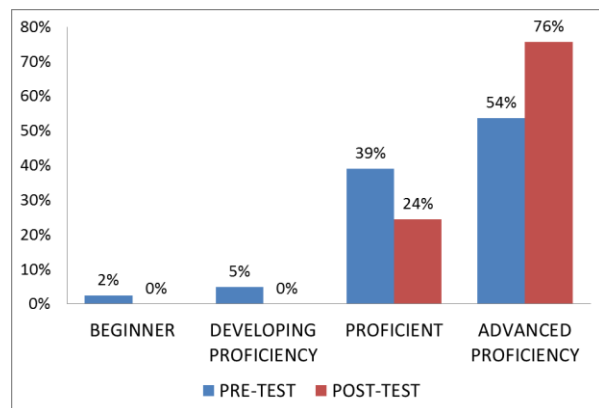


Fig. 2. Students' integrated science process skill proficiency levels

Various studies showed that inquiry-based teaching approaches enhanced students' science process skills which are in agreement with the findings of this study. Numerous studies also revealed the positive effects of science process skills on scientific creativity, academic achievements and attitude towards science.

Science investigations utilize inquiry-based learning as its framework. As students conduct an investigation using the scientific method they gain an understanding of the nature of obtaining solutions to a problem in a systematic way.

Doing science investigations develop students' natural curiosity. They acquire the skills necessary to conduct inquiry and research and show independence in learning. They exercise initiative in applying thinking skills critically and creatively to pose and approach complex problems, identify variables, design appropriate experiments and make reasoned conclusions. This inquiry-based approach in learning allows the students understand science by operational defining variables in the context of their investigation. They are able to express ideas and information confidently and creatively in a variety of modes of communication such as graphs, written and oral presentations. This activity also allows them work effectively and willingly in collaboration with others.

By doing student-led investigations, the students are enable them to manage their time in order to accomplish all tasks within the set deadlines. Collaborating with their partners to critically and positively analyze ideas and constant communication with the teacher, enable them to produce outstanding outputs. They are able to effectively and independently conduct literature reviews from different sources using different forms of technologies. Their knowledge and understanding are effectively transferred and communicated to solve the problem at hand. This activity enabled them to reflect and think of ideas to make a plan, present arguments in a logical sequence, identify problems and evaluate available solutions, and create strategies to solve the problem different perspectives.

It is important to note that the success of the approach may depend on the competence, enthusiasm, and confidence of the science teacher and the ability of the students in making use of the opportunity provided (Abungu *et.al.*, 2014). Student generated questions play an important role in inquiry-based science classrooms. However, science teachers know how to use students' questions to guide instruction (Gibson and Chase, 2002).

#### 4. CONCLUSIONS

The researcher-developed experimental science module emphasize on the development of science process skills and scientific knowledge as its major objectives to give varied opportunities to young scientists to acquire knowledge and skills for solving problems. Students' proficiency in their integrated science process skills is significantly improved after going through the 7-week module.

Further research is needed to compare results reported in this study to other inquiry-based programs. Second, additional studies are needed that follow students for longer periods of time after they take the experimental science module. It would be enlightening to determine the impact of module designed for middle school students have on students' streaming choices. And finally, while students showed a high level of proficiency in the integrated science process skills test, further studies should examine the correlation of among students' interest in science, their understanding of science and their science process skills.



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