MOJES MALAYSIAN ONLINE JOURNAL OF EDUCATIONAL SCIENCES JANUARY 2019, 7 (1)

DEVELOPMENT OF INSTRUMENT IN ASSESSING STUDENTS' SCIENCE MANIPULATIVE SKILLS

***Hidayah Mohd Fadzil**
Rohaida Mohd Saat
Department of Mathematics and Science Education,
Faculty of Education, University of Malaya,
Malaysia
**hidayahfadzil@um.edu.my*

ABSTRACT

Manipulative skills and abilities include skills in the handling and manipulation of materials and apparatus in the context of scientific investigation. Science teachers appeared to be struggling with the mode of assessment in making authentic evaluation of manipulative skills in laboratory. One of the contributing factors is due to lack of instrument developed to assess these skills. This paper explains the development of resource guide in assessing students' manipulative skills at secondary school. This study employed qualitative research methodology. The development of a resource guide in assessing students' manipulative skills involved three phases; (i) analysis, (ii) design and development, and (iii) implementation and evaluation. The evaluation of this guide has been conducted qualitatively with 40 science teachers. Findings show that the development of this resource guide is advantageous and beneficial to facilitate teachers in determining students' manipulative skills competency during practical work so that students can be more prepared for the implementation of the upcoming science practical examination. The findings may contribute towards enriching research on assessment of manipulative skills at secondary school level. Science educators, either pre-service or in-service, may use resource guide to improve their instruction during practical work.

Keywords: *assessment of scientific skills, secondary science, practical work, science manipulative skills*

INTRODUCTION

Science subject require practical training as well as theoretical studies. Practical work is an essential part of science education and is considered as the most distinctive features of science that can ignite students' interest. Practical work in this context can be defined as any scientific activity in which learners need to be actively involved, hands-on and minds-on, to observe physical phenomena (Allen, 2012). Among the aims of practical work is to develop practical skills that include science manipulative skills. Manipulative skills play an important role in science education, especially in higher level sciences and these skills can only be obtained through 'hands-on' practical work. According to past studies, (e.g. Abrahams, Reiss, & Sharpe, 2013; Ferris & Aziz, 2005; Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014; Fuccia, Witteck, Markic, & Eilks, 2012; Tesfamariam, Lykknes, & Kvittingen, 2015; Trowbridge, Bybee, & Powell, 2000) manipulative skills are generally given the least amount of attention in the course of academic instruction even though important aspects of learning can occur in this area.

Students' involvement was still low in conducting experiments and they are not effectively guided by the teacher (Chua & Karpudewan, 2017; Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014).

In order for the teaching and learning of manipulative skills to be effective, it is necessary to know what are the criteria to be assessed. One particular feature of the current assessment of manipulative skills in many countries such as Malaysia is the limited amount of direct assessment of students' practical skills. Thus, there is less inclination amongst teacher to devote time and effort in developing students' manipulative skills (Campbell, 2002; Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014, 2017; Hamza, 2013; Tesfamariam et al., 2015). Furthermore, study conducted with 40 Grade 6 and Grade 7 science teachers have found that teachers still have difficulty to assess students' manipulative skills due to the lack of information as what are to be observed (Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014).

The issue of practical work will become more substantial due to the comeback of practical component of science at national examination level (*Malaysian Certificate of Education)* taken by Grade 11 secondary school students. In this practical exam, students will have to carry out experiments individually based on instructions given, and their marks will be reduced if the invigilator steps in to help them. Practical science tests were carried out in the national exam until 1999, when they were replaced by written tests and continuous school-based practical science assessments. The reintroduction of science practical examinations has been seen as an appropriate move because studies conducted on the implementation of the continuous school-based practical science assessments (for e.g. Hidayah Mohd Fadzil & Rohaida Mohd Saat, 2014a, 2014b; Ishak, 2014; Ng, 2014) have shown many weaknesses in the program which need to be given more attention. Studies (e.g. Ishak, 2014; Ng, 2014) also found that among the factors that hinder the effective implementation of the continuous school-based practical science assessments in school were related to teachers' lack of competence and skills in assessment activities. The findings of this study will be important in providing information on the competency level of students for the implementation of the upcoming science practical examination.

Therefore, the purpose of this research was to develop an instrument, in this case, a resource guide to assess students' manipulative skill and to find out the appropriateness of it from the perspective of experienced science teachers. This research focuses on the following research question: Can the resource guide be used to determine students' manipulative skills competency during practical work, based on the feedback from the experienced science teachers?

METHODOLOGY

This paper discussed the development of resource guide in assessing secondary school students' manipulative skills during practical work. The rubric developed in this resource guide emerged from the first part of this research which explored students' manipulative skills in 8 schools in Selangor. During the data collection phase of the research, laboratory observations during students' practical work have been conducted and each student need to conduct four individual experiments and was video recorded while performing it. They were also interviewed at least four times. The findings from this qualitative research revealed that the main problem arising from the research was that most of the students were unable to master the manipulative skills in using four basic apparatus in science laboratory, namely the measuring cylinder, thermometer, Bunsen burner and microscope.

Responses from science teachers from the research have prompted a need to prepare some form of guide to be used in assessing students' manipulative skills. Thus, the researchers strongly felt that there is a necessity to prepare this rubric based on the emerging findings, in order to facilitate teachers and students in establishing effective manipulative skills. A modified framework of the ADDIE Model has been implemented in this research and the resource guide were then revised, based on the evaluation process feedback. The three (3) phases of preparing the resource guide are shown in Figure 1.

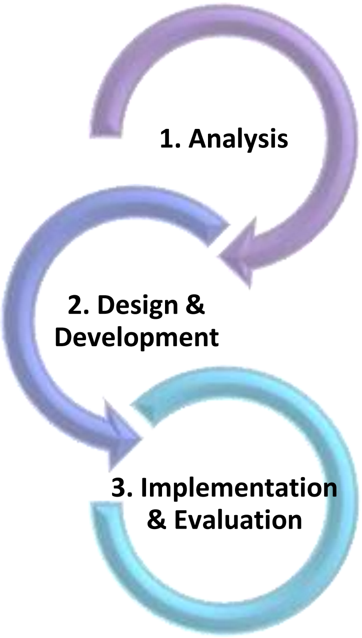

Figure 1. Modified ADDIE Model implemented in the development of resource guide

Development of the Resource Guide

Modified ADDIE model has been implemented in developing the resource guide. It involved three phases which were the (i) analysis, (ii) design and development and (iii) implementation and evaluation.

Phase 1: Analysis

Analysis phase is the pre-planning phase where all the related information for this research is gathered. In this research, a needs analysis was conducted in order to get a comprehensive understanding of the phenomenon. Issues related to assessment of science manipulative skills have been analysed during literature review. The information also emerged from the analysis of data from the first part of the research where findings showed that students confronted with difficulty in acquiring manipulative skills. From the understanding of the phenomenon, potential solutions for the problem can be identified. Based on the needs analysis, a resource guide has been prepared.

Phase 2: Design and development of resource guide

The objectives in preparing this resource guide were to provide science teachers with an appropriate method in identifying student's level of competency in manipulative skills and to provide a systematic rubric for the teachers in identifying the student's proficiency in manipulative skills. The analysis phase indicated that there is a need to gauge the student's level of competency, so that once the students' competency has been determined, teacher will be able to enhance their manipulative skills accordingly. The resource guide has been prepared in the Malay language because Malay language is the medium of instruction in teaching and learning of science at most of the secondary schools. The resource guide comprised of three main part which were the (i) diagnostic tests, (ii) manipulative skills rubric and (iii) description of competency level in manipulative skills. The diagnostic tests served as an instrument for systematic identification of the student's problem in manipulative skills. Four (4) activities were proposed (refer Table 1). Activity A involved the use of measuring the cylinder, the thermometer and the Bunsen burner. Activity B involved the use of microscope which includes the preparation of slide. The apparatuses were chosen from the analysis of the related documents, for example the science practical text books, science curriculum specification, science text books and science teaching and learning materials in secondary school. The information such as learning objectives, learning outcomes, apparatus and materials needed for the experiment, experiment procedures and table for results are provided in the activity sheet for each diagnostic test.

For example, in Task 1, students are required to conduct an experiment to understand how the presence of salts affects the boiling point of water. The learning outcome is to measure the water temperature when impurity such as salt is added to the solution. Students' skills in using the measuring cylinder, the thermometer and the Bunsen burner will be observed during the execution of this experiment. The apparatus and materials needed for the experiment are beakers, thermometers, Bunsen burners, measuring cylinders, tripod stands, spatulas, glass rods, lighters, candles, tongs, distilled water and salt. A guide depicting simple procedures of the experiment for students to follow, are given. They have to write their results in the given space and state the safety procedures they have taken for this experiment.

Table 1
Activities for diagnostic test

Activity	Learning Outcome
Activity A: Understanding water	• To measure the temperature of water when it is heated • To understand how the presence of salts affects the boiling point of water
Activity B: Science under the microscope	• To observe the movement of microorganisms • To understand that organisms are built from the basic units of live

The second section consists of manipulative skills analysis rubric. There were two rubrics provided in this resource guide: rubric for Activity A and Activity B. During the execution of Activity A and B, teachers are required to observe the students' ability, and to give points for each criterion: low = 0 mark, intermediate = 1 mark and high = 2 marks. The total score will reflect the student's ability in manipulative skills for each category. The criteria and categories in the rubric were based on the dimensions and elements from the findings of the previous research. The main categories include: systematic operation of task, management of time and workspace, safety and precautionary measures, numeracy, scientific drawing, technical skills in using measuring the cylinder, the thermometer, the Bunsen burner and the microscope, as well as the preparation of slide for specimen. The scoring rubrics for the resource guide were guided by steps of marking rubric (for e.g. Stevens & Levi, 2005). The teachers were asked to give feedback on the categories which describe the level of quality of skills (ranging from basic, intermediate to high level of competency). The scoring rubrics were revised on the basis of the teachers' feedback. Table 2 summarizes the criteria for the categories in rubrics A and B.

Table 2
Criteria for the categories in rubrics A and B

Category	Criteria
A. Systematic operation of tasks	1. Following instructions in performing overall operation of task 2. Checking the functionality of apparatus 3. Communication with group members to ensure a systematic operation of task
B. Management of time and workplace	1. Using time 2. Condition of working area before, during and after experiment 3. Cleaning and storing of apparatus and materials
C. Safety and precautionary	1. Safety procedure during experiment 2. Technique in using apparatus in order to prevent unwanted damage
D. Numeracy	1. Making assumptions 2. Skill in reading meniscus of measuring cylinder

	3. Skill in reading meniscus of thermometer
E. Scientific drawing	1. Use pencil to draw 2. Production of neat line drawing 3. Appropriate title of the drawing 4. Correct label of scientific drawings 5. Magnification of drawing is indicated 6. Authentic drawing – based on observation
F. Technical Skills in Using Apparatus	(i) The use of measuring cylinder to measure volume 1. Ability to recognize apparatus, their features and functions 2. Using appropriate measuring cylinder in measuring volume of solution 3. Placement of measuring cylinder 4. Eye position when reading meniscus 5. Efficiency in using measuring cylinder 6. The need for guidance
	(ii) The use of thermometer to measure temperature 1. Ability to recognize apparatus, their features and functions 2. Technique in holding the thermometer 3. Using the correct part of the thermometer to measure temperature. 4. Ensuring the thermometer bulb does not touch the bottom or the wall of the beaker. 5. Wait for the temperature to be stable by stirring the solution before taking the temperature. 6. Eye position when reading meniscus 7. Appropriate way of taking the measurement of the water temperature (did not take the thermometer out from the solution) 8. Efficiency in using the thermometer 9. The need for guidance
	(iii) The use of the Bunsen burner 1. Ability to recognize apparatus and their function 2. Ability to identify parts and features of apparatus and their functions 3. Manipulation of gas hole before lighting the Bunsen burner (the collar of the Bunsen burner should be turned so that the air-hole is closed) 4. Light up the candle/lighter before turning on the gas 5. Manipulation of air hole after lighting up the Bunsen burner (Open the air-hole, so that the flame changes to the non-luminous blue flame) 6. Efficiency in using the Bunsen burner 7. The need for guidance
	(iv) Slide preparation 1. The use of correct stain in appropriate amount 2. Technique in using the slide cover
	(v) The use of the microscope 1. Ability to recognize apparatus and their functions 2. Ability to identify parts and features of apparatus and their functions 3. Handling the microscope (techniques in holding it and placing on flat surface) 4. The use of stage clips to secure the specimen slide

	5. The use of the lowest magnification power objective lens by rotating the nosepiece
	6. Ability to coordinate the mirror, condenser and diaphragm in order to get sufficient source of light.
	7. Adjustment of the coarse adjustment knob until the specimen is in focus.
	8. Adjustment of the fine adjustment knob until the focused specimen is well-defined.
	9. Efficiency in using microscope
	10. The need for guidance

Each of the criteria is divided into three main levels of acquisition which are low, intermediate and high. For example, the first criteria in category A, "Systematic operation of tasks" is on student ability to follow instruction in performing overall operation of task. For the "low" level of acquisition, the student is unable to follow overall instructions and the given procedures for the experiment. For the "intermediate" level, the student is able to follow the instruction and procedures but not as effective as the student in the "high" level. The teacher must determine the student level of acquisition for each of the criteria in this category and give the appropriate points: "0 mark" will be given to student with low level of acquisition, "1 mark" for intermediate and "2 marks" for those in the high level. This will be followed by the second category of "Management of Time and Workspace".

The cumulative score for each category will determine the student's level of competency. This score will provide a guide for teachers in determining the student ability in every category of manipulative skills. For example, Student A scores cumulative of 1 mark in the first category, the "Systematic operation of tasks". From the score guide, under this first category, "0-1 marks" is categorized as "basic level" competency, "2-4 marks" as "intermediate level" and "5-6 marks" signify "high level" competency. Student A will be categorized under the "Basic" level of competency for this particular category. However, in using the thermometer the student scores 16 out of 18 marks which is categorized under "high level" of acquisition of skills. From this information, the secondary school teacher should acknowledge Student A's difficulty in performing systematic operation of tasks and can continue to improve the student's skills in this specific category. In using the thermometer, Student A is considered as proficient, but the teacher can analyse the criterion which did not attract full marks- for example, there is the possibility that Student A did not stir the solution using the glass rod. From the score, teachers can determine the student level of competency for each and every category and summarize the student's level of competency.

The third section of this resource guide contains a description of each level of competency in manipulative skills. The guide describes the general criteria of a student with "basic", "intermediate" or "high" competency of manipulative skills. It was constructed based on the research findings and the theories underpinning this research. For example, students with high level of competency of manipulative skills demonstrate smoothness and efficiency in manipulative skills, display high skills to achieve the learning objective and are able to adapt their skills to a new situation. The skills can also be applied with minimum supervision. At this level, the movement has been ingrained the students' minds and most of the action is automatic, where practices will enhance the students' precision and accuracy of manipulative skills.

Phase 3: Implementation and Evaluation

The following phase focuses on the implementation and evaluation of the prepared resource guide. In the evaluation phase, there is the need to critically consider the appropriateness of the resource guide in order for it to be implemented in our local context. The resource guide was implemented and evaluated by a group of teachers. For this purpose, a two-day workshop in a teacher training institute in Kota Bahru, Kelantan was organized. The implementation and evaluation phase were conducted in Kelantan because the approval to collaborate with the Kota Bahru Teacher Training Institute, as well as the Kelantan State Education Department to conduct the workshop, had been obtained. Initially, forty

(40) school teachers agreed to participate in this two-day workshop. However only 39 teachers participated in this workshop and these teachers have an average 14 years of experience in teaching the science subject at school. The two-day workshop included an introductory talk, brainstorming session and the evaluation of the resource guide by the school teachers. In the introductory session, the objectives, overall procedure and the findings of the study were introduced. This is to allow the teachers to get a clear picture of the study and their important roles in evaluating the resource guide. In the discussion or brainstorming session, the teachers were put into eight groups where they were given a set of problems related to the issue in learning manipulative skills. From the session, all the teachers admitted that their students' manipulative skills are weak and much guidance is needed and this was similar to the findings of this study. The teachers explained that the assessment of students' manipulative skills was made through three mediums (a) observation during practical work, (b) the students' ability to give accurate reading, and (c) appropriate scientific drawing in the practical report. Teachers also raised the issues and challenges in teaching manipulative skills. Among the issues are time constraint, lack of laboratory apparatus, students' attitudes and safety issues. During the evaluation of this resource guide, the teachers were requested to go through the whole resource guide and at the end of the session, they were asked to give their feedback on the appropriateness of it during the interview sessions.

Analysis of Data

In this study, data was collected from observations of teachers' in performing the tasks from the resource guide and individual interviews. Data was collected and organized into manageable format. All video and audio data were transcribed. These data were then analysed qualitatively, which involves the process of coding and categorizing from information that emerges from the collected data (Strauss & Corbin, 2008). The validity and reliability of the interview protocol were done through peer review. Categories that emerged during data analysis were also checked by peer review. Two science education experts were involved in the peer review. Peer review is regarded as one of the most reliable techniques used to enhance the credibility and trustworthiness of qualitative research because of its use of external experts in a given field of study (Merriam, 2009).

FINDINGS

Seven questions regarding the developed instrument were asked to encourage meaningful answers from the teachers during the evaluation phase. The analysis of answers for each aspect of the given questions will be discussed in this sub-section.

(1) Clarity of the explanation

During the design and development phase, among the issues to ponder was the suitability of word and sentence structure used to construct the materials in this resource guide. The experiments should be easily understood for the students, whereas the rubrics and instruction for teachers should be well-defined so that teachers can get a clear picture of their role. From the written responses, all the teachers agreed that the instruction and explanation in the resource guide are clear, systematic and suitable for the students. Among the responses were:

> *Yes, the given explanations (in the resource guide) conform to the student's ability. (ST3).*
> *Clear and satisfying, can assist teachers in teaching and learning of manipulative skills. (ST11).*
> *Yes, it is systematic and helpful for teacher to identify what is to be evaluated during practical. (ST9).*
> *The structure of the sentence and language used are simple and clear. (ST12).*

(2) Suitability of the activities or tasks

The teachers who participated in this evaluation phase were experts because of their vast and wide experience in teaching science. Thus, the teachers play an important role in validating the suitability of the given tasks in determining students' level of competency. All the responses from the teachers in regard to this aspect were constructive. They admitted that the activities were suitable to be used for basic experiment and from the observation of the activities, teachers were able to determine students' level of competency in manipulative skills.

(3) Relevancy of the represented criteria in the rubric

The third aspect focused on the relevancy of the criteria in the rubrics in the context of science learning. The criteria were constructed based from the earlier research findings. The following excerpts illustrate the teachers' responses to the third question,

> *Yes, it can be used as guide (to teacher) and it follows the students' appropriate level of competency. (ST1)*
> *It is relevant to the science curriculum for secondary school. (ST13)*
> *Yes, it is relevant and follows the curriculum of secondary school. (ST4, Ss.)*

(4) Clarity of the underlined criteria in the rubric

From the given feedback, the teachers have no problem comprehending all the criteria and among the given response from science teachers were "*it is easily understood*" (ST27) and "*simple criteria, easily understood*" (ST36).

(5) The usability of the Manipulative Skills Competency instrument

As an instructor, it is important for the teacher to be able to follow the instruction in the resource guide accordingly. The important aim of the resource guide is to determine students' ability or level of competency in manipulative skills. Thus, the appropriateness of the instrument needs to be determined. Most of the teachers found this instrument practical, for instance, Teacher 25 responded that "*it is suitable, systematic and can be used to determine the students' level of competency, in accordance with the criteria proposed in the rubric*". "*It can also guide the teachers to identify what needs to be evaluated during practical work* (ST9) and "*to determine which categories of skills that need improvement* (ST28)."

(6) The suitability of the resource guide to be implemented in school

The teachers gave a warm response towards the resource guide. It can assist the teachers in identifying the students' competency of manipulative skills at secondary school (ST1). It is systematic and comprehensive (ST9) and can help teachers and students to understand the concepts of manipulative skills based on the criteria proposed in the rubric (ST13.). The resource guide can also be used to assist teachers in school-based assessment (ST32) and facilitate students to increase their proficiency in manipulative skills.

(7) Improvement to the resource guide

The final question needed the teachers to give some recommendations for improvement. Among the recommendations are:

> *to add more safety measures (ST2)*
> *to use the resource guide to support the continuous school-based practical science assessments (ST8)*
> *come out with a certificate or a form of students' manipulative skills competency at the end of every school year (ST1 & ST14).*

The evaluation phase with the experts was followed by revision of the resource guide. Most of the modifications and adjustments made to the guide focused on the structure and arrangement of the resource guide to facilitate its use by science teachers. The instruction has been clarified to avoid any difficulties in implementing all the resource guide materials. This workshop has received very positive feedback from the experts. The experts agreed that this resource guide should be implemented as it can facilitate science learning at secondary school. It is hoped that this resource guide can serve as an important instrument in bridging the gap in science practical work. Once the teacher can identify the student level of competency and their weaknesses and strengths in manipulative skills, their focus will become clearer and from here the skills can be further moulded, until they achieve the autonomic stage of performing manipulative skills.

DISCUSSION

This study explored the appropriateness of a developed resource guide in assessing secondary school students' manipulative skill from the perspective of experienced science teachers. Developing a resource guide takes a lot of effort, time and consideration. After much deliberation, the researchers decided to use a modified framework of the ADDIE Model. The ADDIE Model is the systematic instructional design model which serves as a basic framework for almost all instructional design models (Isman, Abanmy, Hussein, & Al-Saadany, 2012). ADDIE model provides an organized way to develop learning activity and instructional strategy to ensure competent assessment instruments can be created for the teachers.

Previous studies (for e.g. Ishak, 2014; Ng, 2014) found that Malaysia science teachers lack competence and skills in assessment of manipulative skills during practical work. This is in agreement with the findings from this study where the teachers agreed they still have difficulty to assess students' manipulative skills due to the lack of information as what are to be observed during laboratory work. The excessive number of students in the science classroom complicates matters. It is difficult for teachers to control the classroom and at the same time they have to ensure that each student acquired the intended manipulative skills. To address the aforementioned issue, a rubric has been developed based on emerging finding from the first part of this research.

Rubrics are well-known in pedagogical plateau. Rubric is advantageous in providing teachers with a guideline to envision what is perceived as effective teaching (Sato, Wei, & Darling-Hammond, 2008) as it serves as a medium that can provide concrete evidence of what that need to be achieved. Jonsson and Svingby (2007) argued that rubric offers teachers a roadmap to engage with what is perceived as excellent assessment behaviours and practices. According to Allen and Tanner (2006), rubric not only can be designed to formulate standards for levels of accomplishment but can also be used to guide and improve students' performance. Teachers from this research agreed that the manipulative skills rubrics were relevant and practical to be implemented in the context of secondary school science learning. In other words, this rubric can be used to make the appropriate standards of manipulative skills clear and explicit, not only for teachers but appropriate for the students as well. Students can get a clear sense of what the expectations are for a high level of performance and how they can be met, as suggested by Huba and Freed (2000) and Luft (1999). The teachers agreed the resource guide can be extremely beneficial in enhancing their understanding into how manipulative skills can be assessed. Moreover, the resource guide can provide information on the competency level of students, individually so that students can be more prepared for the implementation of the upcoming science practical examination.

CONCLUSION

In light of the findings, it can be concluded that the development of this resource guide is advantageous and beneficial to facilitate teachers in revealing students' manipulative skills competency during practical work. Based on the positive feedback from the experts, this guide can also serve as a powerful instrument for teachers in enhancing the acquisition of science manipulative skills. The research found that minimal research attention has been directed toward exploring appropriate assessment method in manipulative skills and issues relating to it. Teachers must be aware of the students' different abilities in manipulative skills. This means that the approach in teaching manipulative skills has to be appropriate, in order to address the students' competency in handling apparatus. Innovative pedagogical approaches and effective instructional materials may be used to improve teaching and learning in order to enhance student learning and facilitate the acquisition of manipulative skills. Thus, more research is needed to follow up on the numerous issues raised in this study.

ACKNOWLEDGEMENT

This study is supported by *Small Research Grant Scheme*, grant number BK060-2017 by University of Malaya, Kuala Lumpur, Malaysia.

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