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Exploring Students' Acquisition of Manipulative Skills during Science Practical Work

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ABSTRACT

This paper reports a study on students' science manipulative skills at the lower secondary school level. Students' manipulative skills can be explored by understanding their technical skills and their functional aspects of performing experiment. However, this paper will focus on students' technical skills in using basic scientific apparatus. Technical skills in this study refer to skill, abilities, and knowledge required for accomplishing a specific task in the laboratory. The skills include knowledge and skills needed to properly manipulate and operate scientific apparatus when executing a scientific task. It was found that students perform the skills in a certain pattern that reflects a form of hierarchy. This hierarchy can be used to aid science teachers in teaching manipulative skills. The paper will present the hierarchy of these technical skills and discuss these skills specifically from the perspective of lower secondary science teaching and learning. The results of this study have provided an insight on the issue of science manipulative skills that supports the importance of practical work.

Keywords: practical work, psychomotor skills, science manipulative skills, technical skills

INTRODUCTION

With the advent of information technology, the mastery of science and technology among school students is important to produce well-informed, scientific literate and competent human capital. Nevertheless, science education faces a great challenge. Recent international studies have shown that engagement with school science and motivation to choose science related career among secondary school students are alarming, as students actively reject science related career as a future career option (Kudenko & Gras-Velázquez, 2016; McFarlane, 2013; Van Griethuijsen et al., 2015). According to Gilbert and Justi (2016) evidence of students' lack of engagement in science classes is used to support widespread dissatisfaction regarding students' levels of attainment in international studies and with their disinclination to continue to study science related discipline in higher education institutions. This has led to concern among policymakers about their nation's science and technology workforce, as well as the scientific literacy of their populations (Van Griethuijsen et al., 2015). In regard to international studies, for example, the Trends in International Mathematics and Science Study (TIMSS) has shown disturbing trends among many developing countries. The TIMSS findings suggest that declining attitudes toward science education

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State of the literature

- Science education in the 21st century emphasize on the acquisition of scientific knowledge and development of scientific skills through active teaching and learning approach in order to develop students proficiency in scientific inquiry.
- Students' interest and enthusiasm in the understanding of science can be grasped by performing experiments and creating concepts at first hand in the laboratory, and certainly not by only reading about theories.
- Manipulative skills are generally given the least attention in the course of academic instruction although important aspects of learning can occur in this area. Research in science manipulative skills is still very limited and more research in this area should be carried out to improve students' science practical skills.

Contribution of this paper to the literature

- The aforementioned gap in the literature is addressed in this paper by critically examining students' views through the lens of contemporary theories of manipulative skills acquisition.
- Students' manipulative skills can be illustrated by an understanding of components and elements in technical skills and functional aspects of performing the experiment.
- Findings revealed that students perform the manipulative skills in a certain pattern that reflects a form of hierarchy. The five levels hierarchy of learning technical skills can be used as a guide for teachers to enhance the students' skills in handling of apparatus.

constitutes an international crisis. For example, in Malaysia, the TIMSS science score in 2007 decreased radically to 471 points, 40 points lower than the score of TIMSS 2003. TIMSS 2011 revealed the same trend, with science decreased to 426 points, 45 points lower than the score in 2007 (IEA, 2012). However, the latest TIMSS indicated that Malaysian students' performance in TIMSS 2015 have improved significantly at 471 points, an increase of 45 points from the score of 426 in TIMSS 2011.

In the meantime, issue related to low intake rate in science-related fields at the upper secondary level is also alarming (Fadzil & Saat, 2014; Kennedy, Lyons & Quinn, 2014; Smith, 2011). The trends reported in Malaysia have been echoed in other countries, including Australia (Kennedy, Lyons & Quinn, 2014), England and Wales (Smith, 2011), France (Charbannier & Vayssettes, 2009) and Western European countries (Van Griethuijsen et al., 2015). This indicates that the decline in participation in science education enrolment may go beyond national and cultural borders. To address this declining enrolment, science education needs to be more relevant to ensure a prolonged positive attitude and an interest in science as a school subject.

Recent studies (for e.g. Hasni and Potvin, 2015; McFarlane, 2013; Schwichow, Zimmerman, Croker & Härtig, 2016) have shown that secondary school students prefer teaching methods in which they can play an active role in "doing" science such as collecting scientific data through observation and experimentation. According to McFarlane (2013), in order to enhance students' interest in learning science subjects, there is a need for a more involved and activity-based practical approach that provides students with opportunities to engage with science, as science subject has long been taught and learned as a mono-methodological branch of knowledge (McFarlane, 2013). This attitude needs to change through the practice of embracing more student-centered approaches in science learning. Thus, practical work is one of the most distinctive features of science that may ignite students' interest in learning this subject (Allen, 2012; Sorgo & Spernjak, 2012).

The skill to conduct hands-on practical work in science laboratory is an important scientific process skill and a common intention of science standards (Schwichow, Zimmerman, Croker & Härtig, 2016). Abrahams and Millar (2008) and Abrahams, Reiss, and Sharpe (2013) define the term 'practical work' as any type of teaching and learning that involve manipulating and observing real objects. However, practical work in the context of this study can be defined as any hands-on and minds-on scientific activity in which students work actively, either individually or in small groups, to observe any physical phenomena (Fadzil & Saat, 2013). Practical work emphasizes learning

through inquiry and discovery and encourages students to learn through the discovery of phenomena that occur in the environment. Such a learning strategy might facilitates the acquisition of scientific knowledge and the understanding of scientific theories (Fadzil & Saat, 2013; Schwichow, Zimmerman, Croker & Härtig, 2016).

Research in practical work has developed tremendously over the years and has been given increasingly important emphasis around the world (Allen, 2012; Hofstein & Mamlok, 2007). Through practical work, students get an opportunity to investigate phenomena, draw conclusions, and practice the scientific skills in handling apparatus that lead to meaningful science learning and development of critical thinking skills. However, when it comes to the issue of implementation, recent studies (e.g. Abrahams, Reiss & Sharpe, 2013; Fuccia, Witteck, Markic & Eilks, 2012; Fadzil & Saat, 2013) reported that practical work is still limited in many school science laboratories. Laboratories can be considered the best place to learn scientific skills such as the manipulative skills, and these skills are learned as part of formal instruction in science. Nonetheless, teaching and learning of science focused more on retention of knowledge where students were too involved with too much writing and too little practical work (Campbell, 2001; Fadzil & Saat, 2013).

Due to the lack of practical work in science, students may have to deal with problems obtaining specific skills in manipulating scientific apparatus and equipment in the laboratory. There is consensus throughout the literature that students have difficulties using and handling scientific apparatus proficiently (Fadzil & Saat, 2013; Ferris & Aziz, 2005; Grant, 2011; Hamza, 2013; Tesfamariam, Lykknes & Kvittingen, 2015; Wickman & Ostman, 2002). Research by Delargey (2001) and Buffler, Allei and Lubben (2001) have shown that science laboratory activities at the school level are also vital in preparing students for their higher education level. It is assumed that student progression to the next level of practical skills acquisition depends on their progression in the lower level. Research by Demeo (2005) has shown that students who actually performed manipulations in the laboratory were more successful on evaluations of their practical skills than students exposed to non-laboratory method such as demonstration. This is in line with a small-scale study that reported that university students not only lack appropriate practical skills but also lack of confidence to carry out practical work (Grant, 2011). Grant also found that limited exposure to practical work at school was the main contributing factor to the lack of practical skills at the university level. Thus, higher education institutions have to adapt lab-based teaching to focus on the development of practical skills in first-year practical courses. Similarly, Ferris and Aziz (2005) found that students at tertiary-level institutions who performed well on examinations did not necessarily show competency in laboratory skills. Hamza (2013) argued that students need to experience practical work for future learning and that the science experience can be used fruitfully in another setting. This claim, also supported by Wickman and Ostman (2002), demonstrated that university students learn science by using previous science experiences in school successively. According to Tesfamariam, Lykknes and Kvittingen (2015), the barriers in conducting laboratory work were mainly due to budget constraints, large class size, time constraints, and inadequate teacher preparations. Thus, practical activities are frequently omitted from classroom instruction in most developing countries. The aforementioned studies (Fadzil & Saat, 2013; Ferris & Aziz, 2005; Grant, 2011; Hamza, 2013; Tesfamariam, Lykknes & Kvittingen, 2015; Wickman & Ostman, 2002) clearly illustrate that insufficient opportunities in performing experiments at school level might affect students transition to higher learning institution as they may encounter much difficulty in the future because of the lack of skills and experience.

The development of manipulative skills is one important aim of practical work (Abrahams, Reiss & Sharpe, 2013). These include abilities such as using a microscope, reading the temperature of boiling water using a thermometer, or manipulating a Bunsen burner. According to Kempa (1986), manipulative skills can best be defined as psychomotor skills that relate individual cognitive function with corresponding physical movement. According to Anderson's (1982) framework of skill acquisition, there are two major stages involved in the development of cognitive skills known as declarative stage and procedural stage. These stages are based on long-term memory stores: a declarative memory and a procedural memory (Taatgen, 1999). When the learner receives instruction and information about particular skills, the instruction will be encoded as a set of facts about the skills. These sets of facts will be interpreted further to generate desired behaviour (Anderson, 1982).

In science, manipulative skills emphasize the use and handling of scientific apparatus and chemical substances during scientific investigation in the laboratory. In addition, students are exposed to the proper

technique for using, cleaning, and storing scientific equipment safely. Students' incapability of acquiring science manipulative skills can seriously affect acquisition of other desirable skills in the laboratory, for example, if they struggle to operate a piece of apparatus, this may lead to failure in making important observations and gathering relevant data (Anderson, 1970; Fadzil & Saat, 2014; Johnstone & Al-Shuaili, 2001). Furthermore, students who are competent in science manipulative skills will have better opportunity concentrating on the development of science process skills which involve skills such as observing, classifying, measuring and using numbers, inferring, predicting, communicating, using space-time relationship, interpreting, defining operationally, controlling variables, making hypotheses and experimenting (Johnstone & Al-Shuaili, 2001). Thus these scientific skills need to be taught to students progressively and in this situation, teachers are the main instrument who are responsible in developing, inculcating the skills of science learning, as well as transferring the science manipulative skills to their students.

In order for the teaching and learning of manipulative skills to be effective, it is necessary to know what it is that is being assessed. Lack of reliable assessment have resulted in the unfortunate neglect of experimental work in most of the schools (Abrahams, Reiss & Sharpe, 2013). The assessment of students' practical work in science laboratories is also important because learning science is indistinguishably linked to the evidence collected and analyzed in laboratory settings. Assessment is a process of getting evidence to understand student's acquisition and performance in manipulative skills. In countries such as Malaysia, direct assessment of students' practical skills is limited. Thus, there is less inclination amongst teachers to devote time and effort in developing students' practical skills (Campbell, 2001; Fadzil & Saat, 2013). According to the study conducted with 40 Grade 6 and Grade 7 teachers, science teachers still have difficulty not only in assessing but also in teaching students' manipulative skills because they lack information about what should be observed. For example, teachers overlooked the possible indicators to be observed during practical work such as the students' ability in setting up the apparatus correctly and taking readings appropriately by using the necessary instruments (Fadzil & Saat, 2013). Teachers were also unaware that certain hierarchies can be used to teach manipulative skills in science classrooms (see Ferris and Aziz (2005), Simpson (1972) and Dave (1970) for more information). For instance, Ferris and Aziz's (2005) psychomotor domain taxonomy consists of seven (7) levels of competence: (1) recognition of tools and materials, (2) handling of tools and materials, (3) basic operation of tools, (4) competent operation of tools, (5) expert operation of tools, (6) planning of work operations, and (7) evaluation of outputs and planning means for improvement. The taxonomy assumed that student advancement to the next level of learning is dependent on mastery at the lower level. However, this taxonomy is more appropriate in addressing and imparting manipulative skills in higher learning institutions, specifically, in the engineering education community. In this study, the aforementioned taxonomies serve as a guide in analyzing the students' skills and abilities in the manipulative domain in order to explore and acquire deeper understanding of this phenomenon at lower secondary school level. Thus, scientific research needs to be done with an appropriate methodology as an eye-opener to the relevant stakeholders in the school context. The aims of this study are (i) to explore the students' manipulative skills in using basic apparatus during science practical work and (ii) to explore whether students perform the skills in a certain pattern that reflects a hierarchy that can be used to aid school science teacher in teaching the manipulative skills.

METHODOLOGY

In this section, we describe the background of research, participants and context of the study, validity and reliability, and how our data were collected and analyzed from a qualitative research perspective.

Participants and Context

The present study was conducted in four secondary schools in a suburban district and data collection took 6 months to be completed. Selection of these schools was based on a typical case sampling in which these schools were not unusual in any way, and this reflects the average phenomenon of interest (Merriam, 2009; Patton, 2002). Ten participants were purposely selected by their science teachers. The main criteria in selecting participants were they should be articulate and have the ability to express their opinions. During the data collection, laboratory observations during students' laboratory work have been conducted and at the end of the study, each student

Table 1. Tasks in SMST and its learning outcome

Tasks	Learning Outcome	Specific apparatus used in experiments
Task 1 Theme: Investigating Force and Energy	To measure the temperature of water when it is heated	Thermometer Bunsen burner Measuring cylinder
Task 2: Theme: Investigating Living Thing	To observe the movement of microorganism	Microscope
Task 3: Theme: Matter in Nature	To understand how the presence of salts affect the boiling point of water	Thermometer Bunsen burner Measuring cylinder
Task 4: Theme: Man and the Variety of Living Things	To understand that organism are built from the basic units of life	Microscope

conducted four individual experiments and was video recorded while performing the specific tasks. They were also interviewed at least four times. Prior to the actual study, a preliminary study was conducted to refine the instruments (Science Manipulative Skills Tasks, SMST) to test and validate the SMST for its appropriateness and usability. As the result of the preliminary study, the interview questions were further refined, basically in terms of wording. The numbers of questions were also reduced. The sentence structures were altered to cater to the students' capability in understanding the given questions. For example, the interview protocol initially consisted of 25 questions. During the preliminary study, the number of questions was reduced to only 20 questions. The sentence structure and word usage were also simplified for more meaningful understanding, for example, the words *science apparatus* and *manipulative skills* were considered as a jargon to the participants; instead of "Can you give an example of science apparatus that you have used at primary school?" was reworded to "Can you name some scientific equipment that you have used at primary school?" From the interview in actual study, we noticed the change in students' responses when the different wordings were used.

Science Manipulative Skills Tasks (SMST)

SMST is a set of four tasks designed to understand students' manipulative skills at the lower secondary school level (refer **Table 1**). SMST was developed based on analysis of related documents, specifically the science practical manuals, science curriculum specification, science textbooks, and science teaching and learning materials for the seventh grade. The tasks were not created to evaluate students' knowledge of the scientific concepts, but were developed specifically to measure students' ability to use and handle the apparatus.

The procedures of the experiments in SMST had to be simplified, as compared to the procedures from the text book. For example in the text book, students were given detail instructions such as "measure 100ml of water by using measuring cylinder" and "stir the solution by using glass rod". However in SMST, the instructions given were "measure 100ml of water" and "stir the solution from time to time". These were done to avoid cookbook type of instructions and to see the students' true ability in using the apparatus during the execution of the tasks. Therefore the use of practical activity from the text book was not suitable for this study. The tasks required students to manipulate four basic scientific apparatus: thermometer, measuring cylinder, Bunsen burner, and light microscope. It would be advantageous for students to acquire the manipulative skills needed to handle these scientific apparatus. The tasks served as a basis and a foundation for the acquisition of higher level manipulative skills. For example, the use of a measuring cylinder served as the basis for using other specialized apparatus, such as a burette, a pipette, and a volumetric flask, where the fundamental skills and techniques were not much different.

Validity and Reliability (Trustworthiness of Data)

While designing a qualitative study, validity and reliability are two issues that a researcher should be concerned about (Golafshani, 2003; Lincoln & Guba, 1985; Patton, 2002). Qualitative researchers need alternative

models that can ensure the rigor without sacrificing the relevancy of the qualitative data. Among the approaches implemented in this study is triangulation. Triangulation is one of the strategies for improving and enhancing the internal validity of research in order to control bias. According to Bryman (2006), triangulation refers to the use of more than one approach to the investigation of a research question in order to enhance confidence in the ensuing findings. This study adopts the triangulation of data and methodology. The input came from several sampling strategies so that data at different times and from a variety of sources were gathered. Students were interviewed and observed at a few phases during field work of this study. The data were collected through various techniques which were observation, interview, field notes, video and audio recording. Prolonged and persistent field work was carried out in this particular research in order to enhance the internal validity and reliability in qualitative research (Fraenkel & Wallen, 2008). Consistency over time with regard to what researchers are seeing or hearing is a strong indication of reliability or dependability. There is much about a group that does not even emerge until some time has passed and the members of the group become familiar with and are willing to trust the researchers. This research took six months for data collection and within that time the researchers tried to establish a good connection with the sample in order to ensure the stability of observations over time. In order to avoid the observer effect, the researchers had interacted with the students frequently for a certain period of time. This made the students become familiar with the researchers presence so that they carried out their activities in the usual manner.

Procedure

In this study, observations were conducted in order to understand the students' manipulative skills. According to a literature review on assessing science manipulative skills, direct observation technique, where the students exhibit the skills to an assessor, is the most appropriate instrument for understanding manipulative skills (Johnstone & Al-Shuaili, 2001; Kempa, 1986; Lunette, Hofstein, & Clough, 2007). Two types of observation were carried out: (1) individual observation of tasks from SMST and (2) laboratory observation during students' practical work. During the task performance, we did not interfere with the students' work. We observed the students' skills individually to understand the different ways in which they manipulated the instruments in conducting the experiment. However, if the situation got out of control (for instance, there was an incident where the students tended to hold the thermometer recklessly and tapped it to the surface of the table), we intervened in order to avoid unwanted incidents.

Semi-structured interviews were also employed in this study. We were then able to determine issues experienced by the students regarding acquisition of manipulative skills. The interview sessions were conducted after the students had completed each SMST task. We ensured that the time lapses between the observation of students completing SMST tasks and the interview session were not too long so that the students were able to recall the skills they had performed earlier. One-on-one interviews (Creswell, 2008) were conducted in this study to gain insight about the students' true ability in using and handling the scientific apparatus. Students were expected to rationalize and justify their actions in handling scientific instruments during the execution of the tasks. From the observations and interviews, we were able to explore the students' acquisition of manipulative skills.

Data Analysis

A constant comparative research method was employed in interpreting the data. Data were collected from individual observations of students performing SMST tasks and interviews. The preliminary planning of the data analysis involved a systematic process of organizing a considerably large amount of data from audio-taped interviews and video-taped observations and transformed it into transcripts. These data were then analyzed inductively using the constant comparative method of analysis, which involves the process of coding, categorizing, and developing themes from information that emerges from the collected data, as suggested by Strauss and Corbin (2008).

The detailed analysis started with the process of open coding, where every transcribed observation was explored and coded to generate initial categories and to suggest relationships among categories. This was done to determine the students' technique in manipulative skills during execution of the tasks. The researchers began the analysis on a small part of the data in order to generate a set of initial categories. For example, if one excerpt was

given the label 'efficiency', the researchers examined the observation data for other relevant excerpts that could be given the same code. If reference was made to the same category again, the excerpts related to the 'efficiency' were compared and contrasted in order to determine the commonalities, differences, and dimensions of the highlighted code. During this stage of data analysis, researchers kept in mind the issue of suitability of the codes used for the observation data. Questions were continually addressed during analysis, including: What are the characteristics of each excerpt in the same categories? What characteristics do excerpts with the same code have in common? How are all the excerpts related?, as suggested by Boejie (2002).

General patterns were identified to make a robust conclusion of the findings. Seven categories and 18 subcategories emerged from the first level of analysis. After deliberations, the second level of analysis was constructed, comprising five categories and 11 subcategories. The emerging categories and subcategories were compared and refined until they were mutually exclusive. Refining the thematic framework involves logical and intuitive thinking to ensure that the research objectives are addressed appropriately, as explained by Ritchie and Spencer (1994). For example, to get a general trend of manipulative skills required for each apparatus, this category had to be reanalyzed by segregating and dissecting the data according to the apparatus (i.e., measuring cylinder, Bunsen burner, thermometer, and microscope). Again, these emerging subcategories were compared and contrasted to identify the general trend for each apparatus. This resulted in the identification of subcategories or elements under the component of 'technical skills.' The reliability of the tasks (SMST) and interview protocols was determined by peer review and through multiple processes during preliminary study of this research. Themes and categories identified during data analysis were also judged by a panel of experts in the field of qualitative research and science education. Peer review, as such, is regarded as one of the techniques used to enhance the credibility and trustworthiness in qualitative research (i.e., through the use of experts) (Merriam, 2009).

RESULTS AND DISCUSSION

Based on the results, the students' manipulative skills can be illustrated by an understanding of dimensions and elements in the technical skills and functional aspects of performing the experiment, as represented in **Figure 1**. Technical skills in this study refer to the skills, abilities, and knowledge required to accomplish a specific task in the laboratory. The skills include the knowledge needed to properly manipulate and operate scientific apparatus when executing a scientific task. On the other hand, functional aspects of performing scientific experiments can be defined as specific procedures (apart from the technical skills) that are related to the operation of manipulative skills while performing the experiments. Functional aspect of performing scientific experiments include (i) the systematic operation of tasks which are characterized by the organized manner that the students illustrated during the execution of tasks in the laboratory, (ii) students' ability to complete tasks within the specified time frame and students' attitude in making sure that the appearance of their working area was orderly and neat, (iii) students' ability to clean and store apparatus after using them, (iv) safety and precautionary techniques in science laboratory and (v) the tendency to make assumption, measuring, and the skills in drawing specimens. This paper will focus only on the technical skills of performing experiments.

The technical skills are divided into two main categories: using graduated apparatus and using sequential apparatus. Graduated apparatus are apparatus with lines or markings to indicate the measurement. In this study, a measuring cylinder and a thermometer were categorized as graduated apparatus. Sequential apparatus, on the other hand, are apparatus that require the user to understand and acquire specific knowledge about the sequence of using it in order to use the apparatus efficiently. The Bunsen burner and the microscope are categorized as sequential apparatus. Six (6) categories emerged to reflect the technical competencies that students should acquire in order to manipulate the basic apparatus. These include (i) the ability to recognize apparatus and its function, (ii) the ability to identify parts and features of apparatus and its function, (iii) an understanding of the basic principles of using and handling apparatus, (iv) appropriate approaches to minimize standard errors during measurement in using graduated apparatus, (v) correct sequences in using the sequential apparatus, and (vi) the ability to complete the task efficiently.

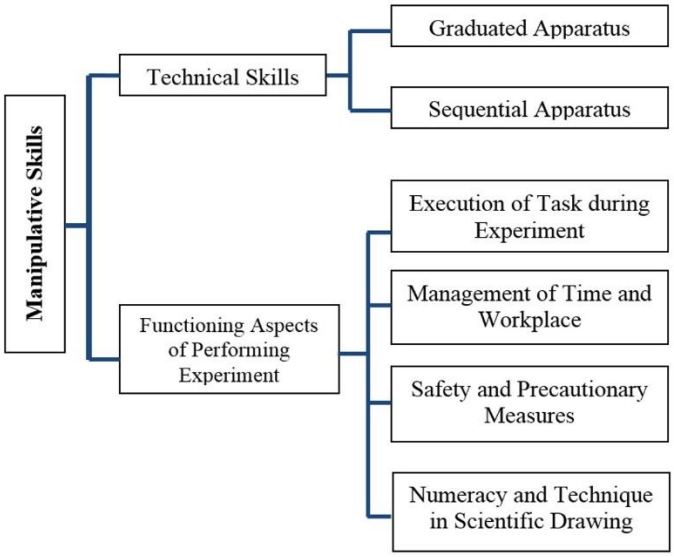

Figure 1. The dimensions and elements of manipulative skills

Ability to recognize apparatus and its function

The students showed good ability in recognizing the apparatus. Almost all of them gave the correct name for the measuring cylinder, thermometer, Bunsen burner, and microscope and the function of each. The following excerpt was taken from an interview session with Student 4:

Researcher: Can you please tell me the name of this apparatus

(showing a measuring cylinder to the student)?

Student 4: Erm…Measuring cylinder.

Researcher: Do you know what is the function of this apparatus?

Student 4: To measure the volume of water.

(Int. 1, S4a, Ln. 65–68)

Recognition is necessary as the first step of being able to use tools or materials effectively. Once the apparatus and its parts have been recognized, it is possible to relate it to other important information. This finding is consistent with Ferris and Aziz's (2005) first level of psychomotor domain taxonomy, which explains that recognition of tools and materials is vital for students' effectiveness and safety when handling scientific apparatus. However, findings from the observation showed that students encountered difficulties in practicing the correct way to use apparatus according to its specific function. For instance, during the experiment, most of the students tended to use the beaker instead of the measuring cylinder to measure a volume of liquid. Theoretically, beakers should only be used for ballpark estimation of the volume of liquid. Thus, this basic technical skill not only involves the students' ability to recognize the apparatus and identify its parts and functions but also takes into consideration their ability to use the apparatus according to its specific function. The task given is not sensitive to the exact volume of water; however, in a higher level of secondary school science, especially in chemistry, the use of a very accurate volume of solution is vital in conducting scientific investigation, such as in the practice of titration.

Ability to identify parts and features of apparatus and its function

This category focused on the students' ability to identify every part and feature of an apparatus and its function. The apparatus must be distinguished in order for the students to master the technical skills of using it.

This category represents an essential aspect of learning technical skills because the ability to identify the different parts of apparatus will help the students in using the apparatus competently. The findings showed that none of the students were aware of the different parts and features of the graduated and sequential apparatus. In using the thermometer, for example, the students could only acknowledge that a thermometer contains mercury. During the interview session, only two students were able to explain the function of the air hole of a Bunsen burner. However, based on our observation, none of them could show the correct technique of adjusting the air hole during execution of the task. This clearly shows that the students had difficulty in practicing what they have learned theoretically in their science classroom.

Students were also incapable of identifying parts of the microscope and their functions. Observation conducted during the laboratory session showed that the students experienced difficulty in following the teacher's instruction during the experiment because of their inability to identify parts of the microscope. For instance, during the laboratory observation, the teacher asked the students to manipulate the coarse adjustment knob in order to examine the onion cell more closely. A number of students were not able to recognize that particular part of the microscope and used the fine adjustment knob instead (S7b, LObs.1, Ln. 25–26). From the observation, we realized that, it is important for the students to be able to distinguish the different parts of apparatus before they are able to operate the apparatus efficiently. During the interview conducted with the students, most admitted that they were not aware of the need to know the different parts of a microscope, as illustrated in the following excerpt:

Researcher: So why couldn't you recognize the important parts of the microscope?

Student 6: I think because I rarely used it…and I don't think it is important for me to memorize each part of the microscope.

(S6b, Ln.39–40)

Past research (e.g., Azizi, Shahrin & Fathiah, 2008) revealed that students showed poor capability in handling the Bunsen burner and were unable to name the different parts of the Bunsen burner and the function of each part. The difficulty in identifying the parts of an apparatus and its function needs to be tackled at the lower level of learning science to ensure smooth operation of a task and to prevent the problem from affecting the students' skills at higher levels of learning. If the student encounters difficulty in identifying the function of each part of the apparatus, it may impede their learning of basic principles of using the apparatus. For instance, in using the microscope, students should be able to distinguish each part of the microscope and its function in order to understand the principles of using it. For example, before the students learn how to use the coarse adjustment knob, they must first identify the coarse adjustment knob and its particular function. The coarse adjustment knob is a round knob on the side of the microscope that is used for focusing the specimen.

An undertanding of the basic principles of using and handling apparatus

Basic principles of using and handling apparatus in this context can be defined as fundamental rules that the students must follow to ensure the correct result is obtained from execution of the task. Inability to follow the rules may prevent the students from obtaining accurate results for the experiment and can put their safety at risk. Students must take adequate precautions to ensure reliable observations and results. The findings showed that most of the students exhibited inappropriate technique in using and handling of graduated and sequential apparatus.

In using the thermometer, most of the students made the common mistake of holding the thermometer at the tip of the upper stem, immersed the wrong end of the thermometer during measurement, let the thermometer bulb touch the bottom of the beaker while taking the temperature of the solution, and had a strong tendency to stir the solution using the thermometer, even though they were given a glass rod. These inappropriate techniques in using the thermometer may prevent the students from obtaining accurate results for the experiment. When it came to the use of sequencing apparatus, students demonstrated poor techniques in using the Bunsen burner and microscope, as displayed in the following observation excerpts:

He took the Bunsen burner and placed it under the tripod stand.

He turned the gas knob without lighting the Bunsen burner.

(Obs.3, Ep.2, S5b)

She did not even use the coarse adjustment knob during this experiment, until her friend asked her to do it. She did as her friend suggested.

(Obs.4, Ep.2, S4b)

The results of the study also suggested that students' understanding of the basic principles of using and handling apparatus depends on their ability to recognize an apparatus and identify its parts and function. For instance, students should be able to distinguish the different parts of the Bunsen burner and its function in order to understand the principles of using it. This also concurs with Ferris and Aziz's (2005) third level of psychomotor domain, which concerns the student's ability to hold the tools, set the tools in action, and perform the tasks in the most basic form. This current study indicated that most of the students were still struggling to acquire these fundamental technical skills.

The findings revealed that students were unable to master the appropriate techniques and basic skills of using apparatus. This could be attributed to the teaching and learning of science at this level that did not emphasize concrete understanding of principles in scientific investigation. For example, students were introduced to the basic rules and principles of using a thermometer in Grade 5, but they did not understand the rationale behind every principle. For instance, they should understand why the tip of the thermometer should not touch the walls or bottom of the container. If the thermometer bulb touches the container, the temperature of the glass will be measured instead of the temperature of the solution. Stirring the solution during heating provides a better representation of the entire solution but should not be done using the thermometer. Students should use a glass rod instead.

The results of the study also suggested that the learning of basic techniques for using apparatus depends on students' ability to process the observed events during the teacher's demonstration and to try to repeat the action by referring to detailed instructions, as reflected during the laboratory observation during students' practical work. The findings of the study also align with the findings of Bandura (1977), Dave (1970), and Simpson (1972). Bandura's observational learning theory (1977) discussed the process of 'attention' which stated that students' observational skills and sensory capabilities can influence the accuracy of information retention. This finding is also consistent with Dave's (1970) 'imitation' category of skills learning, which explained that students' replication of skills can only occur by referring to an exemplar. In the context of this study, the teacher is the exemplar, or model, for learning manipulative skills. Simpson's (1972) category of 'guided response' in the learning of psychomotor domain explains that the early stage in learning a complex skill includes both the process of imitation and trial and error.

Appropriate approaches to minimize standard errors during measurement in using graduated apparatus

This component explores the approach used by the students to minimize the standard error when using graduated apparatus in order to obtain accurate measurements during the experiment. It was noticed that most of the students were aware of the appropriate technique to be followed in order to prevent parallax error. This awareness was also manifested during the interviews. They ensured that their eyes were parallel to the meniscus while taking the measurement. However, the students showed inappropriate approaches to accomplish the criterion. Most of the students were unaware of this basic principle of using the measuring cylinder. For example, they should place the measuring cylinder on a flat surface in order to obtain an accurate measurement of the volume of liquid. It was observed that they tended to raise the measuring cylinder and bring it closer to their sight. For instance, Student 3 lifted the measuring cylinder to his eye level, while the basic principle of using a measuring cylinder is to place the cylinder on a flat surface (refer to **Figure 2**).

Figure 2. Student 3 lifted the measuring cylinder during measurement

Figure 3. Student 4 tilted his head when reading the meniscus

In other cases, the students tilted their head while taking measurement instead of lowering their head to get accurate readings (refer to **Figure 3**). Some of the students chose a different option to simplify the task. For instance Student 4, *'checked on the volume of water by placing the measuring cylinder on the tripod stand' (Obs.1, Eps.2, S3a)*. Doing this placed the meniscus parallel to his eye level so he did not have to lower his eyesight.

Among the common mistakes students made while using the thermometer was removing the thermometer from the beaker and bringing it close to their sight so the meniscus was parallel to their eyes, as illustrated in the following field notes:

> Student 1 took out the thermometer from the beaker and brought it closer to his sight. His eyes narrowed. He put the thermometer back into the water.
>
> (Obs.1, Ep.4, S1a)

This finding revealed that 'hands-on' activity in practical work is a vital component of science learning. In this particular case, students were able to explain how to handle apparatus theoretically during the interview session. However, based on the observation of tasks, the students showed numerous techniques that were considered inappropriate. Students are expected to acquire the skills of reading the scales of the basic measuring instruments and should be able to record an accurate measurement. As the students learn to manipulate the apparatus, they increase their skills and become more efficient in obtaining meaningful data from their science experiences. The difficulties in reading a meniscus occurred when the students read about the skills but had not been given much opportunity to conduct scientific laboratory investigation. The skill of measurement is a basic foundation of acquiring higher measuring skills that require accuracy. This supports the claim that difficulty in mastering the appropriate skills to minimize parallax error may impede the students' ability to be efficient in using the graduated apparatus. Errors such as parallax error need to be minimized in order to achieve accurate and precise readings. Improper manipulative techniques could affect students' experimental results.

Correct sequences in using the sequential apparatus (Bunsen burner and microscope)

The competency in sequencing can be related to student awareness in implementing appropriate precautionary measures during the using and handling of the apparatus. Most of the apparatus use the same principle of operation, even though the sequence can differ slightly according to the apparatus. The suitable sequence of using the apparatus should be followed by the student in order to be familiar with the apparatus, which in turn will lead to greater efficiency in handling. For example, in using the Bunsen burner, the collar of the Bunsen burner should be turned off before the user lights the burner so that the air hole is closed. After the flame is lit, the air hole needs to be open so that the flame changes to a non-luminous blue flame. Inability to recognize this sequence will affect the student's awareness of the appropriate precautionary measures that should be taken during manipulation of the Bunsen burner. None of the students in this study practiced the correct technique of lighting the burner sequentially. They were not aware of the function of the air hole and the correct technique of controlling the amount of gas, as illustrated in the following excerpt:

> He turned the gas valve carefully and lighted the burner. He adjusted the flame and slowly brought the burner under the tripod stand (students did not bother to manipulate the air hole before and after lighting the burner)
>
> (Obs1, Eps 2, S7a)

The inability to recognize the sequence of using the apparatus will affect students' awareness of suitable precautionary measures to be taken when using the Bunsen burner. Students' sequential skills of using a microscope in Grade 7 were considered insufficient. For instance, Student 3 demonstrated an inadequate sequence of technical skills. She did not show any ability in using the stage clips, mirror, condenser, diaphragm, or coarse adjustment knob in sequence. She did not bother to use the lowest magnification power objective lens. The findings showed that the students' sequential skills were very basic. This corresponds to the hierarchy of learning technical skills, which stated that achievement of higher-level skills depends on the achievement of lower skill levels. Thus, the ability to obtain higher skill levels was only made possible through achievement of lower skills. This is clearly demonstrated in the findings of this study. The inability to recognize the sequence of using the apparatus will also affect the students' awareness of the appropriate precautionary measures that should be taken while handling an apparatus. Students should be given ample opportunity to manipulate sequential apparatus beginning in primary school so that learning the sequential skills becomes habitual and the movements become smooth. This finding is consistent with Simpson's psychomotor domain (1972), which stated that competency can only be achieved by practice and repetition.

Ability to complete the task efficiently

This component described the students' ability to use the apparatus efficiently and confidently. It involved two criteria: the mode of action in manipulating the apparatus and the level of guidance in performing technical skills. However, in this study, some of the students showed awkward and choppy movements when handling the thermometer to measure the temperature of boiling water. In another instance, some were able to operate the thermometer in a smooth and appropriate manner. Thus, this criterion has been used as an indicator to understand students' competency in technical skills. The level of guidance in performing technical skills can be determined from the students' skills performance. It emphasizes the teacher's role as an instructor in the science laboratory. The teacher is responsible for transferring technical skills to the students and for further enhancing the appropriate techniques in secondary school.

The skilful performance of technical skills involves complex movement. The students' proficiency in manipulative skills is indicated by a quick, accurate, and highly coordinated performance. It can be recognized by their ability to use the apparatus efficiently and confidently. This concurs with the research finding that categorized the students' 'ability' to complete the task efficiently' as performing the task smoothly and without hesitation. Students are expected to be able to use the apparatus competently, for which the tools were designed. The finding is also in accord with Ferris and Aziz's (2005) psychomotor domain, which concerns a student's ability to perform work tasks efficiently and effectively. The acquisition of manipulative skills during practical work depends on the students' development of cognitive abilities. In this taxonomy, higher-level technical skills involve more complex cognitive and psychomotor abilities. Students need to integrate their psychomotor (hands-on) skills and cognitive (minds-on) ability when performing specific scientific tasks in the science classroom in order to be competent at manipulating a certain apparatus.

Five-Level Hierarchy of Technical Skills

The results of the study suggest that manipulative skills acquisition is very much associated with the students' acquisition of scientific knowledge. Students perform the skills by the inputs that they perceive from declarative memory which involved retention of information. This finding is consistent with Trowbridge et al. (2000) who claimed that the desired behavior in manipulative skills is not an end in itself but the means for cognitive and affective learning in science education. However, the findings clearly show that a gap exists between students' declarative stage and procedural stage where their understanding and knowledge of using and handling apparatus given during interview were not related with their skills' performance.

Based on the six categories related to technical skills that emerged during data analysis, it was found that the students acquire these technical skills in a certain pattern. The pattern in technical skills reflects a hierarchy, as illustrated in **Figure 4**. This hierarchy resonates with earlier studies of psychomotor skills by Dave (1970), Ferris and Aziz (2005), Gagne (1985), and Simpson (1972). In the case of this research, these psychomotor domain taxonomy models provide direction in constructing this hierarchy of learning technical skills that is important for students to master. As discussed earlier, science teachers found that it was difficult for them to teach manipulative skills in the science classroom. Furthermore, the existing taxonomies did not cater to the teaching and learning of manipulative skills at the lower secondary science level. Thus, the five levels hierarchy of technical skills can be very useful for students in acquiring the intended skills.

The proposed hierarchy can be served as a guide to teachers and not to be used rigidly. The hierarchy illustrates that the students' advancement to the next level of skills depends on their achievement of the lower level of technical skills. For example, if the students experience difficulty in mastering the basic level of technical skills, such as the 'recognition of apparatus and its function' and 'identification of parts of apparatus and its function,' these sub-skills will impede their understanding of the basic principles of using the apparatus. This problem may later affect the students' ability to complete the task efficiently.

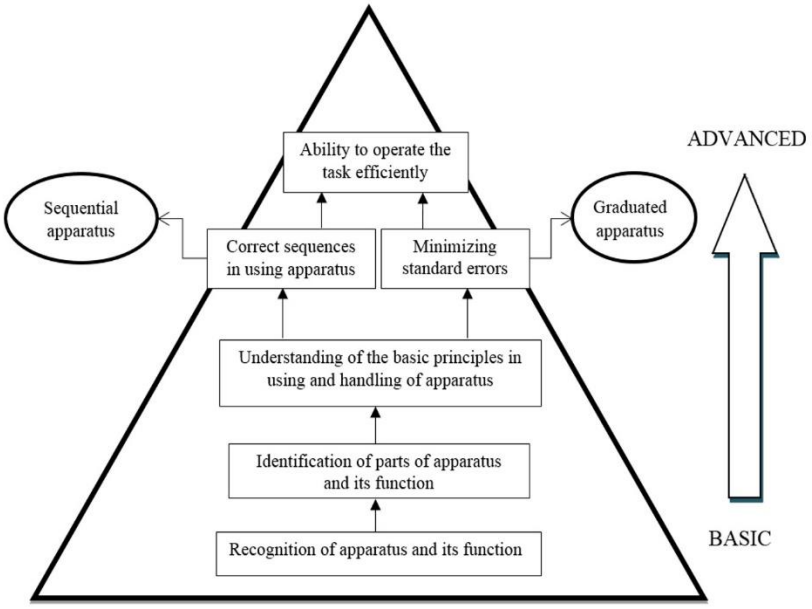

Figure 4. Five (5) levels hierarchy of technical skills

CONCLUSION

Manipulative skills play an important role for students to be able to complete science activities effectively. In order to acquire experience in manipulating specific scientific apparatus, it is important for students to perform various experiments using the apparatus. Good technique in handling and manipulating scientific apparatus is important because it can reduce, minimize, and control misinterpretations and may minimize the error in scientific experiments. Findings of this study show that the students' acquisition of manipulative skills during science practical work was very basic. The students' ability to acquire advanced skills was very much influenced by mastering of basic skills. Students acquire these skills in a certain pattern, and this pattern can serve as a hierarchy. This hierarchy can be used by teachers to teach manipulative skills and can also be helpful to learners. The study also found that the students developed a gap in relating the theory of handling of apparatus during scientific experiments, which they had learned in the classroom, with their actual skills and abilities in performing the experiment. In other words, the students experienced difficulty in putting the theory into practice. In order to bridge this gap, practice serves as a medium for converting practical knowledge into procedural form. Students' lack of exposure to 'hands-on' and 'minds-on' activities could lead to their lack of acquisition of manipulative skills during this period. Merely knowing how to manipulate scientific apparatus theoretically will not assist students' acquisition of manipulative skills and scientific concepts. The understanding of science is achieved not by reading about theories but by performing experiments and creating concepts first-hand in the laboratory. Students should be well trained in core manipulative skills that benefit them for higher learning. In conclusion, the results of this study have provided an insight on the issue of science manipulative skills that supports the importance of practical work. Further studies can be conducted to follow up on this research, including quantitative measure to examine the dimensions and elements transpired from this study and research in other aspects of science process skills, for example in communicating or measuring and using numbers. The findings need to be investigated further since this study involved a small sample.

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