Faculty of Natural and Applied Sciences Journal of Mathematics and Science Education
Print ISSN: 2814-0885 e-ISSN: 2814-0931
www.fnasjournals.com
Volume 3; Issue 1; November 2021; Page No. 48-61

PROCESS SKILLS DEVELOPMENT AND SCIENCE PRACTICAL ACTIVITIES: THE CASE OF GBEWAA COLLEGE OF EDUCATION, GHANA

[1]Azuuga, E.I., [+2]Baawuo, A., & [3]Apene, A.E.
[1-3]Gbewaa College of Education, P.O.Box 157, Pusiga, Upper East Region, GHANA

[+]Corresponding author(email): anthonybaawuo@gmail.com

Abstract
This paper reports a study on colleges of education pre-service teachers' science process skills. Students' development of process skills could be investigated by understanding their technical skills and their functional aspects of experimenting. However, this paper focused on students' technical skills in using basic scientific apparatus. Technical skills in this study refer to skills, 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 could be used to aid science teachers in teaching process skills. The paper presented the hierarchy of these technical skills and discussed these skills specifically from the perspective of colleges of education pre-service teachers teaching and learning science. The results of this study provided an insight on the issue of science process skills that supports the importance of practical work.

Keywords: Process skills, Technical Skills, Pre-service, Knowledge, Scientific Apparatus

Introduction

Science education in the 21st century is driven by the use of information technology coupled with the mastery of science and technology among students. This results in the production of well-informed, scientific literate and competent human resources for industries. Nonetheless, science education faces a great challenge. Recent international studies have shown that the interest and motivation to opt for a science-related profession among secondary school students is quite alarming, as students actively reject science-related professions as future career opportunities (McFarlane, 2013; Van Griethuijsen et al., 2015). According to Gilbert and Justi (2016) evidence of science students' lack of engagement in classes is used to buttress the widespread discontentment regarding students' levels of attainment in international studies and with their reluctance to continue to study science-related programmes in tertiary institutions. This has awakened interest among policymakers and some key stakeholders about the nation's science and technology workforce, as well as the scientific literacy of the populations (Kudenko & Gras-Velázquez, 2016; Van Griethuijsen et al., 2015). Concerning international research, for example, the Trends in International Mathematics and Science Study (TIMSS) have indicated disturbing trends among many developing countries such as Ghana. The findings of TIMSS suggest that waning attitudes toward science education constitute both international and national crises. For example, in Ghana, the TIMSS science score in 2018 decreased drastically to 771 points, 80 points lower than the score of TIMSS 2010. TIMSS 2015 indicated the same trend, with science decreasing to 626 points, 48 points lower than the score in 2016 (International Association for the Evaluation of Educational Achievement,2012). Notwithstanding that, the latest TIMSS has shown that Ghana students' performance in TIMSS 2016 has significantly improved at 471 points, an increase of 48 points from the score of 526 in TIMSS 2019.

In the meantime, issue related to low intake rate in science-related fields at the secondary and colleges of education level is also alarming (Kennedy, Lyons & Quinn, 2014; Smith, 2011). The trends reported in Ghana have been echoed in other countries, including Tanzania, Kenya Uganda and Australia among others (Kennedy, 2014; Lyons & Quinn, 2014), Scotland and Wales (Smith, 2011), France (Fadzil & Saat 2014; Charbannier & Vayssettes, 2009) and Western European countries (Van Griethuijsen et al., 2015). This shows that the decline in participation in science education enrolment may go beyond national borders. To address this issue of declining enrolment, science education at the colleges of education level should be more relevant to ensure a lasting positive attitude and an interest in science among the pre-service science teachers.

Recent studies (e.g. McFarlane, 2013; Schwichow, Zimmerman, Croker & Härtig, 2016) have shown that colleges of education students prefer teaching methods in which they can actively play roles "doing" science such as collecting data through observation and experimentation. To McFarlane (2013) and Hasni and Potvin (2015), to advance colleges of education learners' interest in learning science, there is a need for a more involved and practical based instruction that provides students with opportunities to engage with science, as a science subject has long been taught and learnt as a mono-methodological branch of knowledge (McFarlane, 2013). This attitude should change through the practice of embracing more learner-centred approaches in science learning. Thus, practical work is one of the most unique features of science that has the propensity to ignite pre-service science teachers' interest in teaching and learning science (Allen, 2020; Sorgo & Spernjak, 2012).

The ability to successfully conduct practical work in a science laboratory is an important scientific process skill and a common intention of science standards (Schwichow, Zimmerman, Croker & Härtig, 2016). Abrahams and Millar (2018) and Abrahams, Reiss, and Sharpe (2020) defined practical work as any type of teaching and learning that involves manipulating and observing real objects. However, practical work in the context of this study was 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. It encourages students to learn through the discovery of phenomena that occur in the environment. Such a learning strategy could facilitate the acquisition of scientific knowledge and the understanding of scientific theories (Fadzil & Saat, 2013; Schwichow, Zimmerman, Croker & Härtig, 2016).

Studies regarding practical work have developed tremendously over the years and have been given increasingly important emphasis around the world (Allen, 2020; Hofstein & Mamlok, 2007). Carrying out practical work helps the students get the opportunity to investigate phenomena, draw conclusions, and practise the scientific skills in handling apparatus which could result in meaningful science learning and development of critical thinking skills. Nevertheless, when it comes to the issue of implementation, recent studies (e.g. Abrahams, Reiss & Sharpe, 2020; Fuccia, Witteck, Markic & Eilks, 2012; Fadzil & Saat, 2013) noted that practical work is still not being given the desired attention in many school science laboratories. Laboratories are the best place to learn scientific skills such as manipulative skills, and these skills are learnt as part of formal science instruction. However, teaching and learning of science paid more attention to retention of knowledge where students were too involved with too much writing and too little practical work (Campbell, 2001; Fadzil & Saat, 2013).

As a result of a 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. According to Delargey (2001) and Buffler, et. el., (2001), research has 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 hands-on or practical skills acquisition depends largely on their progression in the lower level. Demeo (2005) has shown that students who performed manipulations in the laboratory were more successful on evaluations of their practical skills than their colleagues who were exposed to a non-laboratory method such as demonstration. This is in line with a small-scale study that indicated that university science students not only lack appropriate practical skills but also lack the confidence to carry out practical work (Grant, 2011). Grant also noted that limited exposure to practical work at school was the main contributing factor to the lack of practical skills at the university level. As a result of this, higher educational institutions should adapt lab-based teaching to focus on the development of practical skills in first-year practical courses. In a similar vein, Ferris and Aziz (2005) observed that students at tertiary-level institutions who performed well on examinations did not necessarily show competency in laboratory skills. Hamza (2013) argued that students should experience practical work for future learning and that the science experience

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61

could be used fruitfully in another setting. This claim was supported by Wickman and Ostman (2020) 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 budgetary constraints, large class size, time constraints, and inadequate teacher preparations. Thus, practical activities are frequently left out of 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, 2020) illustrated that insufficient opportunities in performing experiments at the school level might affect students progression to higher learning institution as they may encounter many difficulties in the future because of the lack of skills and experience. The development of manipulative skills is one of the important aims of practical work (Abrahams, Reiss & Sharpe, 2020). These encompass 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 are best defined as psychomotor skills that relate individual cognitive function with corresponding physical movement. To Anderson (1982) the framework of skill acquisition has two major stages involved in the development of cognitive skills known as a declarative stage and procedural stage. Each of these stages is based on long-term memory stores: declarative memory and procedural memory (Taatgen, 1999). When the learner receives instruction about particular skills, the instruction would be encoded as a set of facts about the skills. These sets of facts could be interpreted further to generate desired behaviour (Anderson, 1982).

Process skills in science emphasize the use and handling of scientific apparatus and chemical substances during scientific investigation in the laboratory. Additionally, students are exposed to the proper technique for using, cleaning, and storing scientific equipment safely. Students' inability to acquire science manipulative skills can seriously affect the acquisition of other desirable skills in the laboratory, for example, if they struggle to operate a piece of apparatus, this could lead to failure in making important observations and gathering relevant data (Fadzil & Saat, 2014; Johnstone & Al-Shuaili, 2001). Furthermore, students who are competent in science manipulative skills are more likely to concentrate on the acquisition of science process skills which include skills such as observing, classifying, measuring and using numbers, inferring, predicting, communicating, using space-time relationships, interpreting, defining operationally, controlling variables, making hypotheses and experimenting (Johnstone & Al-Shuaili,2001). For this reason, these scientific skills should be taught to students progressively and in this situation, teachers are the main instrument who are responsible for developing, inculcating the skills of science learning, as well as transferring the science manipulative skills to their students.

For the teaching and learning of manipulative skills to be effective, it is necessary to determine what is being assessed. Lack of reliable assessment has resulted in the neglect of experimental work in most of the schools (Abrahams, Reiss & Sharpe, 2020). The assessment of students' practical work in science laboratories is important because learning science is intrinsically linked to the evidence collected and analyzed in laboratory settings. Assessment is a process of gathering evidence to understand students' acquisition and performance in process skills. In countries such as Tanzania, direct assessment of students' practical skills is limited. Thus, there is less inclination amongst teachers to devote precious time and effort to develop students' practical skills (Campbell, 2001; Fadzil & Saat, 2013). According to the research conducted with 50 Senior High School teachers, practising science teachers still have challenges related to teaching and assessing students' process skills because they lack information about what should be observed. 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 appropriate instruments (Fadzil & Saat, 2013). Teachers were also not aware that certain hierarchies could be used to teach manipulative skills in science classrooms (Ferris & Aziz, 2020; Simpson, 1972 & Dave, 1970). For instance, Ferris and Aziz's (2020) 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 progression to the next level of learning is dependent on mastery at the lower level. However, this taxonomy is more appropriate in addressing and imparting process skills which relevant when teaching at the basic level. In this study, the aforementioned taxonomies served as a guide in analyzing the students' skills and abilities in the area of process skills to explore and acquire a conceptual understanding of this phenomenon at colleges of education level. Thus, scientific research should be done with a relevant methodology as an eye-opener to the stakeholders within the context of colleges of education. The aims of this study are (i) to explore the students' process skills in using basic apparatus during science practical work and (ii) to explore whether students perform the process skills in a certain pattern that reflects a hierarchy that can be used to enhance the teaching and learning of science process skills.

Literature Gaps

Science education in the 21st century emphasizes the acquisition of scientific knowledge and skills through an active learning approach to develop students' proficiency in scientific inquiry.

 Students' interest and enthusiasm in the understanding of science can be understood by performing experiments and creating concepts first-hand in the laboratory and not by reading only about theories, laws and principles.

The development of process skills is generally given the least attention in the course of academic instruction even though important aspects of learning can occur in this area. Research in science process skills is still very limited and more research in this area should be carried out to improve students' science practical skills.

Research Questions

1. What process skills do colleges of education students utilize when using basic apparatus during science practical work?
2. What special pattern do the students perform the process skills to reflect a hierarchy that can be used to enhance teaching and learning of science process skills?

Materials and Methods

The present study was conducted in Gbewaa College of Education; Pusiga District in the Upper East Region of Ghana and data collection took 5 months to be completed. The selection of this college was based on a typical case study sampling in which the college was not unusual in any way, and this reflects the average phenomenon of interest (Merriam, 2009; Patton, 2002). A sample size of 20 students was purposely selected. The basic criterion used in selecting the students was based on their ability to articulate and express their opinions. During the data collection, laboratory observations during students' practical work were conducted and at the end of the study, each student conducted five individual experiments and was video recorded while performing the assigned specific tasks.

Again, the students were interviewed at least five times. Before the actual study, a preliminary study was conducted to fine-tune the instruments (Science Process Skills Tasks, SPST) to test and validate the SPST for its appropriateness and usability. As the result of the preliminary study, the interview questions were further fine-tuned, fundamentally in terms of wording. The number of questions was reduced. Some of the sentence structures were altered to cater for the students' capability in understanding the given questions. For example, the interview protocol originally consisted of 20 questions. During the preliminary study, the number of questions was reduced to only 10 questions. The sentence structure and word usage were simplified for more meaningful understanding, for example, the words *science apparatus* and process *skills* were considered as jargon to the students; instead of "Can you give an example of science apparatus that you ever used at Senior Secondary School?" was reworded to "Name some scientific equipment that you ever used at Senior Secondary School?" From the interview in the actual study, it was noticed that the students' responses changed when different wordings were used.

Science Process Skills Tasks (SPST)

SPST is a set of four tasks intended to understand students' Process skills at the colleges of education level (refer to **Table 1**). SPST 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 Senior Secondary School. The tasks were not created to evaluate students' knowledge of the scientific concepts but were mainly developed to measure students' ability to use and handle the apparatus.

The procedures of the experiments in SPST were further simplified, as compared to the procedures from the textbook. For example in the textbook, students were given detailed instructions such as "measure 50ml of water using a measuring cylinder" and "stir the solution with a glass rod". However, in SPST, the instructions given were "measure 50ml of water" and "stir the solution from time to time". These were done to avoid recipe book 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 textbook appeared not suitable for the study. The tasks required students to manipulate four basic scientific apparatus. These include a thermometer, measuring cylinder, Bunsen burner, and light microscope. It is advantageous for students to acquire the process skills needed to handle these scientific apparatus. The tasks served as a basis and a foundation for the acquisition of higher-level process 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 all that different.

Table 1: Tasks in SPST and its learning outcome

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

Adopted from Fadzil and Saat (2017).

Validity and Reliability

When designing a qualitative study, validity and reliability are two issues that a researcher should be concerned about (Golafshani, 2003; Lincoln & Guba, 1985; Patton, 2002). Data were collected from individual observations of students performing the said SPST tasks and interviews. The more reliable the data gathering instrument is the more confidence researchers would have in that data gathering instrument.

Reliability is expressed numerically, usually as a reliability coefficient which is obtained by using correlation. A perfectly reliable data gathering instrument would have a reliability coefficient of 1.00, meaning that students' scores perfectly reflected their true status concerning the variable being measured, but also, no test is perfectly reliable. The rating scale for both the observation instrument and the interview protocol was based on a five-point Likert scale ranging from very good = 5, good = 4, satisfactory = 3 unsatisfactory = 2 and poor =1. This was dependent on the students' performers of the task assigned them and the quality of their responses to the interview protocols. Table 1 shows how Reliability Coefficient was determined.

Table 1 - Cronbach's Alpha Reliability Coefficient of students' performance of an assigned task

Cronbach's Alpha	Number of Items	Mean	SD
.71	6	11.67	4.07

Procedure

In this study, observations were conducted to understand the students' process skills. The study included the use of two types of observations: (1) individual observation of tasks from SPST and (2) laboratory observation during students' actual practical work. During the task performance, the students' work was not interfered with. The students' skills were individually observed to understand the different ways in which they manipulated the instruments in conducting the said 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), the researchers quickly intervened. Semi-structured interviews were also used in the study. Through that, the researcher was able to determine issues experienced by the students regarding the acquisition of process skills. The interview sessions were conducted after the students had completed each SPST task assigned to them. The researcher ensured that the time lapse between the observation of students completing SPST tasks and the interview session was not too long so that the students were able to recollect the skills the students had performed earlier. One-on-one interviews (Creswell, 2008) were conducted in this study to gain insight into the true ability of students in using and handling the scientific apparatus. Students were expected to rationalize and justify actions taken in handling scientific instruments during the execution of the tasks. From the observations and interviews, the researcher was able to explore the students' acquisition of process skills.

Data Analysis

Constant comparative research methods were used in interpreting the data. Data were collected from individual observations of students performing the said SPST tasks and interviews. The preliminary planning of the data analysis involved a systematic process of organizing a large amount of data from audio-taped interviews and videotaped observations and transforming it into transcripts. These data were then analyzed inductively using the constant comparative method of analysis, which involved the process of coding, categorizing, and developing themes from information that emerged 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 produce initial categories and to suggest relationships among the categories. This was done to determine the students' technique in process skills during the execution of the tasks. The analysis was started on a small part of the data to generate a set of initial categories. For example, if one excerpt was given the label 'efficiency', the researcher examined the observation data for other relevant excerpts that could be given the same code. If the reference was made to the same category again, the excerpts related to the 'efficiency' were again compared and contrasted to determine the commonalities, differences, and dimensions of the highlighted code. During this stage of analysis, the researcher kept in mind the issue of suitability of the codes used for the observation data. Questions were incessantly addressed during the analysis, including What are the characteristics of each excerpt in the same categories? What characteristics do excerpts that have the same code have in common? How are all these excerpts related?, as suggested by Boejie (2002).

General patterns emerged and were identified to make a robust conclusion of the findings. Six categories and 16 subcategories emerged from the first level of analysis. After deliberations, the second level of analysis was constructed, comprising four categories and 10 subcategories. The emerging categories and subcategories were compared and fine-tuned until they became mutually exclusive. Fine-tuning the thematic framework involved logical and innate 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 process skills required for each apparatus, this category had to be reanalysed by segregating and dissecting the data according to the apparatus (i.e., measuring cylinder, Bunsen burner, thermometer, and microscope). Again, these emerging subcategories were appropriately compared and contrasted to identify the general trend for each apparatus. This led to the identification of subcategories or elements under the component of 'technical skills.' The reliability of the tasks (SPST) and interview protocols was determined by peer review and using multiple processes during the preliminary study of the research. Themes and categories identified during data analysis were also assessed 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

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

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61

The technical skills are divided into two main categories: using graduated apparatus and using sequential apparatus. A graduated apparatus is one 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, is the apparatus that requires the user to understand and acquire specific knowledge about the sequence of using it to use the apparatus efficiently. The Bunsen burner and the microscope were categorized as sequential apparatus. Six (6) categories emerged and reflected on the technical competencies that students should acquire to manipulate the basic apparatus. These include (i) the ability to recognize an apparatus and its function, (ii) the ability to identify parts and features of apparatus as well as its function, (iii) an understanding of the fundamental 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 accomplish the task efficiently.

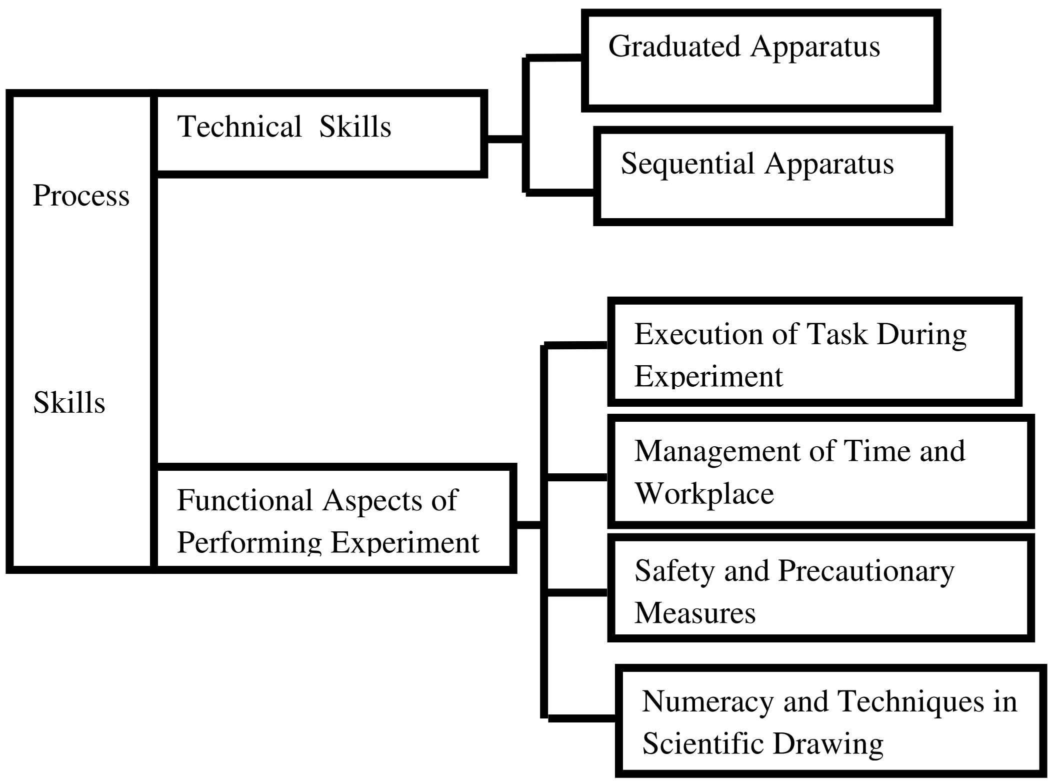

Figure 1. The dimensions and elements of process skills, a*dopted from Fadzil and Saat (2017).*

Ability to recognize apparatus and its function

The students showed good ability in recognizing the apparatus. All 20 students 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: Please tell me the name of this apparatus
(pointing at a measuring cylinder)?
Student 4: Erm…Measuring cylinder.
Researcher: Do you know what this apparatus is used for?
Student 4: To measure the volume of water.

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

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61

with Ferris and Aziz's (2020) first level of psychomotor domain taxonomy, which explains that recognition of tools and materials is vital for students' effectiveness and safety when dealing with scientific apparatus. However, findings from the observation indicated that students encountered difficulties in practising 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 a rough 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 colleges of education science, especially in chemistry, the use of a very accurate volume of solution is imperative in conducting a 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 all the parts and features of an apparatus and its function. The apparatus should be distinguished for the students to master the technical skills of using the apparatus.

This category represented an essential aspect of learning technical skills because the ability to identify the different parts of the apparatus helped the students in using the apparatus competently. The findings revealed that none of the students was aware of the different parts and features of the graduated and sequential apparatus. In using the thermometer, for example, the students were only able to 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. Nevertheless, based on the researcher's observation, no student could show the correct technique of adjusting the air hole during the execution of the task. This indicated that the students had challenges in practising what was learnt theoretically in their science classroom.

Students were also unable to identify parts of the microscope and their functions. Observation conducted during the laboratory session showed that the students encountered challenges in following the teacher's instruction during the experiment because of their inability to identify parts of the microscope. For example, during the laboratory observation, the teacher asked the students to manipulate the coarse adjustment knob to examine the onion cell placed on the stage more closely. Five (5) students were not able to recognize that particular part of the microscope and used the fine adjustment knob instead. From the observation, we realized that it is important for the students to be able to distinguish the different parts of the apparatus before they were able to operate the apparatus efficiently. During the interview session with the students, most of them 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 scarcely used it…and I don't think it is important for me to memorize all the parts.

Azizi, Shahrin and 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 challenge in identifying the parts of an apparatus and its function needs to be tackled at the lower level of learning science to ensure the 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 could impede their ability to learn 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 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 specific function. The coarse adjustment knob is a round knob on the side of the microscope that is responsible for focusing the specimen.

An understanding of the basic principles of using and handling apparatus

Basic principles in using and handling apparatus in this study refer to the fundamental rules that the students must follow to ensure the correct result is obtained from the execution of the task. Inability to follow these rules may prevent the students from getting 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 indicated that most of the students exhibited inappropriate techniques in using and handling graduated and sequential apparatus.

In using the thermometer, a good number 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, allowed the thermometer bulb to 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 for that purpose. These inappropriate techniques in handling and using the thermometer could 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:

He took the Bunsen burner and placed it under the tripod stand.
He turned the gas knob without lighting the Bunsen burner.
He did not even use the coarse adjustment knob during this experiment until her friend prompted her to do so. He did as his friend suggested.

The results of the study also suggested that students' understanding of the basic principles in using and handling apparatus depends on students' 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 to understand the principles of using it. This aligns with Ferris and Aziz's (2020) third level of the psychomotor domain, which focuses on 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 showed that most of the students were still struggling to grasp 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 conceptual understanding of principles in a scientific investigation. For instance, students were introduced to the basic rules and principles of using a thermometer at both the Junior High School and Senior High School level, but they did not understand the rationale behind every principle. For example, they should understand why the tip of the thermometer must 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 rather use a glass rod for the stirring.

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 provided, as reflected during the laboratory observation during students' practical work. The findings of the study also corroborate 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 retained. This finding is also in support of Dave's (1970) 'imitation' category of skills learning, which explained that students' replication of skills can only and only occur by referring to an exemplar. In the context of this study, the researcher was the exemplar, or model, for learning process skills. Simpson's (1972) category of 'guided response' in the learning of psychomotor domain explains that the early stage in learning a complex skill is characterized by both the process of imitation and trial and error.

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

This component explored the approach used by the students to minimize the standard error when using graduated apparatus to obtain accurate measurements during the experiment. It was observed that most of the students were aware of the appropriate technique to be followed to prevent parallax error. This awareness was also exhibited during the interviews. The students made sure that their eyes were parallel to the meniscus while taking the measurement. Nonetheless, the students showed inappropriate approaches to accomplish the criterion. Most of the students were not aware of this basic principle of using the measuring cylinder. For example, they should place the measuring cylinder on a flat surface to obtain an accurate measurement of the volume of liquid. It was observed that students raised up the measuring cylinder and brought 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.

In some cases, the students tilted their heads while taking measurements instead of lowering their heads to get accurate readings. 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'*. 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 in using the thermometer was removing the thermometer from the beaker and bringing it closer 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.
This finding revealed that 'hands-on' activity in practical work is an important component of science learning. In this case, students were able to explain how to handle apparatus theoretically during the interview session. However, based on the observation of tasks, the students indicated numerous techniques that were considered not appropriate. Students are expected to acquire the skills of reading the scales of the basic measuring instruments and should be able to record measurement accurately. As the students learn to manipulate the apparatus, they increase their skills and become more efficient in getting meaningful data from their science experiences. The challenges associated with reading a meniscus occurred when the students read about the skills but had not been given much opportunity to do scientific laboratory investigation. The skill of measurement is an indispensable foundation of acquiring higher measuring skills that require a high degree of accuracy. This supports the claim that challenges in mastering the appropriate skills to minimize parallax error could impede the students' ability to be efficient in using the graduated apparatus. Errors such as parallax errors need to be minimized 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 is related to student awareness in implementing appropriate precautionary measures during the use and handling of the apparatus. Most of the apparatus operates on the same principle, even though the sequence could differ slightly according to the apparatus. The suitable sequence of using the apparatus should be followed by the student to be conversant with the apparatus, which in turn leads 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. When 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 need to be taken during the manipulation of the Bunsen burner. None of the students in this study practised the correct technique of lighting the burner sequentially. They were unaware 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)
The inability to recognise the correct sequence of using the apparatus affected students' awareness of suitable precautionary measures to be taken when using the Bunsen burner. Students' sequential skills of using a microscope in Senior High School were considered inadequate. For example, Student 2 demonstrated an inadequate sequence of technical skills. He did not show any ability in using the stage clips, mirror, condenser, diaphragm, or coarse adjustment knob in sequence. He did not make any attempt to use the lowest magnification power objective lens. The findings indicated that the students' sequential skills were very basic. This corresponds to the hierarchy of learning technical skills, which states that achievement of higher-level skills depends on the achievement of lower skill levels. For this reason, the ability to obtain higher skill levels was only made possible through the achievement of lower skills. This is demonstrated in the findings of this study. The inability to recognise the sequence of using the apparatus would also affect the students' awareness of the appropriate precautionary measures that need to be taken while handling an apparatus. Students should be given ample opportunity to manipulate sequential apparatus right from primary school so that learning the sequential skills becomes routine and the movements become smooth. This finding buttresses Simpson's psychomotor domain (1972), which stated that competency can only be achieved by practice and repetition.

Ability to complete the task efficiently

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61

This component focused on the students' ability to use the apparatus efficiently and confidently. It involved two distinct 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 exhibited awkward and choppy movements when handling the thermometer to measure the temperature of boiling water. In another instance, some of the students were able to operate the thermometer smoothly and appropriately. It is in respect of this that, 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 student's 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 any uncertainty. 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 (2020) psychomotor domain, which focuses on a student's ability to perform given tasks efficiently and effectively. The acquisition of process 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 to be competent at manipulating a certain apparatus

Five-Level Hierarchy of Technical Skills

The results of the study indicate that process 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 the retention of information. This finding is consistent with Trowbridge et al. (2000) who opined that the desired behaviour in process 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 provided during the interview were not related to their skills' performance.

Based on the six categories linked to technical skills that emerged during data analysis, it was noted that the students acquire these technical skills in a certain pattern. The pattern in technical skills reflects a hierarchy, as illustrated in **Figure 2**. This hierarchy resonates with earlier studies of psychomotor skills by Dave (1970), Ferris and Aziz (2020), Gagne (1985), and Simpson (1972). In the context of this research, these psychomotor domain taxonomy models provide direction in constructing this hierarchy of learning technical skills which is important for students to master. As discussed earlier, science teachers found that it was difficult for them to teach process skills in the science classroom. Furthermore, the existing taxonomies did not cater to the teaching and learning of process skills at the senior 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 could be served as a guide to teachers and not be used rigidly. The hierarchy demonstrates that the student's progression to the next level of skills depends on their achievement of the lower level of technical skills. For example, if the students experience challenges 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 could impede their understanding of the basic principles of using the apparatus. This problem could later affect the students' ability to complete the task efficiently.

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61

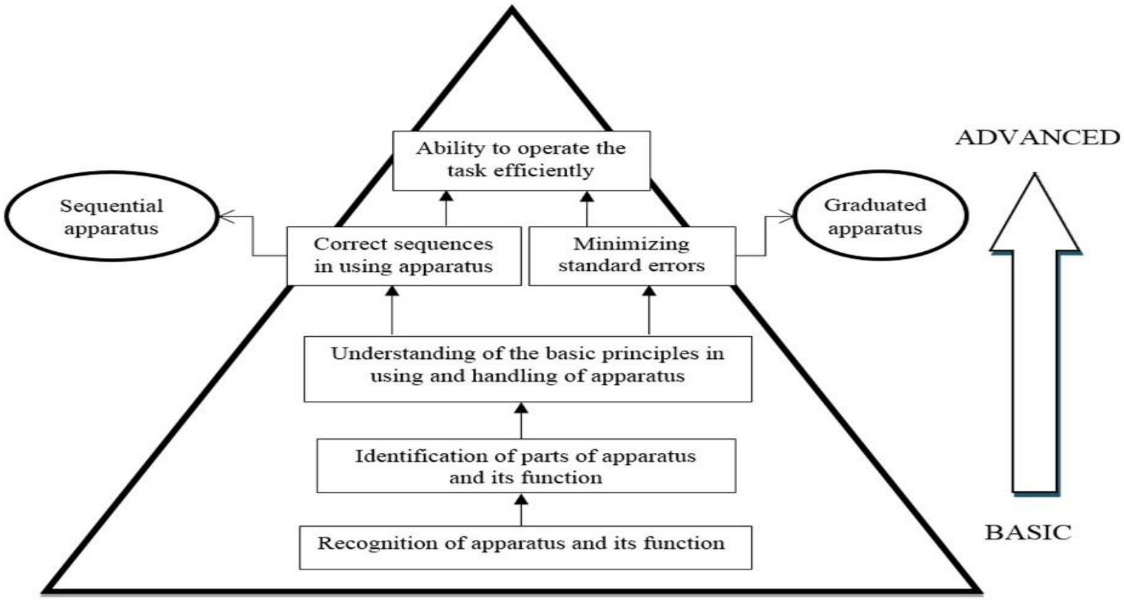

Figure 2. Five (5) levels hierarchy of technical skills, adopted from Fadzil and Saat (2017).

Conclusion

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

References

Abrahams, I., Reiss, M. J., & Sharpe, R. M. (2020). The assessment of practical work in school science. *Studies in Science Education*, *49*(2), 209-251.

Abrahams, I. & Millar, R. (2018). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. *International Journal of Science Education, 30*(14), 1945-1969.

Allen, M. (2020). An international review of school science practical work. *Eurasia Journal of Mathematics, Science and Technology Education*, *8*(1), 1-2.

Anderson, J. R. (1982). Acquisition of cognitive skill. *Psychological Review, 89*, 369-406.

Azizi, Y., Shahrin, H., & Fathiah, M. (2008). Tahap penguasaan kemahiran manipulatif kalangan guru pelatih Kimia Universiti Teknologi Malaysia [Level of manipulative skills acquisition among pre-service Chemistry teachers in Universiti Teknologi Malaysia]. In Yusof Boon & Seth Sulaiman (Eds.) *Permasalahan dalam pendidikan Sains dan Matematik* (pp. 34-51). Johor, Malaysia: Penerbit Universiti Teknologi Malaysia.

Bandura, A. (1977). Self-efficacy: Toward unifying theory of behavioral change. *Psychological Review, 84*(2)*,* 191-215.

Boejie, K. (2002). A purposeful approach to constant comparative method in the analysis of qualitative interviews. *Quality & Quantity, 36*(4), 391-409.

Buffler, A., Allie, S., & Lubben, F. (2001). The development of first year physics students' ideas about measurement in terms of point and set paradigms. *International Journal of Science Education, 23*(11)*,* 1137-1155.

Campbell, B. (2001). Pupils' perceptions of science education at primary and secondary school. In H. Behrendt, H. Dahncke, R. Duit, W. Gräber, M. Komorek, A. Kross & P. Reiska (Eds.) *Research in Science Education-Past, Present and Future* (pp.125-130). Rotterdam, The Netherlands: Springer.

Charbannier, É., & Vayssettes, S. (2009). PISA 2009 Presentation Note (France). *Organisatian for Economic Cooperatian and Development*. Retrieved from http;//v^ww.oecd.arg/pisa/46624019.pdt

Creswell, J. W. (2008). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Pearson.

Dave, R. A. (1970). Psychomotor levels. In Robert, J. A. (Ed.) *Developing and Writing Behavioral Objectives* (pp.20-21). Tucson, AZ: Educational Innovators Press.

Delargey, M. J. N. (2001). How to learn science "quickly, pleasantly and thoroughly": Comenian thoughts. *School Science Review, 82*(301)*,* 79–84.

Demeo, S. (2005). Gazing at the hand: A Foucaultian view of the teaching of manipulative skills to introductory chemistry students in the United States and the potential for transforming laboratory instruction. Curriculum Inquiry, 35(3), 295–338.

Fadzil, H. M., & Saat, R. M. (2013). Phenomenographic study of students' manipulative skills during transition from primary to secondary school. *Sains Humanika*, *63*(2), 71-75.

Fadzil, H. M., & Saat, R. M. (2014). Enhancing STEM education during school transition: Bridging the gap in science manipulative skills. *Eurasia Journal of Mathematics, Science & Technology Education*, *10*(3), 209-218.

Fadzil, H. M., & Saat, R. M. (2017). Exploring Students' Acquisition of Manipulative Skills during SciencePractical Work. *EURASIA Journal of Mathematics Science and Technology Education, 13*(8), 4591-4607

Ferris, T. L, & Aziz, S. (2005, March 1-5). *A psychomotor skills extension to Bloom's taxonomy of education objectives for engineering education.* Paper presented at International Conference on Engineering Education and Research: Exploring Innovation in Education and Research, Tainan, Taiwan.

Fuccia, D., Witteck, T., Markic, S., & Eilks, I. (2012). Trend in practical work in German science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *8*(1), 59-72.

Gagne, R. (1985). *The conditions of learning and the theory of instruction*, (4th Ed.). Holt, Rinehart, & Winston.

Gilbert, J. K., & Justi, R. (2016). *Modelling-based Teaching in Science Education*. Cham, Switzerland: Springer International Publishing.

Golafshani, G. (2003). Understanding reliability and validity in qualitative research. *The Qualitative Report, 8*(4)*,* 597-607.

Grant, B. (2011). *Lab skills of new undergraduates: Report on the findings of small scale study exploring university staff perceptions of the lab skills of new undergraduates at Russell Group Universities in England*. London, United Kingdom: Gatsby Charitable Foundation.

Hamza, M. (2013). Distractions in school science laboratory. *Research in Science Education, 43*, 1477-1499.

Hasni, A., & Potvin, P. (2015). Student's interest in science and technology and its relationships with teaching methods, family context and self-efficacy. *International Journal of Environmental and Science Education*, *10*(3), 337-366.

Hofstein, A., & Mamlok, R. (2007). The laboratory science education: the state of the art. *Chemistry Education Research and Practice, 8*(2)*,* 105-107).

International Association for the Evaluation of Educational Achievement (IEA). (2012). *TIMSS 2011 International Science Report: Findings from IEA's Trends in International Mathematics and Science Study at the Fourth and Eighth Grade.* Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Johnstone, A. H., & Al-Shuaili, A. (2001). Learning in laboratory: Some thoughts from the literature. *University Chemistry Education, 5,* 42-51.

Kempa, R. F. (1986). *Assessment in Science*. Cambridge, United Kingdom: Cambridge University Press.

Kennedy, P., Lyons, T., & Quinn, F. (2014). The continuing decline of science and mathematics enrolments in Australia high schools. *Teaching Science, 60*(2), 34-46.

Kudenko, O., & Gras-Velázquez, À. (2016). The Future of European STEM Workforce: What Secondary School Pupils of Europe Think About STEM Industry and Careers. In *Insights from Research in Science Teaching and Learning* (pp. 223-236). Cham, Switzerland: Springer International Publishing.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Beverly Hills, CA: Sage.

McFarlane, D.A. (2013). Understanding the challenges of science education in the 21st century: New opportunities for scientific literacy. *International Letters of Social and Humanistic Sciences, 4,* 35-44.

Merriam, S. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Wiley.

Patton, M. Q. (2002). *Qualitative evaluation and research methods* (3rd Ed.). Thousand Oaks, CA: Sage.

Ritchie, J., & Spencer, J. (1994). Qualitative data analysis for applied policy research. In A. Bryman & R. G. Burgess (Eds.), *Analyzing qualitative data* (pp.173-194). London, UK: Routledge.

Schwichow, M., Zimmerman, C., Croker, S., & Härtig, H. (2016). What students learn from hands-on activities? *Journal of Research in Science Teaching.* Advance online publication.doi: 10.1002/tea.21320

Simpson, E. (1972). *The classification of educational objectives in the psychomotor domain: The psychomotor domain.* Washington, DC: Gryphon House.

Smith, E. (2011). Staying in the science stream: patterns ot participation in A-level science Subjects in the UK. *Educational Studies, 37*(1), 59-71.

Sorgo, A., & Spernjak, A. (2012). Practical work in Biology, Chemistry and Physics at lower secondary and general upper secondary schools in Slovenia. *Eurasia Journal of Mathematics, Science and Technology Education*, *8*(1), 11-19.

Strauss, A., & Corbin, J. (2008). *Basics of qualitative research: Grounded theory procedures and techniques* (3rd Ed.). Newbury Park, CA: Sage.

Taatgen, N. A. (1999). Explicit learning in ACT-R. In *Mind modelling: A cognitive science approach to reasoning, learning and discovery* (pp. 233-252). Pabst, Lengerich.

Tesfamariam, G. M., Lykknes, A., & Kvittingen, L. (2015). Named small but doing great: An investigation of small-scale chemistry experimentation for effective undergraduate practical work. *International Journal of Science and Mathematics Education*, *13*(1), 1-18.

Trowebridge, L.W., Bybee, R.W. & Powell, C.J (2000). Teaching secondary science. Prentice hall

Van Griethuijsen, R. A., van Eijck, M. W., Haste, H., den Brok, P. J., Skinner, N. C., Mansour, N., & BouJaoude, S. (2015). Global patterns in students' views of science and interest in science. *Research in Science Education*, *45*(4), 581-603.

Wickman, P. O., & Ostman, L. (2020). Induction as an empirical problem: How students generalize during practical work. *International Journal of Science Education, 24*(5), 465-486.

Cite this article as:
Azuuga, E.I., Baawuo, A., & Apene, A.E. (2021). Process skills development and science practical activities: the case of Gbewaa College of Education, Ghana. *FNAS Journal of Mathematics and Science Education, 3*(1), 48-61