International Journal of Multidisciplinary Research and Growth Evaluation.

The Psychomotor Domain: The Role of Manipulative Skills in Science Mastery

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Article Info

ISSN (Online): 2582-7138
Impact Factor (RSIF): 7.98
Volume: 06
Issue: 06
November - December 2025
Received: 05-10-2025
Accepted: 06-11-2025
Published: 03-12-2025
Page No: 990-994

Abstract

The Psychomotor Domain (encompassing the physical skills, physical coordination and tool Use) is an important and often neglected resource for students to be successful in science education. This study evaluated psychomotor skills as a "Hidden Engine" behind science learning in Ghanaian Senior High Schools, identify student competence and appropriate assessment strategies, and use mixed-methods case studies from 3 teachers and 45 students through class observations, interviews and document analysis. The quantitative data averaged moderate levels of competence on practical tasks (Mean = 7.08) and correlated significantly with science grades ($r = 0.62$, $p < 0.01$), while the qualitative data identified difficulties created by large class sizes, lack of resources, and unstructured assessments. Among the strategies identified to improve the practical skills of students were the use of peer assessment and station rotation. Ultimately, the study recommended that to strengthen psychomotor development and improve general science achievement, schools should implement structured practical assessment tools (e.g., checklists, rubrics, and peer supported evaluation) into their continuous assessment systems to facilitate the integration of these tools into their measurement systems.

DOI: https://doi.org/10.54660/.IJMRGE.2025.6.6.990-994

Keywords: Education, Psychomotor Domain, Assessment, Senior High School, Science Education.

1. Introduction

Learning science goes beyond learning about natural phenomena; it also involves learning about related skills in scientific inquiry and everyday life. Recently, there has been widespread support for the fact that the psychomotor domain, which includes physical actions, coordination, manipulation, and the use of tools or other types of instruments, and the notion that we should assess this domain, has never been more prominent in science education. The psychomotor domain is one of the three domains of learning, adding to the cognitive or knowledge (thinking) domain and the affective domain (attitudes and values).

Educational theorists such as Elizabeth Simpson (1972) [17] identified stages in the psychomotor development continuum from simple imitation or copying of physical actions (or movements) to forming new patterns of movement adapted to new and different situations. Psychomotor learning for science education includes the practical skills of using a microscope, preparing a slide for the microscope, the dissection of specimens, preparing a solution of a specific concentration, and carrying out scientific procedures in solving real-life problems, and recording observations. These are all good and essential actions of scientific inquiry, and they should be explicitly taught, practiced, and assessed.

However, traditional approaches to assessing learning in many educational contexts, especially in some developing countries like Ghana, are heavily focused on abstract knowledge and do not consider physical competence or ability. Thus, students may have success in a written examination but fail to demonstrate even the most basic science skills and behaviours in the laboratory or field. By viewing practical skills and their effectiveness and relevance to an academic learning context and their contribution to a student's overall achievement, this work examines the psychomotor arm of the Hidden Engine of Science Achievement.

2. Review of Literature

2.1. Pragmatism in Contemporary Science

One of the common schools of thought for pragmatism is found in the writings of Charles Sanders Peirce, William James, and John Dewey. Pragmatism holds that the way we determine meaning and value is dependent on how we utilize them in our attempts to solve problems within the context of the real world. By contrast, a theoretical approach to understanding things often relies on abstract concepts (Peirce, 1878; James, 1906) [15, 11]. Peirce proposed pragmatism as a strategy to clarify concepts through their conceivable consequences. James extended the idea in stating that truth is verified by pragmatic experience as a reference (James, 1900; 1907) [11].

John Dewey took pragmatism further consideration when integrating it to educational theory as well to concepts of scientific inquiry. Dewey (1938) [5] interpreted knowledge as a tool for acting and argued that learning occurs by engaging in the environment, to mean in science education, students will construct understanding through their own experimenting, investigating, and engaging with real problems vs being passive recipients of facts.

Pragmatism, in current science education, has shifted away from Dewey's original account, emphasizing experiential learning, inquiry-based teaching epistemologies, and assessment based on performance. Biesta and Burbules (2003) [2] provide an argument that many current educational practices, particularly those catering to students' engagement with and assessment of their learning, still remains grounded in Deweyan pragmatism, stating that the idea that knowledge must be useful and validated in action, is centered within pragmatism. Education research in science education reinforces this approach by advocating for students to be able to demonstrate they can apply scientific ideas in a meaningful way, instead of the mere act of writing down the idea (Hodson, 1996; Aikenhead, 2006) [9, 1].

A pragmatic orientation also supports genuine, situated, and action-rich learning experiences. The social relevance of pragmatism has a strong connection in contexts such as Ghana, where the National Pre-Tertiary Curriculum Framework explicitly states its philosophy around competence-based learning, meaningful real-life practice, and the use of practical tasks in the delivery of science teaching (Ministry of Education, 2019) [12]. Pragmatism acts as both methodological and philosophical rationale for assessing students' ability to demonstrate science inquiry or perform scientific tasks or using tools or tools in practical inquiry.

2.2. Psychomotor Domain in Science Education

The psychomotor domain refers to physical movement that requires coordination, use of tools, motor skills, and applying knowledge to action. In terms of science education, the psychomotor domain includes skills like setting up the lab equipment, using the instruments, conducting the experiment, measuring accurately, handling the materials safely, and employing the scientific procedures with precision (Simpson, 1972; Harrow, 1972) [17, 7].

Three major psychomotor taxonomies are available to inform educational practice. The first taxonomy, which was developed by Simpson (1972) [17], has seven levels of organization: perception, set, guided response, mechanism, complex overt response, adaptation, and origination. The different levels acknowledge the progression of the learner from imitative to skilled, to ultimately creative performance. Harrow's (1972) [7] taxonomy focused on movement patterns, coordination, and a series of complex, coordinated skilled actions. The last taxonomy was developed by Dave (1975) [4], who proposed a psychomotor taxonomy of skill development with five levels of organization: imitation, manipulation, precision, articulation, and naturalization. Each level illustrated a growth in independence and fluency in the performance of skills.

Psychomotor competence is important in the teaching and learning of science in general education for completing experiments, working with equipment, taking measurements, constructing equipment, going into the field, and following safety protocols. Studies have shown that when students practice science with their hands and motor skills, it allows them to learn and understand scientific concepts at a higher level (Hofstein & Lunetta, 2004) [10]. Practicing science in this way develops better conceptual understanding, reasoning skills in science, and changes students' attitudes toward science.

However, in many developing contexts—including Ghana—there are significant challenges to facilitating psychomotor skills and assessing them. Previous studies indicate that challenges such as inadequate and limited laboratory space, equipment or both; crowded classrooms and limited time for practical activities are some of the factors (Okebukola, 1990; Effah, 2021) [14, 6]. As a consequence, instructors often rely on cognitive measures when assessing science achievement—even when national assessment systems expect some demonstration of practical competence. This disconnect between what students are expected to do in the curriculum and what actually happens in practice weakens the overall scientific literacy and exam preparedness of students (WAEC, 2022) [19].

2.3. Assessment of the Psychomotor Domain

To assess the psychomotor domain, assessment should focus on what learners are able to do instead of just what they can say. While cognitive assessments will show an understanding of the concept, they will not be able to show if procedures are accurate, coordinated, or technically skilled. So a psychomotor assessment should involve observing a student completing tasks using a more standardized assessment tool (Biggs & Tang, 2011) [3].

Performance tasks are key to a psychomotor assessment, as they require learners demonstrate steps of a specific scientific procedure, such as assembling apparatus, conducting an investigation or measuring a variable, that can be observed and assessed against important aspects of the task. Performance tasks allow teaching practice to be assessed as to technique, safety, accuracy and fluency (Hofstein & Lunetta, 2004) [10].

Observation checklists and rubrics should be used to ensure teacher assessment is as objective as possible. Checklists can emphasize important components of a procedure, while rubrics can define levels of performance, including what constitutes levels of quality. Analytical rubrics are particularly useful for scoring different aspects of the performance, for example accuracy, safety, organization and efficiency separately to help improve reliability and clarity (Moskal, 2000) [13]. The instruments are particularly helpful in large classrooms, when assessing learners' students can be time consuming.

Other methods comprise portfolios, laboratory notebooks, and videos of student performance. Portfolios chronicle a student's practice over time and are great for recording the

development of skills (Herman, Aschbacher, & Winters, 1992) [8]. Video evidence allows for moderation, re-assessment, critique from peers, assessment of learning, and reflection.
Peer assessment and self-assessment are equally important complimentary methods. Topping (1998) [18] provide evidence that when students evaluate each other'sf practice, and doing so with pre-made criteria, they are held more responsible and engaged with the process. Both methods also support metacognition and contribute to a culture of peer-assessment.
An essential tenet of each of the approaches is authenticity: the tasks must be representative of authentic scientific practice. Dewey's pragmatism accentuates that assessment should ideally represent an authentic real-world task (Dewey, 1938) [5], which can give the student an opportunity to demonstrate their practical skill. Authenticity is important in contexts with limited resources, where an authentic, but feasible and meaningful task (appropriate rotating stations, simplified experiments, low-cost available apparatus) may ensure the validity of the assessments, even if resources are limited in some capacity (Safo-Adu, 2020; Effah, 2021) [16, 6]. Studies have indicated that proper structured authentic and observable assessment of psychomotor skill develops student cognition in science, improves students' scientific reputation, and prepares students to engage in conducting similar experimental scientific work (Hofstein & Lunetta, 2004) [10]. In conclusion, it is important to adopt a pragmatic assessment of the psychomotor domain if we determine that science education graduates are going to be knowledgeable, but not capable.

3. Methodology

The purpose of this study was to use a mixed-methods case study design to explore practical methods of assessing the psychomotor domain in science classrooms in selected public senior high schools in Ghana. The case study approach facilitated deep investigation of teachers and students' perceptions and realities of classroom context and practices influencing the assessment of practical skills. The mixed-methods design supported collecting qualitative insights and quantitative performance data to provide a rich and meaningful account of the demonstration of competence by students in science through psychomotor tasks.
Public senior high schools from Ghana's Upper East Region were purposely sampled based on their commitment to practical science lessons and easy access to the researcher. Three science teachers and forty-five students participated in the study. Purposive sampling ensured participation of science teachers who conduct practical lessons on a regular basis, and students who had engaged in school-based practical assessment.
Classroom observations, semi-structured interviews, and document analysis provided the data for this research. Observations recorded student performance of psychomotor tasks in physical education such as setting up a lab, measuring and combining materials, using equipment, practicing safety, following directions, and documenting and displaying observations. Observations also recorded teachers' formal or informal assessment practices, including the use of rubrics and checklists. Field notes recorded student engagement, teacher feedback, and general organization of practical activities.
Semi-structured interviews with teachers focused on their understanding of the psychomotor learning domain, as well as challenges they faced in assessing practical skills and their assessment strategies. Student interviews focused on their experience of practical work, perceptions of assessment methods, perceived fairness of assessments, and perceived usefulness of assessments. Document analysis included lesson plans, assessment sheets, and students' practical exam scores and provided quantitative data to evaluate student competence.
Students were assessed on important psychomotor tasks using a 10-point rubric - on accuracy, procedural fluency, safety, and organization - for each task, before producing descriptive statistics (mean, standard deviation and, percentage mastery) for each task, in addition to a total practical score. Pearson correlation analysis (using SPSS) was then conducted to measure the relationship between practical performance and student science grade overall, and statistical significance. On the other hand, qualitative data from observations, interviews, and documentation were employed in thematic analysis. Codes developed from recurring patterns associated with assessment practices, teacher dilemmas, and student experiences were also abstracted into larger themes. Triangulation among data sources increased validity, while concluding that the investigation would be illustrated by not only measurable outcomes but also contextually significant information for representation overall.

4. Findings and Discussion

The evaluation of students' psychomotor skill sets included five primary areas of evaluation: setting up the experimental apparatus; preparing the solution; using equipment/tools; using safety precautions; and recording/presenting results. Each area had a maximum score of 10 based on the following criteria: Accuracy, fluency of procedure, safety, and organization. Scores for practical assessments were determined using a maximum score out of 50.
Table 1 provides descriptive statistics for students' scores on psychomotor skill sets, indicating moderate competency of the students in the areas evaluated.

Table 1: Descriptive Statistics of Psychomotor Performance

Task	Mean Score	Std. Deviation
Apparatus setup	7.80	1.20
Solution preparation	6.90	1.50
Instrument operation	7.20	1.30
Safety procedures	6.50	1.80
Recording & presentation	7.00	1.40
Overall Practical Score	7.08	1.24

From the descriptive statistics, the highest score is recorded in apparatus set-up (M = 7.80, SD = 1.20) and the lowest score is recorded in safety procedures (M = 6.50, SD = 1.80). Average ratings of Solution preparation (M = 6.90, SD = 1.50), instrument operation (M = 7.20, SD = 1.30), and recording/presentation (M = 7.00, SD = 1.40). This reveals moderate-level skill generally.
Classroom observations indicated that students participated satisfactorily in practical exercises, although assessments were conducted mostly on an informal basis with multiple students in groups. Teachers indicated that large class sizes, limited laboratory equipment, and time constraints posed challenges to formalised systematic assessment of skills; however, students expressed enjoyment for practical lessons

but complained that their practical skills were not included in grading their overall performance; therefore, students wanted structured feedback and assessment for practical skills. Practical and pragmatic suggestions from students to improve their psychomotor competencies included the creation of peer assessments, rotating students through work stations, and using informal checklists.

The findings indicate that while the majority of students are able to demonstrate basic practical task performance, they lacked the necessary ability to ensure safety standards and procedural accuracy. Students stated that informal/group-based assessments do not accurately reflect their skill level; this finding matches results from recent work by Okebukola (1990), WAEC (2022), and Effah (2021) [14, 19, 6] regarding skills assessment of students in Ghanaian and other African contexts. Although resource constraints exist, Dewey's (1938) [5] philosophy of learning by doing identifies practical and hands-on methods that will provide the basis of workable approaches to improve students' practical competence.

Table 2 shows the correlation between student performance in practicals and their overall grade in Science which incorporates both exams and continuous assessment components for one academic year.

Table 2: Pearson Correlation between Practical Performance and Overall Science Grades

Variables	Mean	Std. Dev	r	p-value
Practical Score	7.08	1.24		
Overall Science Grade	65.2	7.5	0.62	0.001**

Note: $p < 0.01$, statistically significant.

The analysis of data indicates a moderate positive correlation between students' practical performance and their overall grade in science ($r = 0.62$, $p = 0.001$), which suggests that students who are more proficient at performing psychomotor skills tend to earn higher grades in their academic studies. Qualitative evidence showed that although work in the laboratory assists in developing an understanding of science concepts, the lack of authentic assessment and constructive feedback received by the students limited them in reaching their highest academic potential. According to teachers, there is often an emphasis on evaluating the student's knowledge in cumulative assessments instead of on psychomotor performance, which limits skill development in both students and teachers.

The positive correlation between practical performance and academic achievement reinforces the need for practical assessment of psychomotor skills. Assessing the practical performance of students is not only a prerequisite for students completing laboratory tasks but it also positively influences their overall academic achievement in science. There are many factors that hinder educators in effectively assessing their students' practical skills. The study revealed that factors such as large class sizes, lack of resources, and a nanostructured method of assessment poses a challenge to assessing the psychomotor domain. There are however many pragmatic approaches that can help reduce these barriers, including peer assessments, station rotation methods, and the use of basic checklists to promote genuine and contextually relevant assessments of students' practical skills.

5. Conclusion

The findings of this research support the hypothesis that the psychomotor component of learning is an overlooked yet integral aspect of a student's science achievement. On average, students demonstrated a moderate level of ability to perform practical activities (mean = 7.08). Additionally, the level of practical performance exhibited by students had a positive correlation with their overall science grade which incorporates both exams and continuous assessment components ($r = 0.62$, and $p < 0.01$). Unfortunately, environmental factors such as having large classes and limited teaching and learning resources, along with in appropriate methods of assessing student performance, negatively affected the development of students' psychomotor skills. Conversely, pragmatic approaches to increasing the effectiveness of these assessments included using peer-assessment techniques, rotations through learning stations in the laboratory, and employing structured rubric templates. These findings illustrate that providing students with structured, authentic, and context-specific assessments allows for increased levels of practical skill development, and significantly contributes to their overall academic success. As a result, the psychomotor component of learning acts as a "hidden engine" of supporting student learning in science.

6. Recommendations

To assess students' practical skills with reliable and consistent evaluations, schools should use structured and authentic assessment tools, such as models, checklists, laboratory notebooks or journals, and student portfolios (i.e., materials demonstrating the students' best work). In addition to these assessment tools, additional resources and class sizes should be available to support hands-on individualised practice. It is recommended that teachers should use peer and/or self-assessment during real-world performance tasks since this can provide opportunities for students to reflect on their performance and interact with real-world situations. It is also essential for teachers to have access to professional development and to develop their capacity to evaluate psychomotor skills accurately and effectively. Conducting professional development will increase the ability of teachers to evaluate the quality of psychomotor skills within competence-based curricula. The study recommended that to strengthen psychomotor development and improve general science achievement, schools should implement structured practical assessment tools (e.g., checklists, rubrics, and peer supported evaluation) into their continuous assessment systems to facilitate the integration of these tools into their measurement systems.

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How to Cite This Article
Agongo A-R, Tindan TN. The psychomotor domain: the role of manipulative skills in science mastery. Int J Multidiscip Res Growth Eval. 2025;6(6):990-994. doi:10.54660/IJMRGE.2025.6.6.990-994.