

A Framework for Assessing Practical Activities in Science Education

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Abstract: Practical activities are an indispensable piece of science education. As such, assessment of these practical activities is vital for continually enhancing the quality of science instruction. This article presents a tentative framework structured for assessing practical activities in science education. The proposed framework is built upon seven components: engagement and participation, relational thinking, stepwise mastery, contextualization, multidimensional integration, empowerment, and scientific articulation. The framework might provide science educators with an alternative lens through which to enhance the effectiveness of practical activities, promote student engagement, and better prepare learners for the future. This framework is designed to be additive and complementary to existing assessment approaches and can be adapted and customized to suit specific local contexts and varying grade levels by science educators in the pursuit of excellence in an ever-evolving science education landscape.

Keywords: Assessment framework; Practical activities; Science education; Assessment method; Assessment example

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1. Introduction

Constructivist theories posit that learners actively build their meaningful knowledge through experience^[1-3]. This experiential approach, for example, hands-on activities, has been shown to promote deep and lasting understanding, as well as long-term retention of knowledge and concepts^[4-6]. Practical activities are one of the avenues to embody this experiential approach. Practical activities, encompassing experiments, hands-on projects, and fieldwork, play a pivotal role in science education in fostering science practice and acquiring scientific knowledge and skills. The benefits of practical activities in science learning are well-documented, including enhanced student motivation, improved scientific literacy, and the cultivation of essential 21st-century competencies^[7,8]. The practical experiences deepen student understanding of science content by interacting with scientific phenomena^[9]. Engaging students in practical activities provides them with

opportunities to explore, experiment, inquire, and/or discover phenomena and laws, enabling them to apply knowledge in practical contexts^[10,11]. For instance, when students engage in hands-on experiments, they learn not only the “what” of scientific concepts—often taught in a theory-heavy classroom setting—but also the “how” of applying and embodying these concepts in the real world. This experiential learning process is crucial for developing a deep understanding of scientific principles, promoting the application of knowledge over time.

However, despite the acknowledged value of practical activities, assessing these experiences effectively remains a significant challenge in science education. Conventional assessment approaches, such as standardized tests and written exams, somewhat focus on rote memorization of facts and are often inadequate for capturing the full range of skills and competencies developed through practical learning. Plus, they hardly capture the affection and skills developed from practical activities such as curiosity, enthusiasm, and communication skills. Additionally, the collaborative, dynamic, and exploratory nature of practical activities often makes it difficult to evaluate them adequately using conventional assessment methods. As a result, teachers may find it difficult to evaluate the effectiveness of practical activities and their impacts on student learning outcomes. This disconnect between conventional assessment practices and practical activities highlights a need for a framework for assessing practical activities in science education. Drawing on previous work^[12-18], we tentatively propose a framework designed to promote the assessment of practical activities, which might improve learning outcomes and promote greater student success in science. This framework serves as a complement and addition to existing assessments in science education.

2. Principles underpinning the framework

Currently, the assessment of practical activities in school science education varies across different countries, with some possibly placing a stronger emphasis on direct assessment of practical skills while others focus more on concepts. These diverse assessment approaches to practical activities have enriched and advanced our understanding of the assessment of practical activities in science education. However, there are no universal assessment approaches and tools that are uniformly applicable to all countries, given the substantial differences in science education contexts across countries. Each country may have its own interpretations of practical activities in science education, leading to the development of distinct assessment frameworks rooted in their unique perspectives. In this article, we view practical activities not merely as a means to acquire or verify scientific knowledge and demonstrate final products or outcomes. Rather, we position them as a valuable vehicle for students to actively cultivate relational thinking, engage in meaningful scientific discourse, progressively develop their knowledge, skills, and competencies, and nurture their affective domain through a multidimensional lens within authentic contexts. Accordingly, we elaborated and formulated the seven principles of experientiality, relevance, progression, authenticity, multidimensionality, agency, and discourse, as listed below, upon which the assessment framework we propose is grounded.

Experientiality: Practical activities should be assessed not just for their end, but for the richness of the learning experience. Active participation, sensory engagement, and the emotional responses students involve, make, or exhibit during practical activities are integral parts of the learning journey that hone their senses and nurture their intellectual curiosity as well as their appreciation of the scientific process, ultimately developing engaged learners.

Relevance: Practical activities should be assessed by students’ ability to articulate the connections and

relationships between seemingly disparate scientific concepts and to link scientific concepts to concrete realities, their lived experiences, and social and ethical issues of science; the ability to make connections across different scientific disciplines to address practical issues and to understand the interdisciplinary and interconnected nature of science.

Progression: Practical activities should be assessed by charting student incremental development of specific skills and competencies over time, rather than merely capturing a snapshot of knowledge, skills, or competencies at a single point, acknowledging that the mastery of scientific competencies is an ongoing and dynamic process and focusing on how students progress in their understanding and application of knowledge and practices.

Authenticity: Practical activities should be anchored in real-world contexts and relevant to students' lives and communities. Assessment should be situated within authentic, contextualized scenarios that reflect the dynamic nature of scientific research and problem-solving and mirror the authentic practices and challenges of scientists in real-world settings.

Multidimensionality: Practical activities should be assessed to capture the multiple dimensions of scientific literacy. Assessment should go beyond factual knowledge to include the integration of disciplinary concepts, science practices, and crosscutting concepts, as well as cognitive, affective, social, and practical skills that contribute holistically to students' scientific sense-making abilities through a comprehensive and integrated manner.

Agency: Practical activities should be assessed by students' active involvement in their learning experiences. Students are empowered to take control of, actively participate in, and direct their learning processes, including having a voice and choice in what and how they learn, conduct activities, set goals, and self-regulate their learning. Students become more autonomous, self-directed, and self-regulated active learners.

Discourse: Practical activities should be assessed by students' ability to engage in meaningful dialogues and exchanges of ideas that occur among students and between students and teachers. This may include talking, writing, and using other modes (like diagrams) to share ideas, defend positions, and construct scientific meaning. Assessment involves evaluating how students engage in scientific argumentation, use scientific language, and make sense of their practical investigations while promoting critical thinking and communication skills.

3. Components of the framework

Building upon the aforementioned principles, the proposed assessment framework for practical activities in science education consists of the following seven components:

3.1. Engagement and participation

By the principle of experientiality, we propose "Engagement and Participation" as a component of the framework. This component focuses on the learning experience itself and acknowledges the role of sensory engagement and affection in students' learning during practical activities. It assesses students' level of interest, active participation, enthusiasm, and sensory interactions with the physical world during practical activities.

Assessment methods may involve observation rubrics to document students' levels of engagement, input,

and interactions of different sensory modalities; participation checklists that track students' involvement in discussions and hands-on activities; and journals where students articulate their thoughts, feelings, and experiences as well as reflect on their contributions to the activity.

Example: In a biology lesson about flower structures, students dissect a flower. A teacher may use an observation rubric to assess a student's engagement in the dissection. Criteria may include: 'Actively participates in the dissection,' 'Asks questions about the flower's structures,' 'Describes the texture and smell of different flower parts,' and 'Shares observations during group discussions.' Students also complete journals reflecting on their experiences, noting their favorite part of the dissection, any challenges they faced, and how the flower's scent or texture helped them understand its function.

3.2. Relational thinking

By the principle of relevance, we propose "Relational Thinking" as a component of the assessment framework. This component emphasizes students' ability to think relationally, to see the interconnectedness of scientific concepts and domains, and to relate their knowledge to real contexts in meaningful ways. This component highlights how understanding one element in science is enriched by its relationship to others.

Assessment methods may involve concept mapping exercises to visualize connections between ideas; real-world scenarios that require integrating knowledge from multiple scientific domains to propose solutions or explain phenomena; interdisciplinary projects that request students to combine scientific knowledge with other fields to address a social and ethical issue or explore a topic from multiple perspectives; connect-the-dots tasks that ask students to explain the missing links between seemingly disparate phenomena.

Example: A teacher might present students with a case study of a local environmental issue (e.g. water pollution) and ask them to analyze the issue from multiple scientific concepts or domains (chemistry, biology, geology) and to demonstrate how these concepts or domains are interconnected as well as how this interconnectedness is entailed to address the issue. The assessment would emphasize their ability to integrate knowledge and concepts from different disciplines to propose solutions via relational thinking.

3.3. Stepwise mastery

By the principle of progression, we propose "Stepwise Mastery" as a component of the assessment framework. This component emphasizes student's ability to continuously develop and demonstrate increasing proficiency in the essential skills and competencies and to adapt and refine their abilities over time. It highlights that students are able to advance in skills and competencies through learning, acquisition, practice, and feedback.

Assessment methods may involve skill-based rubrics that track student developmental mastery of specific competencies over multiple practical activities; demonstrations that show student incremental proficiency through a series of tasks that allow them to build and showcase their skills step-by-step; cumulative performance tasks that integrate multiple skills and competencies to demonstrate their ability to apply knowledge and skills in an incremental and progressive manner.

Example: A teacher might guide students through a series of activities to master the use of a microscope. Students could start by learning the parts of the microscope and their functions through a labeled diagram. They might practice preparing and observing a slide of onion cells, explaining the steps involved in focusing the microscope and identifying key cell structures. Incrementally, students could design an experiment to observe the effects of different staining techniques on the visibility of cell structures, analyzing their

observations and presenting their findings to the class. This stepwise mastery approach allows students to progressively build their skills and understanding of microscopy through increasingly complex tasks.

3.4. Contextualization

By the principle of authenticity, we propose “Contextualization” as a component of the assessment framework. The emphasis of this component is on engaging students in meaningful, contextually relevant scientific learning and investigations, fostering the development of essential skills and competencies within authentic, real-world settings, and bridging the gap between academic learning and practical application.

Assessment methods may involve community-based projects that request students to address local community needs or issues by conducting research, collecting data, and implementing solutions; fieldwork that provides opportunities for students to collect data in natural or built environments and analyze their findings to draw conclusions; problem-based learning that presents students with ill-structured, open-ended real-world issues that require them to analyze the situation, apply relevant concepts and skills, and propose evidence-based solutions.

Example: In an environmental science course, students might investigate the issue of water scarcity in their local region. They would begin by researching the specific factors contributing to water shortages in their community, such as climate change, industrial practices, or infrastructure challenges. Students would then design and carry out investigations to collect data on water usage patterns, identify potential sources of contamination, and analyze the environmental and socioeconomic impacts of limited water access. Throughout the process, they may engage with local water management authorities, environmental organizations, and community members to gather additional contextual information and receive feedback on their proposed solutions. The final assessment would not only evaluate the scientific rigor of the students’ investigations but also their ability to frame their work within the relevant real-world context, generate viable solutions, and communicate their findings to stakeholders beyond the classroom.

3.5. Multidimensional integration

By the principle of multidimensionality, we propose “Multidimensional Integration” as a component of the framework. This component emphasizes students’ ability to apply and seamlessly integrate disciplinary concepts, science practices, and crosscutting concepts to demonstrate scientific sense-making and students’ ability to understand the social, ethical, or civic implications of science through a multidimensional lens.

Assessment methods may involve ethical debates that expose students to complex ethical dilemmas arising from scientific advancements or technological innovations to evaluate their ability to analyze the implications in a multidimensional perspective; small-group investigations that evaluate students’ ability to collaboratively plan experiments, analyze data, and propose innovative solutions that integrate disciplinary knowledge, science practices, and crosscutting concepts; presentations and writings that ask students to highlight the synergistic application of various dimensions of disciplinary concepts.

Example: In a high school biology course, students might be tasked with investigating the factors that contribute to the decline of a local amphibian population. To tackle this real-world challenge, students would need to draw upon their disciplinary knowledge of ecology, zoology, and environmental science. They would then employ scientific practices, such as fieldwork data collection and modeling, to develop a comprehensive understanding of the issue. Throughout the process, students would recognize and leverage crosscutting concepts, like systems thinking and cause-and-effect relationships, to identify the multiple factors driving the

amphibian population decline.

3.6. Empowerment

By the principle of agency, we propose “Empowerment” as a component of the assessment framework. This component focuses on the extent to which students drive their own learning journey through practical activities as self-regulated active learners, emphasizing self-directed learning and active involvement, encouraging them to take an active role in engaging with scientific concepts and practices, and promoting a personalized and meaningful experience.

Assessment methods may involve student-led investigations where students define their research questions and experimental protocols; self-assessment rubrics by which students evaluate their performance against established criteria; and reflective portfolios documenting students’ learning journey and growth in self-directed inquiry skills. Student-initiated modifications or redesigns of practical activities based on their analysis of assessment data and personal learning needs.

Example: Students are given a broad topic, such as the effects of different variables on plant growth. Instead of following a prescribed procedure, they are tasked with designing their own experiment to investigate a specific question within that topic. They develop their hypothesis, choose their variables, design their experiment, collect and analyze data, and draw conclusions. The assessment would focus on their autonomy to justify their experimental design, critically evaluate their data, and reflect on the merits and demerits of their studies. They would also participate in peer-review sessions, providing and receiving feedback on their experimental designs and interpretations.

3.7. Scientific articulation

By the principle of discourse, we propose “Scientific Articulation” as a component of the assessment framework. This component emphasizes students’ ability to clearly and persuasively communicate their scientific understanding and reasoning during and after practical activities, and students’ ability to articulate observations, construct evidence-based arguments, engage in constructive dialogues, and effectively convey complex scientific ideas in various modes of communication.

Assessment methods may involve structured debates where students argue for different interpretations of data or propose alternative experimental designs; multimodal presentations that require students to communicate their research process, data analysis, and interpretations in a coherent and compelling manner; peer-review activities where students evaluate the clarity, persuasiveness, strengths, and weaknesses of each other’s arguments; group discussions in which students articulate their understandings of scientific concepts, respond to peers, and defend their viewpoints with evidence from their practical activities.

Example: After a lab activity on photosynthesis, students are assigned to participate in a group discussion about the factors that affect the rate of photosynthesis. Each student is assigned different viewpoints, such as light intensity, carbon dioxide levels, or temperature, and must present evidence from their inquiries to support their assigned position. The assessment focuses on their ability to clearly articulate their understandings of the biological processes involved, construct a logical argument supported by evidence, respectfully engage with opposing viewpoints, and effectively persuade their audience. Criteria may include: ‘clearly explain the experimental procedure,’ ‘present data in an organized and understandable format (e.g., graphs, tables),’ ‘provide a logical explanation of the results, linking them back to the original hypothesis,’ and ‘respond thoughtfully to questions from the audience.’

4. Conclusion

Practical activities are an integral piece of science education for cultivating scientific literacy. This article proposes a tentative framework for assessing practical activities in science education in order to capture the multifaceted nature of this experiential learning beyond traditional assessments focused on rote knowledge recall. By grounding the framework in seven components—engagement and participation, relational thinking, stepwise mastery, contextualization, multidimensional integration, empowerment, and scientific articulacy—we offer an alternative approach to evaluating student learning in practical contexts and provide science educators with concrete areas to focus on when designing and assessing practical activities. Intended to be complementary and additive to existing assessment methods, this framework is not presented as a one-size-fits-all solution. Rather, it should be thoughtfully adapted and customized to suit specific local contexts and grade levels. Science education practitioners can use the framework as a whole or selectively focus on specific components that align with their curricular goals and assessment needs. By embracing the principles of the framework, the assessment lens of practical activities may be broadened and enriched to better prepare students with the knowledge, skills, and mindsets necessary to become scientifically literate citizens of the future.

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