INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 13, Issue 2, (2024) E-ISSN: 2226-6348

Strategies for Mastering Science Process Skills and Manipulative Skills in Practical Work

[1]Engku Mohd Sharul Akimi Engku Ismail, [2]Mohd Effendi @ Ewan Mohd Matore

[1]Faculty of Education, The National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia, [2]Research Centre of Education Leadership and Policy, Faculty of Education, The National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

Corresponding Author Email: effendi@ukm.edu.my

To Link this Article: http://dx.doi.org/10.6007/IJARPED/v13-i2/21256 DOI:10.6007/IJARPED/v13-i2/21256

Published Online: 23 April 2024

Abstract

Science is a discipline based on theory and practice. Practical work or science experiments play an important role in the learning process involving scientific skills, namely scientific process skills and manipulative skills. However, discussions on the concept of strategies for mastering science process skills and manipulative skills in practical work are very limited. Therefore, this concept paper aims to explain the concept of science process skills and manipulative skills in science learning and then examine learning strategies that can improve the mastery of these scientific skills. The findings show that three main strategies have been identified, namely the inquiry-based learning approach, scientific argumentation-based learning and the use of information and communication technology in science learning. This concept paper has implications for inspiring science educators to use appropriate strategies in science teaching and learning and subsequently contributing to the improvement of students' science process skills and manipulative skills. The main strategies outlined can be focused on target groups such as science teachers in lower and secondary schools. Further research proposals in the future can be carried out such as the development of instruments to measure students' scientific skills and the implementation of science practical work using distance and hybrid learning approaches.

Keywords: Science Process Skills, Manipulative Skills, Scientific Skills, Practical Work, Learning Strategy

Introduction

Science literacy has become a major necessity in today's world filled with continuous scientific advancements. In this rapidly evolving landscape, active engagement in conversations about technological and scientific developments is essential. Various tasks demand in-depth knowledge, skills, and productive communication, and mastery of science process skills can help achieve these goals (Soylu, 2004). Padilla (1990) explains that when science process skills are explicitly outlined as a target science learning outcome, students are more likely to learn them effectively.

In a contemporary world where technological advances facilitate access to knowledge, students need to not only acquire existing knowledge but also understand the nature of science, engage in scientific knowledge generation, pose and interpret problems, and develop problem-solving skills (Gultepe, 2016). Providing students with existing knowledge and making them acquire the ability to solve problems independent of everyday life will not be sufficient to prepare them for their future (Rillero, 1998). In this case, the main goal of science education is to improve science literacy. Science literacy can be achieved through the application of scientific methods, enabling students to engage in critical thinking, continuous learning, problem solving, and making decisions based on scientific frameworks.

Global education system assessments through international large-scale assessments (ILSAs), such as the Program for International Student Assessment (PISA), serve as a method to scrutinize the performance of education stakeholders and policy makers. ILSAs provide a platform for education systems to measure the achievement of their students on a global scale, offer insights into areas of improvement and enable the use of best practices from high-achieving countries.

Based on the PISA 2023 results, Malaysia recorded a huge drop of 22 points in the average score of science achievement to 416 from 438 in PISA 2018. In fact, this average score is much lower than the average of 485 points in the Organization for Economic Co-operation and Development (OECD) countries. Weak results in science performance suggesting deficiencies in scientific assessment capabilities require concerted efforts from interested parties in the science education system. One of the ways to identify students' scientific reasoning skills is through the assessment of their science process skills.

Science Process Skills (SPS)

Science process skills are complex skills commonly used by scientists in carrying out scientific investigations into a series of learning processes (Darmaji et al., 2022). This skill is a behavior that allows individuals to acquire knowledge and disseminate this knowledge effectively to improve both mental and psychomotor skills optimally (Gunawan et al., 2019).

Basic process skills can be categorized into two groups, namely basic science process skills that involve observing, classifying, measuring, and predicting; and integrated science process skills that include identifying and defining variables, collecting and transferring data, constructing data tables and graphs, describing relationships between variables, interpreting data, manipulating materials, modifying data, formulating hypotheses, designing investigation, making generalizations and conclusions (Temiz, 2020). These skills enable students to understand the scientific phenomena being investigated, gain information, and increase their sense of responsibility for their own learning during science experiments (Kim, 2018).

Kurniawan et al. (2020) reported that science process skills play an important role in training students in critical thinking processes and fostering scientific attitudes. The process of learning and teaching science process skills is designed to help students understand facts, concepts, and their relation to the theory of science process skills and shape their attitudes towards the subject. The application of these basic science skills can be effectively demonstrated through hands-on practical work.

Science Practical Work

Practical work is often considered fundamental to a national science curriculum that aims to foster science process skills in students. The ability to engage in hands-on practical work in a science laboratory is an important science process skill and is an objective of science learning standards (Schwichow et al., 2016). This emphasis is based on the belief that having science process skills is essential to achieving scientific literacy (Halim, 2013). Abrahams et al (2013) state that practical work is any form of teaching and learning that involves the manipulation and observation of real objects. In the context of this study, practical work is specifically described as any scientific activity that is both hands-on and mind-on, in which students take an active part, whether individually or in small groups, through inquiry and discovery.

In Malaysia, practical word is regarded as a booth strategy to enable students to develop their science process skills, and as a result, it is widely implemented in science booths. Practical work provides opportunities for students to explore phenomena, make inferences, and hone scientific skills in controlling apparatus, contributing to meaningful science learning and the development of critical thinking skills. This approach encourages students to learn by actively seeking out phenomena in their environment. Such a learning strategy has the potential to facilitate the acquisition of scientific knowledge and improve the understanding of scientific theory (Fadzil & Saat, 2013; Schwichow et al., 2016). The emphasis of practical work is on active learning through observation of physical phenomena (Fadzil & Saat, 2013).

Manipulative Skills

Abraham et al (2013) state that one of the main goals of practical work is the development of manipulative skills among students. Manipulative skills can be defined as psychomotor skills that interweave cognitive functions with corresponding physical movements (Kempa, 1986). For example, these skills include using tools such as microscopes, reading temperatures with a thermometer, or manipulating a Bunsen burner. In the framework of skill acquisition, Anderson (1982) explains that there are two main phases in the development of cognitive skills, namely the declarative level and the procedural level. Instructions and information about specific skills, when received by the learner, are encoded as factual knowledge, which is then interpreted to generate the desired behavior (Anderson, 1982).

In the field of science, manipulative skills emphasize the efficient use and control of scientific equipment and chemicals while carrying out practical work in the laboratory. Students are also introduced to the correct techniques for using, cleaning, and storing scientific equipment safely. The inability to acquire science manipulative skills can hinder the acquisition of other desired skills. For example, students who face difficulties in controlling a piece of equipment may hinder their ability to make important observations and collect relevant data (Fadzil & Saat, 2014).

In addition, students who master science manipulative skills are in a better position to provide support for the development of science process skills. The Malaysian Ministry of Education (2017) emphasizes that manipulative skills are psychomotor skills when students do science investigations. Figure 1 shows the elements of manipulative skills implemented in the science curriculum in Malaysia.

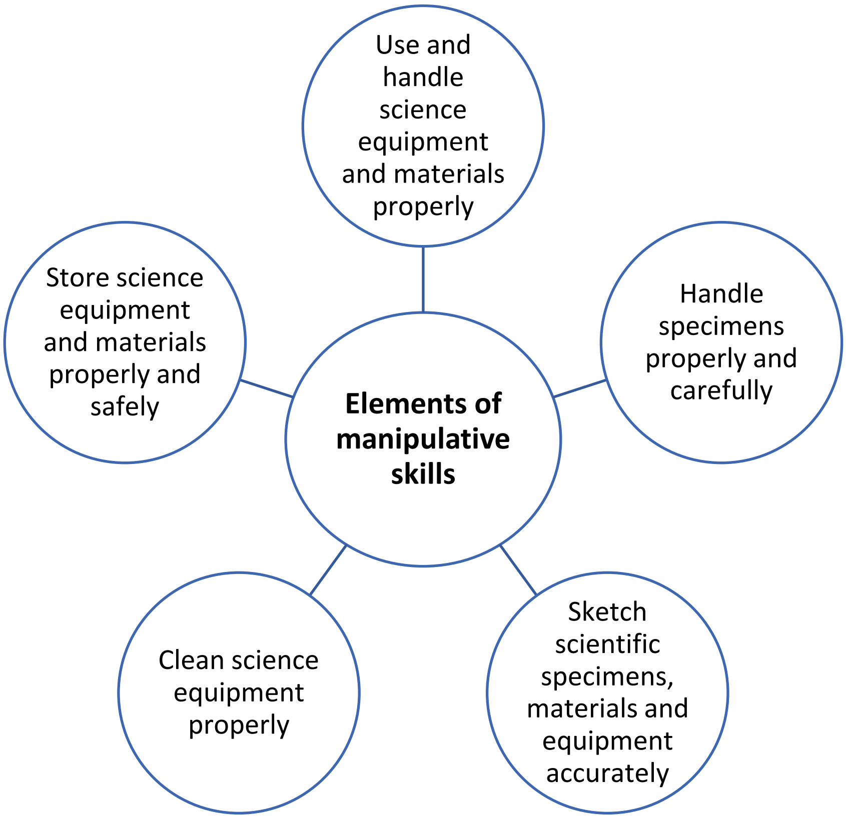

Figure 1. Elements of Manipulative Skills.

Strategies for mastering science process skills and manipulative skills

Science process skills and manipulative skills are scientific skills that need to be developed among students and should be the standard objective for science learning in schools. Therefore, efficient learning strategies need to be implemented to foster the development of science process skills and manipulative skills among students.

A. Inquiry-Based Learning Approach

In the context of education, inquiry is the process of obtaining information through observation or experimentation to find answers and solve problems, using critical and logical thinking skills. The inquiry-based learning approach in science education is not focused on memorizing facts but rather on formulating questions and finding solutions that have the power to progress to questions and problems. Basically, the purpose of inquiry learning is to assist students in formulating questions, finding answers, or solving problems to satisfy their curiosity, contribute to a deeper understanding of the theory or idea being studied in addition to fostering penmanship skills (Gultepe, 2016).

Jufri (2013) reported that the inquiry-based learning approach offers more hands-on learning opportunities to students, allowing them to practice and develop science process skills, critical thinking skills, and a scientific mind. As a result, students are not only encouraged to understand the content of the lesson but also actively engage in scientific exploration and creation (Anam, 2015). Unlike traditional learning environments that focus on delivering established facts, inquiry-based learning approaches spark curiosity, bringing students to actively engage in problem solving through science experiments. For example, students learn chemical kinetics through inquiry-based learning activities in science experiments (Chairam et al., 2015). The core concept in modern education initiatives is to actively engage students in inquiry-based learning.

The inquiry process is considered a valuable approach in science education because it supports students in various aspects of learning. Tatar (2012) argues that engaging in the inquiry process can help students explain concepts, share knowledge, express opinions, listen to alternative views, engage in conversations, and retain their ideas. Participation in inquiry-based activities allows students to understand the nature of science, various scientific phenomena and concepts. It also helps them develop critical appraisal skills for scientific data and promotes their involvement in scientific communities (Saputro, 2019).

The active participation of learners in the inquiry process is seen as a method to promote physical and mental engagement. This engagement allows students to acquire scientific knowledge and solidify their understanding through processes such as critical thinking and scientific inquiry. However, teachers need sufficient experience to effectively implement inquiry learning methods in science teaching, moving away from direct teaching. In this approach, teachers act as facilitators rather than mentors, and students become active learners rather than passive recipients (Hirca, 2015).

Inquiry learning exposes students to various situations, questions or tasks that allow them to "discover" concepts or subjects freely. Bahtiar and Dukomalamo (2019) found this approach is able to maximize students' overall skills, encourage them to investigate systematically, critically and logically, and seek knowledge, attitudes and skills on their own. Teachers can use inquiry-based learning models to guide students through experimental activities aimed at discovering knowledge related to the subject of learning, thereby improving students' science process skills.

In fact, Borrull and Valls (2021) support an inquiry-based approach that combines learning and practice can provide supporting facts and explanations about natural events while improving students' science process skills. In addition, Guritno et al. (2015) suggested that students who have high science process skills generally achieve better psychomotor learning outcomes than students who have lower basic science process skills. Inquiry-based learning serves as a technique to assist students in creating and structuring knowledge, emphasizing attentive participation and active inquiry.

B. Scientific Argumentation-Based Learning Approach

Science learning involves the process of building and using tools to generate knowledge about the natural world (Erduran et al., 2004). Based on this definition, argumentation can serve as an effective tool in building scientific knowledge. As a process of scientific investigation, argumentation in science learning involves justifying claims based on evidence using science process skills (Gultepe & Kilic, 2015). Therefore, by developing argumentation skills one can also develop science process skills in addition to learning science content. Science education aims to equip students with the ability to see the world from multiple perspectives, achievable through assessing multiple reasons for scientific phenomena in the process of argumentation.

In argumentation-based science learning, students understand the link between claims and evidence, contributing to the development of science process skills (Erduran et al., 2004). In conducting an experiment, students engage in a process of judgment, examining an event from multiple perspectives and suggesting various alternative solutions. Through the testing process, students not only learn to think (Driver et al., 2000), but they also face authentic scenarios related to their daily lives. The open-ended questions in the worksheets, based on these scenarios, encourage students to think critically and carry out a thorough study.

Through a learning approach based on scientific argumentation, students' scientific literacy and communication skills can be enhanced by providing hands-on learning activities (Demirbağ & Günel, 2014). By introducing debriefing sessions in science practical work, it provides opportunities for students to pose questions to assess their peers' explanations, analyze and interpret data, and explore alternative explanations (Gultepe & Kilic, 2015). Ping et al. (2020) suggested that science experiments are a direct way to educate students about argumentation skills in science learning. Through argumentation sessions, students can align hypotheses with evidence and assess the reasoning provided by their peers through a rigorous process while ensuring science process skills are directly engaged.

Outcome-based science learning is an effective pedagogical technique that provides opportunities for learners to acquire scientific knowledge by giving them a rationale for affirmation rather than expecting them to pretend to acquire knowledge. Fadzil & Saat (2017) found that functioning, communicating, and cooperating in teams does not necessarily lead to students being able to form excellent written and oral scientific judgments. Through argumentation sessions, students need to engage themselves in building evidence-based rationalizations or arguments for the investigated scientific phenomena. Explicit argumentation in science experiments can guide students and lead to higher science development.

C. Use of Information and Communication Technology

Science process skills are important to 21st century learners, but the development of these skills often faces challenges such as limited availability of materials and radars for practical work. To address these challenges caused by the constraints of doing practical work in traditional labs, the use of virtual media such as virtual labs is increasingly being practiced. Jaya (2012) defines a virtual laboratory as an interactive environment designed to create and run simulation experiments, essentially functioning as a playground for experimentation. It includes domain-dependent simulation programs, experimental units, tools for controlling objects and reference materials. Simulation programs in virtual environments offer advantages in explaining experiments, enhancing students' understanding of science, providing clear visualization, ease of operation, fostering creativity, making science concepts more accessible, visually representing science phenomena, and offering entertainment value (Çelik et al., 2015). Simulations in a virtual laboratory contribute to the development of students' thinking skills by allowing them to combine visual patterns and oral communication in problem solving.

Virtual reality, as a medium of instruction, is considered an important component in the learning system. Virtual learning serves as a way for teachers to engage with students, enabling the illumination of microscopic and macroscopic phenomena at a certain scale through simulations that students can observe (Arista & Kuswanto, 2018). In fact, multimedia resources allow students to review learning materials so that they understand the content naturally (Muslem & Abbas, 2017). The overarching goal is to foster problem-solving skills and provide students to control their future professional needs.

In addition, the application of virtual reality (VR) in science learning can help students understand abstract scientific concepts and internalize knowledge structures. VR, or virtual reality, involves a 3D interactive interface that blends augmented reality and virtual nature, creating an audio-visual environment that users can experience by looking in different directions, providing a sense of being in a real setting. Therefore, the application of VR technology to science learning can allow students to see dynamic virtual objects and create real, viewable models while engaging in virtual 3D science experiments while increasing students' interest in scientific exploration and investigation (Chen et al., 2020).

In fact, the use of VR in science experiments can significantly improve students' understanding of scientific concepts (Arista & Kuswanto, 2018). Additionally, Artun et al. (2020) found that participants' perspectives during VR implementation supported the acquisition of basic science process skills such as observing, inferencing, classifying, and predicting. In addition, participants developed integrated science process skills, including experimenting, formulating hypotheses, operating variables, and interpreting data. This shows that VR applications effectively improve various science process skills in science experiments.

The use of information and communication technologies such as computers and the internet as teaching aids can make the process of teaching and learning science more effective and fun. According to Lee et al. (2019), incorporating communication technology in practical work can help students build self-efficacy towards science learning. In fact, Imaduddin and Hidayah (2019) suggested that designing and completing science experiments through online activities can overcome the constraints of space and time. In a study conducted by Gultepe (2016) on teachers' opinions on the most effective environment for developing science process skills, more than half of the respondents used collaborative computer programs involving both teachers and students. This finding is in line with the study of Shana and Abulibdeh (2020) who emphasized the role of programmed computer environments in science learning, especially for explaining experiments that may pose challenges for practical implementation in traditional laboratory settings.

Overall, the use of technology in science education, such as VR-assisted science experiments and the use of virtual media, has proven efficacy in improving students' understanding of scientific concepts and science process skills (Arista & Kuswanto, 2018). The integration of information and communication technology in science teaching can strengthen the science learning process in a more effective and fun way and overcome challenges in the implementation of science practice. Thus, the use of technology in science education has a positive impact on improving students' science literacy and science process skills to meet the needs of today's evolving world.

Limitations and Reserves for Further Study

This concept paper suggests some strategies that can be implemented to improve students' mastery of science process skills and manipulative skills. In teaching and learning these two skills, it is important to know what are the criteria and constructs that an individual needs to master to confirm that the individual has mastered both science process skills and manipulative skills. However, this concept paper does not discuss an actionable assessment method to measure the level of mastery of these two skills among students. The lack of a reliable method of assessment has led to neglect in the implementation of practical work in most schools (Abrahams et al., 2013). Assessment of students' practical work is important because science learning is closely related to the evidence collected and analyzed while carrying out practical work in the laboratory and serves as a method to obtain evidence to understand students' proficiency and performance in manipulative skills (Fadzil & Saat, 2017).

In addition, due to practical constraints, this concept paper cannot provide a comprehensive overview of the challenges or issues that may arise while implementing the proposed learning strategies. Therefore, this concept paper could be enriched with the addition of more detailed information on implementation strategies and solutions to challenges that may be encountered in implementing science learning in the context of fostering science process skills and manipulative skills.

Based on the above limitations, further studies on the development of instruments that can measure students' scientific skills can be carried out. Performance-based assessments can be implemented that consider factors such as a good rubric, feedback to students and the correct implementation time (Giammatteo, 2018). An analysis rubric is used to describe the progress of students in acquiring proficiency in the laboratory and to determine what is expected of them. With the same rubric, teachers can provide customized feedback on learner performance that can improve their performance in subsequent laboratory classes. This reduces the time teachers spend on individual assessment and facilitates student-teacher communication. Gobaw and Atagana (2016) argue that manipulative skills should be assessed in the laboratory by observing what students actually do rather than grading written laboratory reports or answers to examination questions.

In addition, further studies can be carried out that include various learning strategies. An example would be exploring the implementation of science practical work using distance and hybrid learning approaches through inquiry-based learning. This approach can involve the use of inquiry-based learning modules or specialized software to facilitate virtual learning at flexible times and can provide opportunities for students to carry out practical work at home. This study on the development of science process skills in the context of distance and hybrid learning is important as the approach is gaining increasing attention (Idris et al., 2022). This follow-up study can provide new insights and practical guidance for educators in enhancing the learning of science process skills and manipulatives in the context of science practical work.

Conclusion

Science understanding is achieved not by reading about theory alone, but by doing practical work and creating concepts directly in the laboratory. Mastery of the two main skills, namely scientific process skills and manipulative skills that are often related to each other in the implementation of practical work can benefit students in science learning. The strategies discussed, namely inquiry-based learning, scientific argumentation-based learning and the use of information and communication technology can be implemented to improve the mastery of science process skills and manipulative skills among students.

Based on current trends and the potential for continued growth in technology and pedagogy, the integration of virtual reality (VR) applications in science education is likely to become a commonly used strategy in the next 10 years. The interactive and testing nature of VR technology offers unique opportunities to enhance students' understanding of complex science concepts and engage them in practical virtual experiments, making it a valuable tool for creating engaging and effective learning experiences in science education. With VR technology becoming increasingly accessible and integrated into the educational environment, it is expected to play a significant role in changing the way science is taught and learned in the future.

The successful achievement of science across schools requires a high degree of cooperation among teachers in designing and implementing strategies to improve the level of science education. Therefore, the key to advancing the quality of science teaching and learning lies in effective design that takes place within the school environment. This design involves a holistic and harmonized approach that brings together educators from different disciplines to ensure a comprehensive and cohesive strategy for improving the quality of science education.

Contribution

The research on mastering science process skills and manipulative skills in practical work makes a significant theoretical and contextual contribution by emphasizing the importance of hands-on learning experiences and innovative teaching strategies in science education. By focusing on inquiry-based learning, scientific argumentation-based learning, and the integration of technology in science teaching, this research expands the understanding of effective pedagogical approaches to enhance students' scientific literacy and critical thinking skills. The theoretical contribution lies in the exploration of how these strategies can bridge the gap between theoretical knowledge and practical application, providing students with opportunities to engage in authentic scientific practices. In the context of contemporary education, where STEM skills are increasingly valued, this research plays a vital role in preparing students for future challenges and opportunities in the scientific field. By promoting a holistic approach to science learning that incorporates theory, practice, and technological advancements, this research contributes to the cultivation of a scientifically literate and skilled workforce capable of addressing complex real-world problems.

References

Abrahams, I., Reiss, M. J., & Sharpe, R. M. (2013). The assessment of practical work in school science. *Studies in Science Education, 49*(2), 209-251.

Anam, K. (2015). *Pembelajaran Berbasis Inkuiri: Metode dan Aplikasi*. Yogyakarta: Pustaka Pelajar.

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

Arista, F. S., & Kuswanto, H. (2018). Virtual physics laboratory application based on the android smartphone to improve learning independence and conceptual understanding. *International Journal of Instruction, 11*(1), 1-16.

Artun, H., Durukan, A., & Temur, A. (2020). Effects of virtual reality enriched science laboratory activities on pre-service science teachers' science process skills. *Education and Information Technologies*, *25*(6), 5477-5498.

Bahtiar, B., & Dukomalamo, N. (2019). Basic science process skills of biology laboratory practice: improving through discovery learning. *Biosfer: Jurnal Pendidikan Biologi*, *12*(1), 83-93.

Borrull, A., & Valls, C. (2021). Inquiry Laboratory Activity: Investigating the Effects of Mobile Phone on Yeast Viability. *Journal of Turkish Science Education*, *18*(2), 176 191.

Chairam, S., Klahan, N., & Coll, R. (2015). Exploring secondary students' understanding of chemical kinetics through inquiry-based learning activities. *Eurasia Journal of Mathematics, Science and Technology Education*, *11*(5), 937-956.

Çelik, H., Sarý, U., & Harwanto, U. N. (2015). Developing and evaluating physics teaching material with algodoo (phun) in virtual environment: Archimedes' principle. *International Journal of Innovation in Science and Mathematics Education, 23*(4), 40 50.

Chen, J. C., Huang, Y., Lin, K. Y., Chang, Y. S., Lin, H. C., Lin, C. Y., & Hsiao, H. S. (2020). Developing a hands-on activity using virtual reality to help students learn by doing. *Journal of Computer Assisted Learning*, *36*(1), 46-60.

Darmaji, D., Kurniawan, D. A., & Irdianti, I. (2019). Physics Education Students' Science Process Skills. *International Journal of Evaluation and Research in Education*, *8*(2), 293-298.

Darmaji, Astalini, D. A. Kurniawan, dan E. F. Setiya Rini (2022). Gender analysis in measurement materials: Critical thinking ability and science processing skills. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni*, *11*(1), 113-128.

Demirbağ, M., & Günel, M. (2014). Integrating argument- based science inquiry with modal representations: Impact on science achievement, argumentation, and writing skills. *Educational Sciences: Theory & Practice, 14*(1), 386-391.

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*, 287-312.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into Argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88(*6), 915-933.

Evrim Ural & Durdu Mehmet Gençoğlan (2020). The Effect of Argumentation-Based Science Teaching Approach on 8th Graders' Learning in the Subject of Acids-Bases, their ttitudes towards Science Class and Scientific Process Skills. *Interdisciplinary Journal of Environmental and Science Education, 16*(1), e02207.

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 science practical work. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(8), 4591-4607.

Giammatteo, L. (2018). Competency-based assessment in the science laboratory. *Observatory of Educational Innovation*. https://observatory.tec.mx/edu-bits-2/competency-based -assessment-in-the-science-lab [24 September 2018].

Gobaw, G. F., & Atagana, H. I. (2016). Assessing laboratory skills performance in undergraduate biology students. *Academic Journal of Interdisciplinary Studies, 5*(3), 113–121.

Gultepe, N. (2016). High School Science Teachers’ Views on Science Process Skills. *International Journal of Environmental and Science Education*, *11*(5), 779-800.

Gultepe, N., & Kilic, Z. (2015). Effect of scientific argumentation on the development of scientific process skills in the context of teaching chemistry. *International Journal of Environmental and Science Education*, *10*(1), 111–132.

Gunawan, G., Harjono, A., Hermansyah, H., & Herayanti, L. (2019). Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept. *Jurnal Cakrawala Pendidikan*, *38*(2), 259-268.

Guritno, T. A. M. R., Masykuri, M., & Ashadi. (2015). Pembelajaran kimia melalui model pemecahan masalah dan inkuiri terbimbing ditinjau dari keterampilan proses sains (KPS) dasar dan sikap ilmiah siswa. *Jurnal Inkuiri*, *4*(2), 1–9.

Halim, L. (2013). *Pendidikan Sains dan Pembangunan Masyarakat Berliterasi Sains* [Science Education and Development of Science Literate Community]. Selangor, Malaysia: National University of Malaysia Publisher.

Hirça, N. (2015). Developing a constructivist proposal for primary teachers to teach science process skills: “Extended” simple science experiments (ESSE). *Asia-Pacific Forum on Science Learning and Teaching*, *16*(1), 1–16.

Idris, N., Talib, O., & Razali, F. (2022). Strategies in mastering science process skills in science experiments: A systematic literature review. *Jurnal Pendidikan IPA Indonesia*, *11*(1), 155-170.

Imaduddin, M., & Hidayah, F. F. (2019). Redesigning laboratories for pre-service chemistry teachers: from cookbook experiments to inquiry-based science, environment, technology, and society approach. *Journal of Turkish Science Education*, *16*(4), 489 - 507.

Jaya, H. (2012). Pengembangan laboratorium virtual untuk kegiatan paraktikum dan memfasilitasi pendidikan karakter di SMK. *Jurnal Pendidikan Vokasi, 2*(1), 81- 90.

Juhji, J., & Nuangchalerm, P. (2020). Interaction be- tween scientific attitudes and science process skills toward technological pedagogical content knowledge. *Journal for the education of gifted young scientists*, *8*(1), 1-16.

Jufri, W. (2013). *Belajar dan pembelajaran sains*. Bandung: Pustaka Reka Cipta.

Kementerian Pelajaran Malaysia. (2017). *Kurikulum Standard Sekolah Menengah Sains*. (B. P. Kurikulum, Ed.). Kuala Lumpur.

Kim, M. (2018). Understanding children’s science identity through classroom interactions. *International Journal of Science Education*, *40*(1), 24- 45.

Kurniawan, W., Pathoni, H., Muliawati, L., Kurniawan, D. A., Romadona, D. D., Ningsi, A. P., & Dari, R. W. (2020). Relationship of science process skills and critical thinking of students in physics subject. *Universal journal of educational research*, *8*(11), 5581- 5588.

Lee, M. H., Liang, J. C., Wu, Y. T., Chiou, G. L., Hsu, C. Y., Wang, C. Y., Lin, J. W., & Tsai, C. C. (2019). High School Students Conceptions of Science Laboratory Learning,Perceptions of the Science Laboratory Environment, and Academic Self-Efficacy in Science Learning. *International Journal of Science and Mathematics Education, 18*(1).

Muslem, A., & Abbas, M. (2017). The effectiveness of immersive multimedia learning with peer support on English speaking and reading aloud. *International Journal of Instruction, 10*(1), 203-218.

Padilla, M. J. (1990). The science process skills. *Research matters – To the science teacher* (No. 9004). National Association for Research in Science Teaching.

Rillero, P. (1998). Process skills and content knowledge. *Science Activities, 35*(3), 3-5.

Saputro, A. D., Rohaeti, E., & Prodjosantoso, A. K. (2019). Using inquiry-based laboratory instruction to improve critical thinking and scientific process skills among preservice elementary teachers. *Eurasian Journal of Educational Research*, *19*(80), 151-170.

Schwichow, M., Zimmerman, C., Croker, S., & Härtig, H. (2016). What students learn from hands-on activities. *Journal of research in science teaching*, *53*(7), 980-1002.

Shana, Z., & Abulibdeh, E. S. (2020). Science practical work and its impact on high students'academic achievement. *Journal of Technology and Science Education*, *10*(2), 199-215.

Soylu, H. (2004). *New approaches to science teaching*. Ankara, Turkey: Nobel Yayınları.

Tatar, N. (2012). Inquiry-based science laboratories: An analysis of preservice teachers'beliefs about learning science through inquiry and their performances. *Journal of Baltic Science Education*, *11*(3), 248–267.

Temiz, B. K. (2020). Assessing Skills of Identifying Variables and Formulating HypothesesUsing Scenario-Based Multiple-Choice Questions. *International Journal of AssessmentTools in Education, 7*(1), 1-17.