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# Development of Virtual Science Laboratory Oriented Higher Order Thinking Skills Using Articulate Storyline

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**ABSTRACT**

*This study aims to examine the feasibility and practicality of a science virtual laboratory oriented towards Higher Order Thinking Skills (HOTS) using Articulate Storyline. The research employed a Design and Development Research (DDR) approach based on the ADDIE model, comprising the stages of Analysis, Design, Development, Implementation, and Evaluation. Data were collected using validation questionnaires completed by six experts in content and media, along with user responses from 37 pre-service science teachers. The results were analyzed descriptively to determine the feasibility and practicality categories of the developed product. Content expert evaluations yielded average scores of 3.78 for presentation, 3.83 for content quality, 3.70 for language use, and 4.00 for HOTS orientation, all categorized as valid. Media expert evaluations resulted in average scores of 3.73 for software engineering, 3.83 for instructional design, 3.67 for visual communication, and 3.56 for virtual laboratory components, all falling within the valid and usable range. Meanwhile, user responses indicated a practicality percentage of 87.79%, categorized as very practical. The structured practical activities and post-practice evaluation tasks provided within the virtual laboratory effectively contributed to enhancing the Higher Order Thinking Skills of pre-service science teachers.*

**Keywords**: *articulate storyline, higher order thinking skills, pre-service science teachers, virtual science laboratory,*

## INTRODUCTION

The 21$^{st}$ century marks an era of rapid and transformative advancement across diverse sectors, including education, technology, communication, information, economics, and transportation. In this dynamic landscape, the ability to adapt, innovate, and think critically is no longer optional but essential. Pre-service science teachers, as future educators and agents of change, must develop these competencies to survive and thrive in an increasingly complex world (Dinni, 2018; Nugroho, 2018; Stark et al., 2017). Central to 21st-century skills are the four pillars of critical thinking, creativity, communication, and collaboration—of which critical and creative thinking are recognized collectively as Higher Order Thinking Skills (HOTS) (Gradini, E; Firmansyah, B; Noviani, 2018; Gradini, 2019; Marzano, 1992).

The cultivation of HOTS is crucial from an early educational stage through to higher education. Instilling higher-level thinking patterns early on ensures individuals are better prepared to face the uncertainties, challenges, and rapid changes of modern life (Laelasari & Anggraeni, 2017). This necessity has been increasingly reflected in national education policies, which emphasize the importance of integrating HOTS-oriented learning to foster resilient and innovative learners (Istiqomah, 2018; Juhji & Suardi, 2018). In the context of higher education, particularly in teacher education programs, HOTS development is vital for preparing students to think independently, use technology judiciously, and apply knowledge creatively to real-world situations (Laelasari & Maisyanah, 2022; Wijaya et al., 2016). Effectively nurturing these skills requires strategic selection of instructional models and media that promote high cognitive engagement (Nisa et al., 2020; Widodo, T & Kadarwati, 2013). Among these strategies, laboratory practice holds a pivotal role, offering experiential learning opportunities that bridge theoretical understanding with practical application (Dewi, P S., Saefudin., Supriatno, B and Anggraeni, 2016; Laelasari & Supriatno, 2019).

However, multiple studies and preliminary investigations reveal substantial barriers to implementing effective laboratory experiences, including shortages of equipment, lack of laboratory space, and restrictive time constraints (Bogar et al., 2023). These challenges are compounded by curriculum pressures that reduce the time available for hands-on scientific inquiry. As a result, there is an urgent need for innovative, scalable solutions that retain the pedagogical value of laboratory experiences while overcoming logistical limitations.

One such solution is the use of **virtual laboratories**, which replicate real-world experimental environments through digital platforms (McCabe T M and Olimpo T, 2020; Sugiarto, 2023). Virtual labs provide diverse experimental experiences with minimal resource investment, offering advantages such as cost-effectiveness, ease of maintenance, accessibility, and adaptability to learner needs (Grodotzki et al., 2018; Daineko et al., 2017; Kapici et al., 2019) (Grodotzki et al., 2018; Daineko et al., 2017; Kapici et al., 2019). Moreover, virtual laboratories not only simulate practical activities but also foster critical thinking, problem-solving, and engagement, aligning perfectly with the goals of 21st-century education (Hernández-de-Menéndez et al., 2019).

The virtual laboratory leverages software and application technologies as an innovative approach to enhance laboratory service activities, offering numerous advantages—most notably, broader accessibility, increased efficiency, and the elimination of geographical and logistical barriers. This accessibility is facilitated by the ability of the software or applications to operate seamlessly on Android devices and other platforms (Jufriansah et al., 2022; Manikowati & Iskandar, 2018). Virtual laboratory activities have been shown to enhance user motivation, stimulate critical thinking skills, and foster active engagement in practical scientific tasks (Azhar et al., 2023; Sugiarto, 2023). Furthermore, they serve as an effective alternative to traditional laboratory experiences, particularly when material abstraction or limited laboratory equipment renders conventional approaches impractical (Masril et al., 2018; Nirwana, 2017).

Among the various technological platforms supporting the development of virtual science laboratories, Articulate Storyline stands out. Articulate Storyline is a multimedia authoring tool that integrates text, animation, charts, images, videos, and audio into interactive, web-based (HTML5) applications or printable modules. These outputs are compatible with a range of devices, including tablets, laptops, and smartphones, making information delivery more engaging and accessible. This application has been widely adopted to create interactive learning media, including virtual laboratories, enhancing the attractiveness and effectiveness of educational content (Husna, 2022; Ike Yunia Pasa et al., 2023; Mallu & Samsuriah, 2020).

Previous research into the development of virtual laboratories includes initiatives such as the construction of a physics virtual laboratory using the PhET application to improve learning outcomes (Bogar et al., 2023), the development of a vertebrate identification virtual lab (Sugiarto, 2023), and the creation of inquiry-based virtual labs to enhance process skills (Azhar et al., 2023),. Similarly, Saputra et al.(2021) demonstrated that guided inquiry-based virtual science learning devices using PhET applications effectively foster scientific process skills. These studies consistently highlight that virtual laboratories are both feasible and valid tools for improving science education outcomes.

To further explore trends in virtual laboratory development and their relationship with higher-order thinking skills (HOTS) in science education, a narrative literature review was conducted using Google Scholar (GS). Google Scholar was selected due to its widespread use as a web-based academic search engine and its growing comprehensiveness, making it a valuable complement to traditional literature databases (Haddaway et al., 2015; Halevi et al., 2017).

The literature search revealed that Articulate Storyline has predominantly been utilized for creating interactive science learning media (Agustina et al., 2022; Aulia & Masniladevi, 2021; Daryanes et al., 2023; Nurmala et al., 2021). However, there remains a notable research gap: to date, no published studies have developed a science-oriented virtual laboratory explicitly designed to foster higher-order thinking skills (HOTS) using Articulate Storyline. This is a significant oversight given the growing body of evidence suggesting that virtual laboratories have substantial potential to cultivate HOTS, including analytical reasoning, evaluation, and problem-solving abilities (Anisa et al., 2020; Hentian et al., 2022; Salsabila et al., 2025).

Building on this foundation, the current initiative seeks to develop a virtual science laboratory using Articulate Storyline as an innovative alternative to traditional laboratory activities, particularly for topics that are difficult to replicate in physical laboratories due to equipment limitations or the abstract nature of the material. It is anticipated that this virtual laboratory will not only enhance pre-service science teachers' engagement in practical activities but also significantly strengthen their higher-order thinking skills.

## METHODOLOGY

This study employed the Design and Development Research (DDR) methodology, aimed at developing a virtual science laboratory oriented toward higher-order thinking skills (HOTS) using Articulate Storyline software as an alternative approach to practical work in integrated science courses. DDR is particularly well-suited for the development of both instructional and non-instructional products (Richey & Klein, 2014). The development process followed the ADDIE model, which consists of five sequential phases: Analysis, Design, Development, Implementation, and Evaluation (Aldoobie, 2015).

During the Analysis phase, a needs assessment was conducted through personal communication with potential users. This involved analyzing the responses of five science lecturers and eighteen pre-service science teachers, focusing on their needs, experiences, and challenges encountered during laboratory activities, particularly within integrated science courses. The goal was to identify key obstacles and formulate targeted solutions. In the Design phase, a storyboard (initial draft) for the virtual laboratory was prepared using Articulate Storyline. This draft included essential components such as laboratory tools and materials, step-by-step procedures, data tables, and interpretation frameworks for various basic science experiments. Four types of virtual laboratory prototypes were designed: food testing, electrical conductivity, specific heat capacity, and the moment of a force (torque). In addition, research instruments for data collection were designed to be utilized in the subsequent phases.

The Development phase involved the creation of the initial product, followed by expert validation to assess its validity and feasibility prior to field use. A total of six validators participated in this stage, with three validators assigned to each aspect of expert validation. The Implementation phase consisted of two stages. Initially, the virtual laboratory product was piloted on a small scale involving seven pre-service science teachers (two males and five females) enrolled in integrated science courses. Subsequently, broader classroom implementation was carried out with thirty-seven pre-service science teachers (twelve males and twenty-five females) also enrolled in the second semester of the integrated science course. Participants were selected using purposive sampling to align with the research objectives. Finally, the Evaluation phase involved reviewing and analyzing the entire experimental process to refine and improve the virtual laboratory product, culminating in the development of the final version.

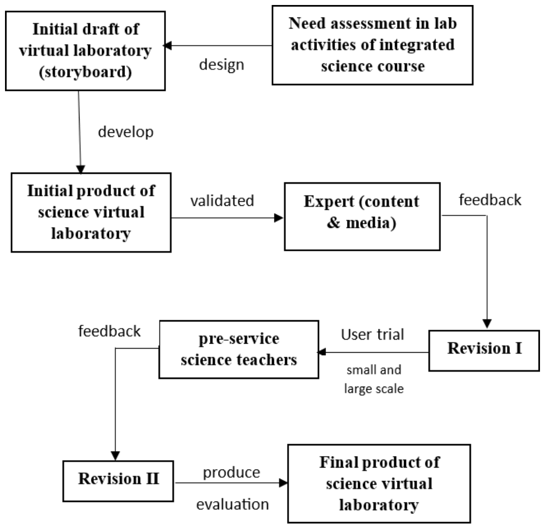



**Figure 1. Procedure of Product Development**

To assess the feasibility and practicality of the product, the researcher employed three types of questionnaires: media expert validation, content expert validation, and user response surveys. The content validation focused on evaluating aspects such as presentation quality, content accuracy, language appropriateness, and the promotion of higher-order thinking skills. Meanwhile, media validation addressed criteria related to software engineering, instructional design, visual communication, and the integration of virtual laboratory components. The user response questionnaire encompassed all of these categories to provide a comprehensive evaluation. Subsequently, the results of expert validations were analyzed using the feasibility criteria outlined in Table 1 to determine the overall quality and suitability of the product.

**Table 1. Feasibility Criteria of Virtual Laboratory**

| Average score | Criteria | Catogory |
|---|---|---|
| 3,26 - 4,00 | valid | feasible |
| 2,51 -3,25 | quite valid | |
| 1,76 - 2,50 | less valid | not feasible |
| 1,00 - 1,75 | invalid | |

(Febriana, 2014)

Meanwhile, the results of the user response evaluations were analyzed to assess the practicality of the virtual laboratory, based on the practicality criteria outlined in Table 2.

**Table 2. Practicality Criteria of Virtual Laboratory**

| Criteria | Level of Practicality Category |
|---|---|

| | |
|---|---|
| 81% - 100% | very high |
| 61% - 80% | high |
| 41% - 60% | medium |
| 21% - 40% | low |
| 0% - 20% | very low |

(Marthalena et al., 2021)

## RESULT AND DISCUSSION

The research on the development of a virtual laboratory aimed at enhancing higher-order thinking skills through the use of Articulate Storyline was conducted in five distinct stages. The initial phase of product development involved the creation of a prototype that included the initial page layout, the Graduate Learning Outcomes (GLO), and four key science laboratory activities. These activities were focused on the following concepts: food testing, electrical conductivity, specific heat, and the moment of a force (torque). Each component was designed to facilitate an engaging and interactive learning experience, laying the foundation for the subsequent stages of development and refinement.


**Figure 2. Display The Product Home Page**

Each laboratory activity within the virtual environment is structured around three core elements: indicators and objectives, foundational theory, and the virtual lab activity itself. Each lab activity is further divided into four key components: tools and materials, practical procedures, data analysis, and evaluation. To promote the development of higher-order thinking skills, the researchers integrated cognitive challenges into the practical tasks. For instance, at the outset of each activity, users are required to select the appropriate tools and materials from a provided set, encouraging critical decision-making. Additionally, higher-order thinking skills are further fostered through a series of reflective questions presented during the post-practical evaluation phase, prompting users to analyze and synthesize the knowledge gained during the activity.


**Figure 3. Main Features and Higher Order Thinking Skills Integration**

The subsequent stage of product development involved validation, which aimed to assess the feasibility of the virtual laboratory. The product was considered feasible if it was deemed valid by the validators, based on the scores they assigned and their feedback or suggestions. The validation process was conducted through expert judgment, involving both content and media experts. Content validation focused on evaluating the product's alignment with key criteria, including presentation quality, content relevance, language clarity, and the incorporation of higher-order thinking skills. The results of the validation process, as provided by the validators, are presented in Figure 4.

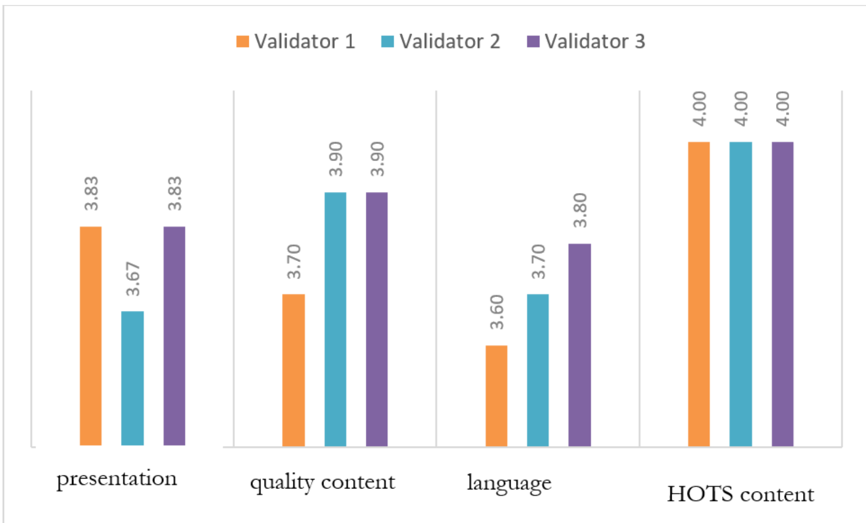



**Figure 4. Content Expert Validation Average Score**

As shown in Figure 4, the average score for content validation across all indicators is 3.83, which falls within the valid and feasible range. Specifically, the average scores for each individual aspect are as follows: presentation criteria received a score of 3.78, quality content scored 3.83, language aspects received 3.70, and the higher-order thinking skills content achieved a score of 4. The average scores provided by each validator were 3.83, 3.67, and 3.83, respectively, for the first, second, and third validators. These scores indicate that the product meets the valid criteria overall. In conclusion, the final assessment of the virtual laboratory, particularly in terms of higher-order thinking skills, confirms its feasibility. The results of the media expert validation are presented in Figure 5.

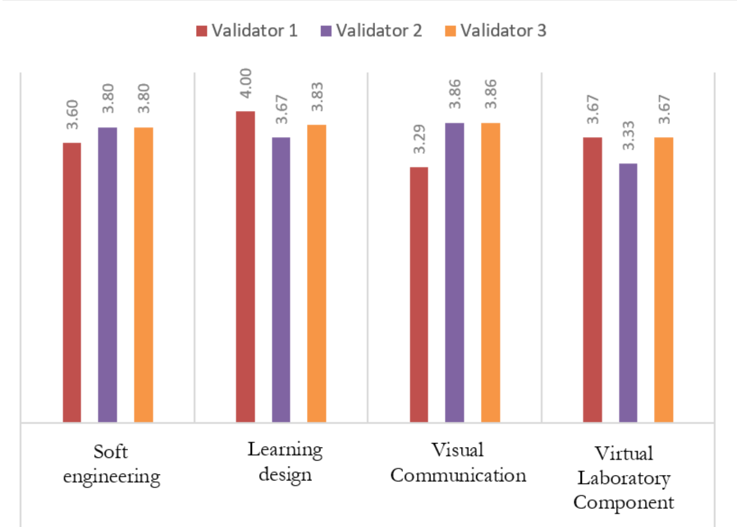


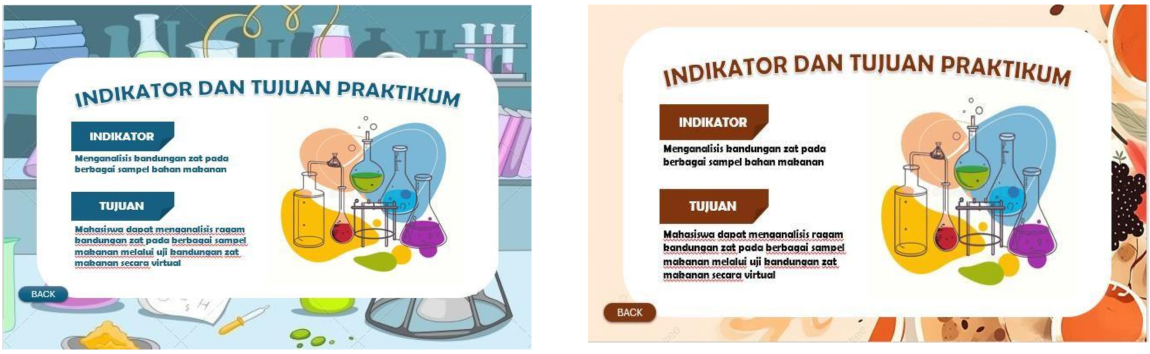

**Figure 5. Media Expert Validation Average Score**

As presented in Figure 5, the media expert validation was conducted across four key aspects: software engineering, learning design, visual communication, and virtual laboratory components. The overall average score for all indicators was 3.69, which places the product in the valid and feasible category. More specifically, the average scores for each indicator were as follows: software engineering received a score of 3.73, learning design scored 3.83, visual communication achieved 3.67, and the virtual laboratory component was rated 3.56. All four aspects were deemed valid and feasible, with the learning design category particularly highlighted as strong. After the product was deemed feasible and revised according to the feedback provided by the validators, further testing was conducted to assess the practical usability of the virtual laboratory. A large-scale trial involving 37 pre-service science teachers was carried out, yielding a practical score of 89.77%, categorizing the product as highly practical. The detailed user responses, which were used to measure the quality of the virtual laboratory, are presented in Table 3**.**

**Table 3. User Response Score Analysis**

| Aspect | Average score | Percentage | Level of practicality |
|---|---|---|---|
| Software engineering | 14.95 | 93.41 | Very high |
| Visual Communication | 11.19 | 93.24 | Very high |
| Virtual laboratory component | 15.65 | 78.24 | High |
| Learning Design | 10.95 | 91.22 | Very high |
| Presentation | 9.35 | 77.91 | High |
| Content quality | 10.85 | 90.41 | Very high |
| Language | 10.45 | 87.08 | Very high |
| Integration HOTS in Virtual lab | 14.54 | 90.88 | Very high |
| Average score | **12.24** | **87.79** | **Very High** |

In line with the development model followed, evaluation plays a critical role in the completion of the virtual laboratory product. This evaluation phase is conducted at each stage of the product development process. It serves as a mechanism for analyzing and refining the science virtual lab, ensuring that the product evolves effectively from development to field implementation. The primary objective is to continuously improve the product, making it more efficient and effective for its intended users. Evaluations are carried out through expert judgment and user responses, providing valuable feedback for enhancement. An example of the improvements made to the product based on such evaluations includes adjustments to the color background, which were modified to create a more cohesive and visually appealing user experience, as illustrated in Figure 6. These refinements are part of an ongoing process aimed at optimizing the virtual laboratory's functionality and usability.




Before revision After revision

**Figure 6. Sample of Evaluation Process**

Four practical laboratory activities have been developed within the virtual laboratory: food testing, electrical conductivity, specific heat, and the moment of a force (torque). The food test activity includes amylum, fat, glucose, and protein tests, which are part of biochemistry content, while the other three activities pertain to biophysics. All of these topics fall within the scope of an integrated science course. The Graduate Learning Outcomes (GLO) for the integrated science course focus on knowledge aspects that encompass a fundamental understanding of synthesizing physics, chemistry, and biology, as well as the specific skills necessary for designing laboratory setups, managing laboratory activities, and evaluating the use of scientific laboratories.

The validation of the virtual laboratory product was conducted by content and media experts to assess its feasibility before implementation. This validation process aligns with the goal of the development research, which seeks to produce a scientifically tested model or product (Trisnaningsih et al., 2021). Content validation showed that the highest average score was awarded to the aspect of higher-order thinking skills. The virtual laboratory product successfully integrates higher-order thinking skills not only in the evaluation portion but also throughout the practical activities. For example, in the tools and materials section, users must select the appropriate equipment before starting their experiments. If the wrong selection is made, the next step cannot proceed, prompting users to critically consider their choices. Furthermore, in the data analysis section, users are tasked with collecting data from their experiments and analyzing it to draw conclusions, fostering deeper cognitive engagement. This demonstrates the potential of the virtual laboratory to enhance the higher-order thinking skills of pre-service science teachers during and after lab activities. These findings align with previous research, which indicates that lab activities can enhance students' thinking skills by optimizing both hands-on and minds-on learning experiences (Dewi, P S., Saefudin., Supriatno, B and Anggraeni, 2016; Laelasari & Supriatno, 2019; Permana et al., 2021). Additionally, the assessment by content validators plays a crucial role in ensuring the alignment of the material with the basic competencies and GLO of the science curriculum, as well as determining the appropriateness of the content for the target users' cognitive level (Sasmito et al., 2017; Wakhidah et al., 2020).

A large-scale trial of the virtual laboratory was conducted in an integrated science course, where users—pre-service science teachers—were asked to complete lab activities and subsequently fill out a questionnaire to assess the practicality of the developed media. The average score obtained was 89.39%, categorizing the product as highly practical. This result suggests that the virtual laboratory, developed using Articulate Storyline, can effectively support the learning process in integrated science courses. It offers the advantage of substituting traditional hands-on experiments with virtual simulations, overcoming limitations in equipment, time, and cost. This aligns with research indicating that virtual labs provide significant benefits, including low investment costs, ease of maintenance, customization for students' needs, and the promotion of active learning, all while presenting challenges that help users develop various skills (Hernández-de-Menéndez et al., 2019). Virtual laboratories can also support educators in enhancing practical experiences and offer solutions to the challenges posed by high costs and time constraints in traditional lab settings (Daineko et al., 2017; Fuadi et al., 2021; Lavtania et al., 2021).

One of the key strengths of the developed product is its integration of higher-order thinking skills, which fosters critical and creative thinking abilities in users. The product is delivered through an attractive software interface, making it engaging for users. However, there are some limitations, such as the product being accessible only to users with the correct link and the absence of background music in the application. Therefore, further development is needed to ensure that the virtual lab can be effectively utilized in science education, particularly in integrated science courses. Based on the findings of this study, the researchers recommend conducting experimental studies with the developed product to evaluate its effectiveness and impact on users' higher-order thinking skills. Additionally, it will be important to develop supplementary instruments to collect data in future studies.

## CONCLUSION

The virtual laboratory in science has been developed with an emphasis on higher-order thinking skills, using Articulate Storyline. The development followed a structured process encompassing five stages: analysis, design, development, implementation, and evaluation. The final product, as evaluated by content experts, received an average score of 3.83, while media experts awarded it a score of 3.69, both of which fall within the valid and very feasible criteria. The practicality of the developed product was assessed through field testing, which yielded a final percentage score of 89.36%, classifying it as highly practical. This demonstrates that the virtual laboratory can serve as a viable alternative for conducting practical work in science education. Despite these positive findings, there are some limitations to the research, most notably the lack of investigation into the impact of the virtual laboratory on pre-service science teachers' higher-order thinking skills (HOTS). Further studies are required to explore this aspect and to refine the instruments used to measure and enhance higher-order thinking skills effectively.

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## REFERENCES

Agustina, R., Irhasyuana, Y., & Sauqina, S. (2022). Pengembangan Media Articulate Storyline Topik Mekanisme Pendengaran Manusia dan Hewan Untuk Peserta Didik SMP. *JUPEIS: Jurnal Pendidikan Dan Ilmu Sosial*, *1*(3).

Aldoobie, N. (2015). ADDIE Model. *American International Journal of Contemporary Research*, *5*(6).

Anisa, M. K., Permana, N. D., & Nova, T. L. (2020). Penggunaan Simulasi Virtual Pada

Pembelajaran Fisika Untuk Meningkatkan Higher Order Thinking Skill (Hots) Siswa : Meta Analisis. *Jurnal Kumparan Fisika*, *3*(2), 163–170.

Aulia, A., & Masniladevi, M. (2021). Pengembangan Multimedia Interaktif Berbasis Articulate Storyline 3 untuk Meningkatkan Minat Belajar Peserta Didik pada Pembelajaran Tematik Terpadu di Kelas III SD. *Jurnal Pendidikan Tambusai*, *5*(1).

Azhar, A., Irianti, M., & Rahmadhani, M. (2023). The Effectiveness of The Virtual Lab-Assisted Guided Discovery Learning Model on Students' Science Process Skills. *Jurnal Penelitian Dan Pengembangan Pendidikan Fisika*, *9*(1).

Bogar, D. ., Jufriansah, A., & Prasetyo, E. (2023). Pengembangan Laboratorium Virtual untuk Meningkatkan Hasil Belajar Peserta Didik. *Buletin Edukasi Indonesia, Vol 2 (3), 102-112.*, *2*(3), 102–112.

Daineko, Y., Dmitriyev, V., & Ipalakova, M. (2017). Using Virtual Laboratories in Teaching Natural Sciences: An Example Of Physics Courses In University. Computer Applications in Engineering Education. *Wiley Online Libary*, *25*(1), 39–47.

Daryanes, F., Darmadi, D., Fikri, K., Sayuti, I., Rusandi, M. A., & Situmorang, D. D. B. (2023). The development of articulate storyline interactive learning media based on case methods to train student's problem-solving ability. *Heliyon*, *9*(4).

Dewi, P S., Saefudin., Supriatno, B and Anggraeni, S. (2016). Penerapan Diagram Vee dalam Problem Based Learning dan Discovery Learning untuk Meningkatkan Kemampuan Literasi Kuantitatif Siswa Pada Materi Pencemaran. *Proceeding Biology Educations Confrence*, 128–132.

Dinni, H. N. (2018). HOTS (Higher Order Thinking Skills) dan Kaitannya dengan Literasi Matematika. *Prisma: Prosiding Seminar Nasional Matematika*, 170–176.

Febriana, L. C. (2014). *Pengembangan Lembar Kerja Siswa (LKS) Fisika Materi Tekanan Mencakup Ranah Kognitif, Afektif, Dan Psikomotor Sesuai Kurikulum 2013 Untuk SMP/MTs*. Universitas Negeri Malang.

Fuadi, H., Melita, A. S., & Syukur, A. (2021). Inovasi LKPD dengan Desains Digital Sebagai Media Pembelajaran IPA di SMPN 7 Mataram Pada Masa Pandemi Covid-19. *Jurnal Ilmiah Profesi Pendidikan*, *6*(2), 167–174.

Gradini, E; Firmansyah, B; Noviani, J. (2018). Menakar Kemampuan berpikir Tingkat Tinggi Calon Guru Matematika melalui Level HOTS Marzano. *Eduma: Mathematics Teaching and Learning*, *7*(2), 41–48.

Gradini, E. (2019). Menilik Konsep Kemampuan Berpikir Tingkat Tinggi (Higher Order Thinking Skills) dalam Pembelajaran Matematika. *Jurnal Numeracy*, *6*(2), 189–203.

Grodotzki, J., Ortelt, T. R., & Tekkaya, A. E. (2018). Remote and Virtual Labs for Engineering Education 4.0: Achievements of the ELLI project at the TU Dortmund University. *Procedia Manufacturing*, *26*, 1349–1360.

Haddaway, N. R., Collins, A. M., Coughlin, D., & Kirk, S. (2015). The Role of Google Scholar in Evidence Reviews and Its Applicability to Grey Literature Searching. *PLoS ONE*, *10*(9), e0138237.

Halevi, G., Moed, H., & Bar-Ilan, J. (2017). Suitability of Google Scholar as a source of scientific information and as a source of data for scientific evaluation—Review of the Literature. *Journal of Informetrics*, *11*(3), 823–834.

Hentian, N. Y., Ramdhan, B., & Setiono. (2022). Profil Higher Order Thinking Skills dan Literasi Sains Siswa dalam Pembelajaran Inkuiri Terbimbing Berbantuan Virtual Lab. *Biodik*, *8*(3), 79–90.

Hernández-de-Menéndez, M., Vallejo Guevara, A., & Morales-Menendez, R. (2019). Virtual reality laboratories: a review of experiences. *International Journal on Interactive Design and Manufacturing, 13*(3), 947–966.

Husna, M. N. (2022). Tutorial pembuatan media aplikasi articulate storyline 3 untuk pembelajaran di SD. *Jurnal Ilmiah Multidisiplin, 1*(2), 41–48.

Ike Yunia Pasa, Yoga Sahria, & Cahyo Anggoro. (2023). Articulate Storyline sebagai Media Pembelajaran Interaktif bagi Guru SD Negeri Bedug. *Lentera Pengabdian, 1*(03), 338–346. https://doi.org/10.59422/lp.v1i03.104

Istiqomah. (2018). *Pembelajaran dan Penilaian Higher Order Thinking Skills*. CV Pustaka Media Guru.

Jufriansah, A., Lering, L., & Donuata, P. B. (2022). Utilization of PhET simulation in flipped classroom to improve students' critical thinking skills. *Jurnal Riset Dan Kajian Pendidikan Fisika, 9*(1), 17–24.

Juhji, & Suardi, A. (2018). Profesi Guru Dalam Mengembangkan Kemampuan Berpikir Kritis Peserta Didik Di Era Globalisasi. *Geneologi PAI: Jurnal Pendidikan Agama Islam*, *5*(1), 16–24.

Kapici, H. O., Akcay, H., & de Jong, T. (2019). Using Hands-On and Virtual Laboratories Alone or Together—Which Works Better for Acquiring Knowledge and Skills? *Journal of Science Education and Technology*, *28*(3), 231–250.

Laelasari, I., & Anggraeni, S. (2017). Improving Critical Thinking and Metacognition Ability Using Vee Diagram through Problem-Based Learning of Human Respiratory System. *Atlantis Press*, 45–51. https://doi.org/10.2991/icmsed-16.2017.16

Laelasari, I., & Maisyanah. (2022). Digital Literacy Level Analysis of Pre-service Biology Teacher Integrated Islamic Values. *Journal of Biology Education*, *5*(2), 108–119.

Laelasari, I., & Supriatno, B. (2019). Analisis Komponen Penyusun Desain Kegiatan Laboratorium Bioteknologi. *JURNAL BIOEDUKATIKA*, *6*(2), 84. https://doi.org/10.26555/bioedukatika.v6i2.10592

Lavtania, N., Nulhakim, L., & Utari, E. (2021). Pengembangan LKPD Digital Menggunakan Pendekatan Saintifik Berbasis Kreativitas Mata Pelajaran Kimia Materi Pembuatan Makanan Berupa Koloid. *Quantum: Jurnal Inovasi Pendidikan Sains*, *12*(2), 172. https://doi.org/10.20527/quantum.v12i2.11320

Mallu, S., & Samsuriah, S. (2020). Implementasi Articulate Storyline dalam Pembuatan Bahan Ajar Digital pada STMIK Profesional Makassar. *Proseding SNTEI*.

Manikowati, & Iskandar, D. (2018). Pengembangan Mobile Virtual Laboratorium untuk Pembelajaran Praktikum Siswa SMA, Kwangsan. *Jurnal Teknologi Pendidikan*, *6*(1), 23–42.

Marthalena, R., Kartini, K., & Maimunah, M. (2021). Perangkat Pembelajaran Matematika dengan Pendekatan Realistic Mathematics Education untuk Memfasilitasi Kemampuan Pemecahan Masalah Matematis. *Jurnal Cendekia : Jurnal Pendidikan Matematika*, *5*(2), 427–1438.

Marzano. (1992). *Assesing Student Outcomes: Performance Assesment Using the Dimensions of Learning Models*. Alexandria,Virginia : Association for Supervision and Currciculum Development.

Masril, Hidayati, & Darvina, Y. (2018). The Development of Virtual Laboratory Using ICT for Physics in Senior High School. *IOP Conference Series: Materials Science and Engineering.*, 1–8.

McCabe T M & Olimpo T. (2020). Advancing Metacognitive Practices in Experimental Design: A Suite of Worksheet-Based Activities to Promote Reflection and Discourse in Laboratory Contexts. *Journal of Biology and Microbiology & Biology Education*, *20*(1).

Nirwana, R. R. (2017). Pemanfaatan Laboratorium Virtual dan E-Reference dalam Proses

Pembelajaran dan Penelitian Ilmu Kimia. *Phenomenon: Jurnal Pendidikan MIPA*, *1*(1).

Nisa, W. M., Nafiah, Z., & Wilujeng, I. (2020). Profile of critical thinking skills in student's SMPN 1 Kalipare at topic of substance and its characteristics. *Journal of Physics: Conference Series, 1440*(1), 1–5. https://doi.org/10.1088/1742-6596/1440/1/012081

Nugroho, A. (2018). *HOTS (Higher Order Thinking Skills)*. Grasindo.

Nurmala, S., Triwoelandari, R., & Fahri, M. (2021). Pengembangan Media Articulate Storyline 3 pada Pembelajaran IPA Berbasis STEM untuk Mengembangkan Kreativitas Siswa SD/MI. *Jurnal Basicedu*, *5*(6).

Permana, N. D., Wibowo, F. C., Susilawati, Zarkasih, Z., Bakhtiar, N., Darman, D. R., & Siswanto, S. (2021). Development of a Basic Physics Practicum Guide that is Integrated with Qur'anic Verses for Prospective Natural Science Teachers. *AIP Conference Proceedings*, 2320.

Richey, R. C., & Klein, J. D. (2014). *Design and Development Research: Methods, Strategies, and Issues.* Routledge Taylor & Francis Group.

Salsabila, N. A., Salamah, W. I., Daulay, A. H., Badri, L. N., & Salsabila, U. H. (2025). Pemanfaatan Teknologi untuk Meningkatkan Higher Order Thinking Skills (HOTS) di Era Digital. *Jurnal Ilmu Pendidikan Dan Psikologi*, *2*(2), 115–125.

Saputra, I. G., Harnifa, H., & Akhfar, M. (2021). Development of Science Learning Device Oriented Guided Inquiry with Virtual Laboratory to Train Science Process Skills of Junior High School Students in Kendari. *Jurnal Penelitian Dan Pengembangan Pendidikan Fisika*, *7*(1).

Sasmito, A., Suciati, & Maridi. (2017). Analisis Potensi Bahan Ajar Biologi Kelas XI pada Kurikulum 2013 dalam Memberdayakan Kemampuan Berkomunikasi Siswa. *Scientiae Educatia: Jurnal Pendidikan Sains*, *6*(2), 182–196.

Stark, E., Bistak, P., Kozak, S., & Kucera, E. (2017). Virtual laboratory based on Node.js technology. *International Conference on Process Control (PC, Strbske Pleso, Slovakia.*

Sugiarto, W. (2023). Pengembangan Vili-Have (Virtual Lab Identifikasi Hewan Vertebrata) Untuk Menguatkan Literasi Sainspeserta Didik. *Jurnal Indopedia (Inovasi Pembelajaran Dan Pendidikan), Volume 1 (1), 7-18.*, *1*(1), 7–18.

Trisnaningsih, D. R., Parno, P., & Setiawan, A. M. (2021). The Development of Virtual Laboratory-based STEM Approach Equipped Feedback to Improve Critical Thinking Skills on Acid-Base Concept. *Advances in Engineering Research, Volume 209, 209*, *20*(9), 288–296.

Wakhidah, N., Ibrahim, M., Agustini, R., & Erman, E. (2020). Validitas Strategi Scaffolding Imwr (Inspiring-Modeling-Writing-Reporting) Pada Pendekatan Saintifik. *Edukasi: Jurnal Pendidikan, 18*(1), 1. https://doi.org/10.31571/edukasi.v18i1.1714

Widodo, T & Kadarwati, S. (2013). Higher Order Thinking Berbasis Pemecahan Masalah untuk Meningkatkan Hasil Belajar Berorientasi Pembentukan Karakter Siswa. *Cakrawala Pendidikan, 32*(1), 161–171.

Wijaya, E. Y., Sudjimat, D. A., & Nyoto, A. (2016). Transformasi Pendidikan Abad 21 sebagai Tuntutan Pengembangan Sumber Daya Manusia Di Era Global. *Seminar Nasional Pendidikan Matematika*.