International Journal of Studies in International Education

E-ISSN: 3048-0884
P-ISSN: 3047-356X

Research Article

Development of Chemical Bonding LKPD Assisted by Augmented Reality with a Deep Learning Approach and its Effect on Learning Activities and Higher Level Thinking Skills (Hots) of Eleventh Grade High School Students

Dita Novita Rini[1]*, Eli Rohaeti[2]

[1-2] Universitas Negeri Yogyakarta, Indonesia
* Corresponding Author: dyta358@gmail.com

Abstract: This study aims to develop a Student Worksheet (LKPD) on Chemical Bonding assisted by Augmented Reality (AR) based on deep learning and to examine its feasibility, practicality, and effectiveness in improving learning activities and higher-order thinking skills (HOTS) of high school students. The research employed a 4D development model (define, design, develop, and disseminate) using a pretest posttest control group design involving 11th grade students. Research instruments included expert validation sheets, learning activity questionnaires, and HOTS test instruments. Data were analyzed using descriptive and inferential statistical methods. The results indicated that the AR-based LKPD met very feasible and practical criteria based on expert judgment and student responses. Furthermore, there was a statistically significant difference between the experimental and control groups in learning activities and HOTS achievement ($p = 0.005$). The increase in HOTS scores in the experimental group was categorized as moderate, indicating meaningful learning gains. These findings demonstrate that the AR-assisted Chemical Bonding LKPD is effective as an innovative learning medium for supporting students' understanding of abstract chemistry concepts and fostering higher-order thinking skills.

Keywords: Augmented Reality; Chemical Bonds; HOTS; Learning Activities; Student Worksheets.

Received: 11 November 2025
Revised: 17 December 2025
Accepted: 18 January 2026
Online Available: 21 January 2026
Curr. Ver.: 21 January 2026

1. Introduction

The era of globalization and the Industrial Revolution 5.0 demands that students possess Higher Order Thinking Skills (HOTS), namely the abilities to analyze, evaluate, and create as outlined in the revised Bloom's taxonomy (Akrong et al., 2021; Foo & Foo, 2022). These competencies are essential for enabling learners to adapt to complex problems, think critically, and generate innovative solutions in rapidly evolving scientific and technological contexts. HOTS has therefore become a central focus in contemporary education, particularly at the secondary school level where foundational cognitive skills are further developed.

However, learning practices in schools still tend to emphasize the mastery of factual knowledge and procedural understanding. Instruction is often dominated by teacher-centered approaches that prioritize memorization rather than reasoning and reflection. As a result, students have limited opportunities to engage in problem-solving activities or apply concepts in meaningful, real-world contexts, which contributes to the low level of HOTS achievement among learners (Wicaktini et al., 2020; Tuela & Palar, 2022).

In chemistry education, especially in the topic of chemical bonding, learning challenges are more pronounced due to the abstract nature of the concepts involved. Chemical bonds, atomic interactions, and molecular structures cannot be directly observed, making them difficult for students to conceptualize accurately. These difficulties are frequently exacerbated by the lack of effective visualization tools and inquiry-based learning activities in conventional classrooms, leading to learning obstacles and persistent misconceptions (Hazzi & Dumon, 2014; Hofstein & Lunetta, 2004).

The integration of Augmented Reality (AR) technology offers a promising solution to these challenges. AR enables the visualization of chemical structures and bonding processes through interactive three-dimensional representations, making abstract concepts more concrete and accessible. Previous studies have demonstrated that AR-based learning can enhance students' conceptual understanding, motivation, and engagement, while simultaneously fostering the development of HOTS through exploratory and inquiry-oriented activities (Yang et al., 2018; Badriyah et al., 2023; Waliyuddin & Sulisworo, 2022).

Furthermore, the deep learning approach emphasizes conceptual interconnectedness, reflection, and knowledge transfer, making it highly relevant for addressing the complexity of abstract chemistry concepts. Deep learning encourages students to actively construct understanding rather than merely recall information, supporting sustained cognitive engagement and higher-level thinking (Lynch et al., 2012; Sun, 2023). Therefore, the development of an Augmented Reality-assisted student worksheet (LKPD) based on a deep learning approach represents a strategic innovation to enhance learning activities and Higher Order Thinking Skills (HOTS) of eleventh-grade high school students, while providing a more concrete, interactive, and meaningful learning experience in chemical bonding topics.

2. Literature Review

Chemistry Learning

Chemistry learning involves abstract concepts at the macroscopic, microscopic, and symbolic levels, which often lead to learning difficulties and misconceptions if not properly designed (Hazzi & Dumon, 2014; Lahlali et al., 2023; Etokeren & Abosede, 2022). Therefore, students need to be positioned as active subjects through constructivist approaches that encourage exploration and conceptual understanding (Naibert & Barbera, 2022; Nurafifah & Man, 2018). Student Worksheets (LKPD) serve as strategic instructional tools to facilitate structured learning and foster meaningful understanding of chemistry concepts.

Student Worksheets (LKPD)

LKPD are instructional materials that promote active student engagement through observation, analysis, and reflection, thereby supporting meaningful learning (Setianingrum et al., 2022; Yulkifli et al., 2020). LKPD bridge theory and practice in line with constructivist approaches that position students as active learners (Nurafifah & Man, 2018). Activities embedded in LKPD can also enhance Higher Order Thinking Skills (HOTS) through problem-solving and data analysis, making the integration of technologies such as Augmented Reality relevant for visualizing abstract chemistry concepts (Hatiti et al., 2021; Masruroh et al., 2023).

Augmented Reality (AR) Technology in Chemistry Learning

Augmented Reality (AR) integrates the real world with interactive digital elements to visualize abstract concepts concretely, thereby increasing student engagement, motivation, and understanding (Yang et al., 2018; Talib et al., 2022). In chemistry learning, AR facilitates the visualization of microscopic concepts such as chemical bonding and molecular structures through 3D models, helping students develop deeper conceptual understanding (Merino et al., 2022; Khairani & Prodjosantoso, 2023). Furthermore, AR promotes active learning activities and the development of HOTS as students are involved in interactive exploration, analysis, and reflection (Badriyah et al., 2023; Saputri et al., 2024).

Deep Learning Approach in AR-Assisted Chemistry LKPD

Deep learning emphasizes reflective engagement, conceptual understanding, and the transfer of knowledge to new contexts, in contrast to surface learning that relies primarily on memorization (Sun, 2023; Wang, 2023b). In chemistry learning, this approach helps students connect macroscopic, microscopic, and symbolic levels, thereby minimizing misconceptions (Luxford & Bretz, 2014; Dhindsa & Treagust, 2014). The integration of AR strengthens deep learning through interactive 3D visualizations that encourage exploration, reflection, and knowledge restructuring, enabling AR-assisted LKPD to simultaneously enhance learning activities and HOTS (Socrates & Mufit, 2022; Huwer et al., 2018).

AR-Assisted LKPD

AR-assisted Student Worksheets (LKPD) are innovative learning media that combine structured learning activities with interactive visualizations, allowing students to understand abstract concepts in a more concrete and engaging manner (Badriyah et al., 2023; Waliyuddin & Sulisworo, 2022). The use of AR in LKPD increases motivation, active engagement, and Higher Order Thinking Skills (HOTS) as students explore, analyze, and independently construct understanding in accordance with constructivist principles.

Higher Order Thinking Skills (HOTS)

HOTS are complex thinking skills that include analysis, evaluation, and creation as defined in the revised Bloom's taxonomy, and are essential in 21st-century learning, particularly in science education (Akrong et al., 2021; Foo & Foo, 2022). HOTS can be developed through contextual learning, guided inquiry, and the use of technologies such as AR, and are assessed through tasks, projects, and analytical questions that emphasize thinking processes rather than memorization (Badriyah et al., 2023; Waliyuddin & Sulisworo, 2022).

Learning Activities

Learning activities encompass students' cognitive, affective, and psychomotor engagement, which can be enhanced through AR-assisted LKPD due to their interactive and engaging learning experiences. Indicators include interest, motivation, emotional engagement, collaborative attitudes, persistence, and responses to instructional methods (Naibert & Barbera, 2022; Prince, 2004; Badamian et al., 2023).

Supporting Theories for the Development of AR-Assisted LKPD and Their Impact on HOTS and Learning Activities

The development of Augmented Reality (AR)-based LKPD is supported by constructivist theory, the Cognitive Theory of Multimedia Learning, and the revised Bloom's taxonomy. Constructivist theory emphasizes active learning in which students construct knowledge through exploration, social interaction, and scaffolding, allowing AR to be utilized for collaborative and reflective learning experiences (Piaget & Vygotsky; Sulindra et al., 2024). The Cognitive Theory of Multimedia Learning states that effectively organized visual and verbal information can reduce cognitive load and strengthen mental schema formation, thereby enhancing higher-order thinking skills (Mayer; Hu et al., 2021). Meanwhile, the revised Bloom's taxonomy emphasizes the development of HOTS through cognitive levels of analyzing, evaluating, and creating, which can be implemented through experiments, projects, and the use of AR to concretely represent abstract concepts (Krathwohl, 2002; Foo & Foo, 2022). The integration of these three theories ensures that AR-assisted LKPD promote active learning activities while simultaneously enhancing students' HOTS.

Developmental Research

Developmental research (R&D) aims to produce educational products that are valid, practical, and effective, including technology-based LKPD such as those utilizing AR (Sugiyono, 2016). Commonly used models include the 4D model (Thiagarajan et al., 1974), ADDIE (Sudrajat, 2022), and Borg & Gall (Shidqi et al., 2023). Validity is assessed through evaluations by content and media experts (Pratikno et al., 2020), practicality relates to ease of use (Jalmo et al., 2022), and effectiveness is measured by improvements in students' learning activities and HOTS (Putra et al., 2024; Rahmadani & Susantini, 2021). The integration of technologies such as AR and e-learning further strengthens LKPD innovation by enhancing motivation, learner autonomy, and student engagement (Ropawandi et al., 2022; Mahzumi et al., 2024; Zamzam et al., 2023).

Chemical Bonding Material

Chemical bonding material is an abstract concept that requires the ability to visualize microscopic particles and interatomic relationships, which often leads to learning difficulties and misconceptions among students (Merino et al., 2022; Lahlali et al., 2023). The use of interactive visual media, particularly Augmented Reality (AR), facilitates the understanding of structures, shapes, and mechanisms of chemical bonds by presenting manipulable three-dimensional representations (Khairani & Prodjosantoso, 2023; Sung et al., 2019). The integration of AR into LKPD also supports the development of Higher Order Thinking Skills (HOTS) through activities involving analysis, evaluation, and molecular model construction, while simultaneously increasing student engagement and reflection (Mahzumi et al., 2024; Utaminingsih et al., 2024). Thus, the application of AR in chemical bonding instruction provides a more interactive and meaningful learning experience that enhances conceptual understanding and students' critical thinking skills (Talib et al., 2022; Buditjahjanto & Irfansyah, 2023; Saputri et al., 2024).

3. Materials and Method

Research Method

This study employed the Four-D (4D) development model proposed by Thiagarajan (1974), which consists of the Define, Design, Develop, and Disseminate stages. The Define stage focused on analyzing learning needs related to chemical bonding materials. The Design stage involved developing an Augmented Reality (AR)-based Student Worksheet (LKPD) grounded in constructivist principles and the Cognitive Theory of Multimedia Learning (Issa et al., 2013; Wei et al., 2024). The Develop stage included prototype development, expert validation, and limited trials, while the Disseminate stage evaluated the effectiveness of the LKPD in improving students' learning activities and Higher Order Thinking Skills (HOTS) (Setianingrum et al., 2022; Talib et al., 2022). The 4D model was applied to produce LKPD that are valid, practical, and effective, while supporting the visualization of abstract chemical concepts through AR technology (Pratikno et al., 2020; Mahzumi et al., 2024).

Trial Design

The trial design employed a quasi-experimental pretest–posttest control group design, conducted in two stages: a small group trial to assess readability, instructional clarity, activity flow, and visual attractiveness, and a field test to evaluate learning activities and HOTS in the experimental class (using AR-assisted LKPD) and the control class (using conventional LKPD) (Pratikno et al., 2020; Setianingrum et al., 2022). The sample consisted of 60 eleventh-grade students from SMAN 2 Tulang Bawang Tengah in the 2025/2026 academic year, with 30 students assigned to the experimental group and 30 to the control group through simple random sampling. Group equivalence was assessed based on students' report card scores and classroom observations to ensure comparable initial abilities (Talib et al., 2022).

Data Collection Techniques

Data collection techniques included learning activity questionnaires, HOTS tests based on the revised Bloom's taxonomy, student and teacher response questionnaires, and expert validation instruments for content and media (Talib et al., 2022; Pratikno et al., 2020). The learning activity questionnaire measured students' motivation, engagement, and attitudes, while the HOTS test assessed analytical, evaluative, and creative abilities related to chemical bonding material. Expert validation ensured the appropriateness of content, language, visual design, and AR integration to produce LKPD that are feasible and of high quality.

Data Analysis

Data analysis was conducted using descriptive quantitative methods to evaluate the feasibility and practicality of the LKPD based on Likert-scale assessments, with feasibility percentages and participant response scores calculated accordingly (Setianingrum et al., 2022; Aulia et al., 2022). Improvements in learning activities and HOTS were analyzed using the N-Gain formula, while inferential analysis was performed using MANOVA to compare simultaneous differences in both variables between the experimental and control groups. Assumption tests for normality, homogeneity, and independence were also conducted (Fattah, 2017). The effectiveness of the LKPD was measured using partial eta squared to determine the contribution of AR-assisted LKPD to improvements in learning activities and HOTS (Cohen, 1988; Richardson, 2011).

4. Results and Discussion

Product Development Results

Introduction

The introduction section consists of the cover page, preface, instructions for using the LKPD, concept map, learning outcomes, and learning objectives.

Figure 1. Cover Page.

Figure 1 illustrates the cover page, which presents the title, author identity, and science-related visual elements infused with technological themes to attract students' attention and convey an innovative image.

Figure 2. Preface.

Figure 2 contains the preface, which summarizes the rationale for using Augmented Reality (AR), emphasizes the deep learning approach, and highlights the orientation toward the development of Higher Order Thinking Skills (HOTS) as the theoretical foundation of the product.

Figure 3. Learning Outcomes and Learning Objectives.

Figure 3 illustrates the Learning Outcomes (CP) and learning objectives, which are formulated specifically to align with the curriculum and provide clear direction for learning activities.

Figure 4. Instructions for Using the LKPD.

Figure 4 presents the page that provides instructions for using the LKPD along with the operational procedures for Augmented Reality (AR), including QR code scanning steps and interaction with 3D models, thereby ensuring the practicality of classroom implementation.

Figure 5. Concept Map.

To reduce cognitive load, Figure 5 presents a concept map that links types of chemical bonds, molecular shapes, physical properties, and their applications, serving as an advance organizer before students engage in the core learning activities.

Core Activities

The core activities in the implementation of the Augmented Reality–assisted Chemical Bonding LKPD are designed to operationalize the guided inquiry syntax in order to foster deep learning. These activities begin with orientation to phenomena and guiding questions that lead students to formulate problems and initial hypotheses.

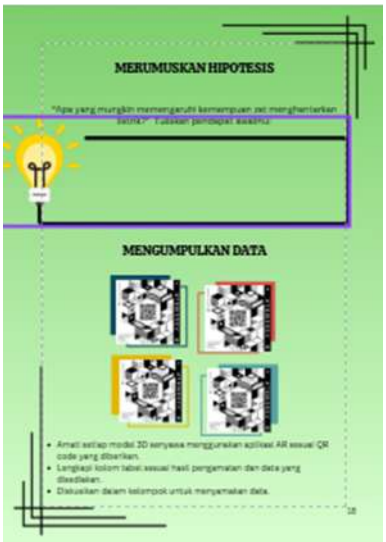

Figure 6. Core Activities.

Figure 6 illustrates the core activities, which begin with a brief phenomenon-based orientation or guiding questions, followed by guided formulation of problems and hypotheses. Students then explore objects through Augmented Reality by scanning QR codes and manipulating 3D models to collect relevant data in tables or worksheets. The collected data are analyzed through structured group discussions by linking representations (microscopic–macroscopic), associating bond types with substance properties, and constructing scientific arguments to address the guiding questions. The next stage involves verification and generalization, in which students test the consistency of their findings using other examples, identify patterns, and communicate their results through short presentations.

Closing Activities

As shown in Figure 7, students write the main conclusions regarding the relationships among bond types, molecular shapes/structures, and material properties along with their real-world implications, while the teacher ensures that these conclusions align with the learning objectives. This is followed by a brief reflection on the identified patterns, valid generalizations, and their applications in daily life. As reinforcement of formative assessment, a "Let's Play a Game" QR code directs students to a quiz that provides immediate feedback.

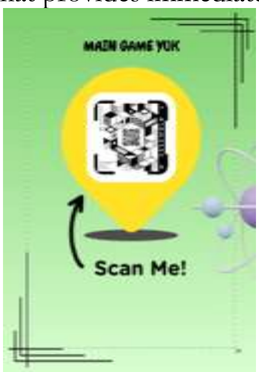

Figure 7. Closing Section.

Final Product Review

The final product is an Augmented Reality–assisted Student Worksheet (AR-LKPD) for chemical bonding material, developed using the Four-D (4D) model consisting of Define, Design, Develop, and Disseminate stages. The Define stage revealed that chemical bonding instruction in eleventh-grade classrooms still faces obstacles due to the abstract nature of the material, while students demonstrate high interest in visual media and technology. The Design stage produced an AR-LKPD incorporating guided inquiry syntax, concept maps, usage instructions, and 3D models accessed via QR codes, aligned with deep learning principles, constructivism, and multimedia learning theory to facilitate active and reflective learning.

The Develop stage indicated that the product was highly feasible in terms of academic content and media quality, with validation results of 81.25% from content experts and 94.17% from media experts. The AR-LKPD was also found to be practical for classroom use, as evidenced by positive responses from teachers (95.8%) and students (87.3%), with revisions focused on improving video quality, AR usage instructions, and the alignment of learning objectives. The Disseminate stage, conducted through field testing, demonstrated a significant effect of the AR-LKPD on students' learning activities and Higher Order Thinking Skills (HOTS) (MANOVA, $p = 0.005$), with a moderate N-gain score for HOTS (0.6) and the largest effective contribution observed for HOTS ($\eta p^2 = 0.133$).

Overall, the AR-assisted Chemical Bonding LKPD is valid, practical, and effective, making it suitable for implementation in senior high school classrooms. Furthermore, it has strong potential to be further developed for other chemistry topics that require spatial visualization and the enhancement of Higher Order Thinking Skills.

5. Conclusion

The development of an Augmented Reality (AR)–assisted Chemical Bonding Student Worksheet (LKPD) using a deep learning approach based on the Four-D (4D) model resulted in a product that is valid, practical, and effective. The AR-LKPD features a structured learning sequence consisting of orientation, problem formulation, three-dimensional model exploration, reflection, and practice quizzes, and applies guided inquiry syntax that supports the development of students' Higher Order Thinking Skills (HOTS).

Validation results indicate that the AR-LKPD falls into the highly feasible category, with content expert validation reaching 81.25% and media expert validation reaching 94.17%. Student and teacher responses also demonstrate high levels of readability and practicality (87.3%–95.8%). Inferential analysis using MANOVA revealed a significant difference in learning activities and HOTS between the experimental and control groups ($p = 0.005$), with the contribution of AR-LKPD usage being more dominant in improving HOTS (partial eta squared = 0.133) compared to learning activities (partial eta squared = 0.025). Therefore, the AR-assisted LKPD is effective in enhancing students' HOTS in chemical bonding material for eleventh-grade senior high school students.

References

Aisyah, R., & Sugesti, I. (2022). Factors Affecting Students' Learning Interaction And Engagement In Online Learning. International Social Sciences And Humanities, 2(1), 287–294. Https://Doi.Org/10.32528/Issh.V2i1.124

Akatyev, A. (2024). A Systematic Review Of Digital Technologies For Science Learning And Student Engagement. Education And Information Technologies, 29. Https://Doi.Org/10.1007/S10639-023-11829-Y

Akrong, B., Chaka, C., & Walt, C. (2021). A Modified Version Of Bloom's Taxonomy And Critical Language Awareness: Evaluating Eal Textbooks For Junior High Schools In Ghana Through A Critical Literacy Approach. International Journal Of Applied Linguistics & English Literature, 10(4), 106. Https://Doi.Org/10.7575/Aiac.Ijalel.V.10n.4p.106

Alam, K. (2021). Embedding Augmented Reality Technology In The Educational Learning System. Pakistan Journal Of Educational Research, 3(1). Https://Doi.Org/10.52337/Pjer.V3i1.31

Alkan, F. (2015). The Effect Of Technology-Assisted Chemistry Teaching On The Understanding Of Chemical Phenomena. Journal Of Baltic Science Education, 14(1), 60–72.

Alshammari, J., Reynolds, R., & Ferguson-Patrck, K. (2020). Ipads For Cognitive Skills In Efl Primary Classrooms: A Case Study In Saudi Arabia. English Language Teaching, 14(1), 13. Https://Doi.Org/10.5539/Elt.V14n1p13

Amiruddin, A., Baharuddin, F., Takbir, T., & Setialaksana, W. (2023). May Student-Centered Principles Affect Active Learning And Its Counterpart? An Empirical Study Of Indonesian Curriculum Implementation. Sage Open, 13(4). Https://Doi.Org/10.1177/21582440231214375

Andika, A., Tahrun, T., & Firdaus, M. (2023). Developing English Grammar Instructional Materials Oriented To Constructivism Theory. Journal Of Languages And Language Teaching, 11(2), 286. Https://Doi.Org/10.33394/Jollt.V11i2.6838

Arizen, A., & Suhartini, S. (2020). Mobile Learning Student Worksheet Based On Socio-Scientific-Issues: Enhancing Students' Scientific Literacy Skills In Biology. Jpbi (Jurnal Pendidikan Biologi Indonesia), 6(1), 15–24. Https://Doi.Org/10.22219/Jpbi.V6i1.11196

Armadhani, R., Zaman, W., & Wahyudi, W. (2023). Development Of Comics Learning Media On The Origins Of Mount Kelud Using Fiction Story Material For Class 4 Students Of Sdn Tarokan 3. Jurnal Eduscience, 10(3), 710–722. Https://Doi.Org/10.36987/Jes.V10i3.4777

Badamian, H., Delavarpour, M., & Asl, N. (2023). The Role Of Family Communication Patterns In Students' Academic Engagement In Online Classes. Jayps, 4(9), 43–51. Https://Doi.Org/10.61838/Kman.Jayps.4.9.5

Badriyah, N., Yusuf, M., & Efendi, A. (2023). Augmented Reality As A Media For Distance Learning In The Digital Era: Contribution In Improving Critical Thinking Skills. International Journal Of Information And Education Technology, 13(11), 1769–1775. Https://Doi.Org/10.18178/Ijiet.2023.13.11.1988

Buditjahjanto, I., & Irfansyah, J. (2023). Augmented Reality On Students' Academic Achievement Viewed From The Creative Thinking Level. Journal Of Technology And Science Education, 13(3), 597. Https://Doi.Org/10.3926/Jotse.1813

Cohen, J. (1988). Statistical Power Analysis For The Behavioral Sciences (2, Ed.). Lawrence Erlbaum Associates.

Dewi, L., Gunamantha, I., & Wibawa, I. (2022). Assessment Instruments Of Caring Attitudes And Science Knowledge Competencies Iv Grade Elementary School Student. Journal For Lesson And Learning Studies, 5(2), 309–315. Https://Doi.Org/10.23887/Jlls.V5i2.52576

Dhindsa, H., & Treagust, D. (2014). Prospective Pedagogy For Teaching Chemical Bonding For Smart And Sustainable Learning. Chemistry Education Research And Practice, 15(4), 435–446. Https://Doi.Org/10.1039/C4rp00059e

Diana, S., Rachmatullah, R., & Rahmawati, Y. (2015). Profil Kemampuan Literasi Sains Peserta Didik Sma Di Bandung Berdasarkan Scientific Literacy Assessment (Sla). Seminar Nasional Xii Pendidikan Biologi Fkip Uns, 285–291.

Erika, F., Supardi, Z., & Tukiran, T. (2019). Development Of Student Worksheet For Improving The Self-Efficacy And Ability To Argue Of Chemistry Teacher Candidates Study On Junior High School Students Behavior Based On Keirsey Personality Type. Https://Doi.Org/10.2991/Miseic-19.2019.31

Etokeren, I., & Abosede, O. (2022). Effect Of Concept Mapping Teaching Strategy On Students' Misconceptions About Chemical Bonding In Rivers State. International Journal Of Chemistry Education Research, 16–28. Https://Doi.Org/10.20885/Ijcer.Vol6.Iss1.Art3

Fattah, A. (2017). Uji Manova (Multivariate Analysis Of Variance) Dengan Menggunakan Model Rerata Sel (Cell-Means Model). Jurnal Statistika Universitas Muhammadiyah Semarang, 5(1), 1–8. Https://Doi.Org/10.26714/Jsunimus.V5i1.2472

Foo, S., & Foo, K. (2022). Purposeful Field Trip: Impact On Experiential Learning Opportunities And Critical Thinking Skills. Pertanika Journal Of Social Sciences And Humanities, 30(1), Preprint. Https://Doi.Org/10.47836/Pjssh.30.1.01

Fuadi, H., Gunawan, G., & Susilawati, S. (2022). Feasibility Of Pbl (Problem Based Learning)-Based Sound Wave Electronic Student Worksheet For High School Students Using The Liveworksheet Application. Jurnal Penelitian Pendidikan Ipa, 8(4), 2255–2265. Https://Doi.Org/10.29303/Jppipa.V8i4.1982

Fung, F., Tan, C., & Chen, G. (2018). Student Engagement And Mathematics Achievement: Unraveling Main And Interactive Effects. Psychology In The Schools, 55(7), 815–831. Https://Doi.Org/10.1002/Pits.22139

Guo, S. (2024). Implementation Of Immersive Virtual Reality Games And Learning Engagement For Selected Mathematical Concepts Among Middle School Students In Ganzhou City, China. International Journal Of Social Science And Human Research, 7(06). Https://Doi.Org/10.47191/Ijsshr/V7-I06-99

Hadi, S., & Novaliyosi. (2019). Kajian Literasi Matematika Dan Sains Berdasarkan Hasil Timss Dan Pisa. (Isi Nama Jurnal Sesuai Sumber Asli).

Hambali, M., Mirizon, S., & Heryana, N. (2021). Difficulty Index And Cognitive Skills Of English Textbook For Senior High School. Indonesian Journal Of Efl And Linguistics, 6(1), 17. Https://Doi.Org/10.21462/Ijefl.V6i1.331

Hartikainen, S., Rintala, H., Pylväs, L., & Nokelainen, P. (2019). The Concept Of Active Learning And The Measurement Of Learning Outcomes: A Review Of Research In Engineering Higher Education. Education Sciences, 9(4), 276. Https://Doi.Org/10.3390/Educsci9040276

Hasim, A., & Abdillah, A. (2024). Student Worksheet Design Peration Material For Rank Shape And Root Shape To Develop Students' Comprehension Skills. Cjre, 1(1), 40–54. Https://Doi.Org/10.54373/Cjre.V1i1.93

Hatiti, A., Distrik, I., & Rosidin, U. (2021). The Effect Of Hots-Oriented Blended Learning Student Worksheets On Students' Cognitive Learning Outcomes On Work And Energy Materials. Berkala Ilmiah Pendidikan Fisika, 9(3), 381. Https://Doi.Org/10.20527/Bipf.V9i3.11176

Hazzi, S., & Dumon, A. (2014). Conceptual Integration Of Covalent Bond Models By Algerian Students. Chemistry Education Research And Practice, 15(4), 675–688. Https://Doi.Org/10.1039/C4rp00041b

Hofstein, A., & Lunetta, V. N. (2004). The Laboratory In Science Education: Foundations For The Twenty-First Century. Science Education, 88(1), 28–54. Https://Doi.Org/10.1002/Sce.10106

Hu, C., Barrett, N., & Liu, G. (2021). The Development And Construction Of An Ar-Guided Learning Model With Focused Learning Theories. Journal Of Computer Assisted Learning, 37(5), 1423–1440. Https://Doi.Org/10.1111/Jcal.12583

Huwer, J., Lauer, L., Seibert, J., Thyssen, C., Dörrenbächer Ulrich, L., & Perels, F. (2018). Re-Experiencing Chemistry With Augmented Reality: New Possibilities For Individual Support. World Journal Of Chemical Education, 6(5), 212–217. Https://Doi.Org/10.12691/Wjce-6-5-2

Issa, N., Mayer, R., Schuller, M., Wang, E., Shapiro, M., & Darosa, D. (2013). Teaching For Understanding In Medical Classrooms Using Multimedia Design Principles. Medical Education, 47(4), 388–396. Https://Doi.Org/10.1111/Medu.12127

Jaberzadeh, S., & Mansouri, F. (2021). Short-Term Research Projects In Cognitive Neuroscience For Undergraduate Students: A Contingency Plan To Maintain Quality Teaching During Covid-19 Pandemic. Advances In Physiology Education, 45(2), 376–383. Https://Doi.Org/10.1152/Advan.00012.2021

Jalmo, T., Rakhmawati, I., & Nuraini, K. (2022). The Effect Of Respiratory Augmented Reality Media On Analysis And Evaluation Skills Of Eight Grades Students. Biosfer Jurnal Pendidikan Biologi, 15(2), 169–177. Https://Doi.Org/10.21009/Biosferjpb.23142

Khairani, R., & Prodjosantoso, A. (2023). Application Of Augmented Reality On Chemistry Learning: A Systematic Review. Jurnal Penelitian Pendidikan Ipa, 9(11), 1221–1228. Https://Doi.Org/10.29303/Jppipa.V9i11.4412

Korhonen, V., Mattsson, M., Inkinen, M., & Toom, A. (2019). Understanding The Multidimensional Nature Of Student Engagement During The First Year Of Higher Education. Frontiers In Psychology, 10. Https://Doi.Org/10.3389/Fpsyg.2019.01056

Krathwohl, D. (2002). A Revision Of Bloom's Taxonomy: An Overview. Theory Into Practice, 41(4), 212–218. Https://Doi.Org/10.1207/S15430421tip4104_2

Lahlali, A., Chafiq, N., Radid, M., Atibi, A., Kababi, K., Srour, C., & Moundy, K. (2023). Students' Alternative Conceptions And Teachers' Views On The Implementation Of Pedagogical Strategies To Improve The Teaching Of Chemical Bonding Concepts. International Journal Of Engineering Pedagogy (Ijep), 13(6), 90–107. Https://Doi.Org/10.3991/Ijep.V13i6.41391

Law, Q., Chung, J., Leung, L., & Wong, T. (2017). Perceptions Of Collaborative Learning In Enhancing Undergraduate Education Students' Engagement In Teaching And Learning English. Us-China Education Review A, 7(2). Https://Doi.Org/10.17265/2161-623x/2017.02.002

Luxford, C., & Bretz, S. (2014). Development Of The Bonding Representations Inventory To Identify Student Misconceptions About Covalent And Ionic Bonding Representations. Journal Of Chemical Education, 91(3), 312–320. Https://Doi.Org/10.1021/Ed400700q

Lynch, R., Mcnamara, P., & Seery, N. (2012). Promoting Deep Learning In A Teacher Education Programme Through Self- And Peer-Assessment And Feedback. European Journal Of Teacher Education, 35(2), 179–197. Https://Doi.Org/10.1080/02619768.2011.643396

Mahzumi, E., Herliana, F., Sari, R., Elisa, E., & Halim, A. (2024). Development Of Contextual Teaching And Learning (Ctl) Worksheet Based On Blended Learning To Enhance Students' Critical Thinking. 289–298. Https://Doi.Org/10.2991/978-2-38476-216-3_30

Maria, M., Silalahi, S., Aggarwal, Y., & Galadima, U. (2023). Implementation Of Science Student Work Sheet Based On Multiple Intelligence Materials Temperature And Their Changes. Journal Evaluation In Education (Jee), 4(3), 104–109. Https://Doi.Org/10.37251/Jee.V4i3.698

Mariyana, M., Syahri, W., & Haryanto, H. (2023). Based E-Lkpd Development Based Problem Based Learning To Improve Students' Creative Thinking Skills On Acid-Base Material. Jurnal Pendidikan Kimia, 15(2), 163–169. Https://Doi.Org/10.24114/Jpkim.V15i2.48264

Marrahi-Gomez, R., & Belda-Medina, J. (2024). Assessing The Effect Of Augmented Reality On English Language Learning And Student Motivation In Secondary Education. Frontiers In Education. Https://Doi.Org/10.3389/Feduc.2024.1359692

Masruroh, V., Lusiana, R., & Susanti, V. (2023). Development Of Student Worksheets Oriented To Problem Based Learning Integrated 21st Century Skills. Al-Ishlah Jurnal Pendidikan, 15(1), 519–532. Https://Doi.Org/10.35445/Alishlah.V15i1.2466

Merino, C., Marzábal, A., Quiroz, W., Pino, S., López-Cortés, F., Carrasco, X., & Miller, B. (2022). Use Of Augmented Reality In Chromatography Learning: How Is This Dynamic Visual Artifact Fostering The Visualization Capacities Of Chemistry Undergraduate Students? Frontiers In Education, 7. Https://Doi.Org/10.3389/Feduc.2022.932713

Merriënboer, J., & Sweller, J. (2005). Cognitive Load Theory And Complex Learning: Recent Developments And Future Directions. Educational Psychology Review, 17(2), 147–177. Https://Doi.Org/10.1007/S10648-005-3951-0

Metzgar, M. (2023). Revised Bloom's Taxonomy In A Principles Of Economics Textbook. Acta Educationis Generalis, 13(3), 15–28. Https://Doi.Org/10.2478/Atd-2023-0019

Miseliūnaitė, B., & Cibulskas, G. (2024). Enhancing Active Learning Through A Holistic Approach: A Case Study Of Primary Education In Lithuania. Education Sciences, 14(6), 592. Https://Doi.Org/10.3390/Educsci14060592

Munifah, M., Tsani, I., Yasin, M., Zuroidah, N., Huda, S., Lestari, F., & Rahmat, A. (2019). Management Development Of Student Worksheets To Improve Teacher Communication Skills : A Case Study Self-Efficacy And Student Achievement. Journal For The Education Of Gifted Young Scientists, 7(4), 777–798. Https://Doi.Org/10.17478/Jegys.625618

Naibert, N., & Barbera, J. (2022a). Development And Evaluation Of A Survey To Measure Student Engagement At The Activity Level In General Chemistry. Journal Of Chemical Education, 99(3), 1410–1419. Https://Doi.Org/10.1021/Acs.Jchemed.1c01145

Naibert, N., & Barbera, J. (2022b). Investigating Student Engagement In General Chemistry Active Learning Activities Using The Activity Engagement Survey (Aces). Journal Of Chemical Education, 99(7), 2620–2629. Https://Doi.Org/10.1021/Acs.Jchemed.2c00276

Nimmermark, A., Öhrström, L., Mårtensson, J., & Davidowitz, B. (2016). Teaching Of Chemical Bonding: A Study Of Swedish And South African Students' Conceptions Of Bonding. Chemistry Education Research And Practice, 17(4), 985–1005. Https://Doi.Org/10.1039/C6rp00106h

Norouzian, R., & Plonsky, L. (2018). Eta- And Partial Eta-Squared In L2 Research: A Cautionary Review. Second Language Research, 34(2), 257–271. Https://Doi.Org/10.1177/0267658316670205

Nurafifah, R., & Man, S. (2018). Design Of Student Worksheets Based On Learning Cycle 5e Learning Model For Viii Junior High School Students In Indonesia. International Journal Of Engineering & Technology, 7(4.30), 16–20. Https://Doi.Org/10.14419/Ijet.V7i4.30.21994

Permata Sari, A., & Munir. (2024). Pemanfaatan Teknologi Digital Dalam Inovasi Pembelajaran Untuk Meningkatkan Efektivitas Kegiatan Di Kelas. Jurnal Digitech: Jurnal Pendidikan Teknologi Informasi, 6(1), 1–12. Https://Jurnal.Itscience.Org/Index.Php/Digitech/Article/Download/5127/3920/23739

Pratikno, P., Suyono, S., & Agustini, R. (2020). The Validity Of Student Worksheets And Student Textbooks Inquiry Training Model On The Colligative Properties Of Solution. International Journal For Educational And Vocational Studies, 2(11). Https://Doi.Org/10.29103/Ijevs.V2i11.3006

Prince, M. (2004). Does Active Learning Work? A Review Of The Research. Journal Of Engineering Education, 93(3), 223–231. Https://Doi.Org/10.1002/J.2168-9830.2004.Tb00809.X

Priyanto, P., & Sumarwan, S. (2023). Development Of Augmented Reality Learning Media In Chemistry Subject High School. International Journal Of Artificial Intelligence Research, 7(2), 123. Https://Doi.Org/10.29099/Ijair.V6i2.912

Putra, M., Madlazim, M., & Hariyono, E. (2024). Exploring Augmented Reality-Based Learning Media Implementation In Solar System Materials. Ijorer International Journal Of Recent Educational Research, 5(1), 29–41. Https://Doi.Org/10.46245/Ijorer.V5i1.440

Rahmadani, D., & Susantini, E. (2021). Implementation Of E-Lkpd Virus Material Based On Know-Learned (K-L) Strategy To Train Student Metacognitive Skills. Berkala Ilmiah Pendidikan Biologi (Bioedu), 10(3), 471–478. Https://Doi.Org/10.26740/Bioedu.V10n3.P471-478

Rehman, R., & Fatima, S. (2020). An Innovation In Flipped Class Room: A Teaching Model To Facilitate Synchronous And Asynchronous Learning During A Pandemic. Pakistan Journal Of Medical Sciences, 37(1). Https://Doi.Org/10.12669/Pjms.37.1.3096

Richardson, J. T. E. (2011). Eta Squared And Partial Eta Squared As Measures Of Effect Size In Educational Research. Educational Research Review, 6(2), 135–147. Https://Doi.Org/10.1016/J.Edurev.2010.12.001

Ropawandi, D., Halim, L., & Husnin, H. (2022). Augmented Reality (Ar) Technology-Based Learning: The Effect On Physics Learning During The Covid-19 Pandemic. International Journal Of Information And Education Technology, 12(2), 132–140. Https://Doi.Org/10.18178/Ijiet.2022.12.2.1596

Ryoo, K., & Bedell, K. (2017). The Effects Of Visualizations On Linguistically Diverse Students' Understanding Of Energy And Matter In Life Science. Journal Of Research In Science Teaching, 54(10), 1274–1301. Https://Doi.Org/10.1002/Tea.21405

Safitri, N., & Tanjung, I. (2023). Development Of Stem-Based Student Worksheets On Virus Material To Improve Student Science Literacy. Jurnal Penelitian Pendidikan Ipa, 9(3), 1457–1464. Https://Doi.Org/10.29303/Jppipa.V9i3.3288

Santosa, T., Angreni, S., Sari, R., Festiyed, F., Ahda, Y., Alberida, H., & Arsih, F. (2024). Effectiveness Of Higher Order Thinking Skills-Based Test Instruments In Science Learning In Indonesia: A Meta-Analysis. Jurnal Penelitian Pendidikan Ipa, 10(5), 242–249. Https://Doi.Org/10.29303/Jppipa.V10i5.6654

Saputri, A., Mohtar, L., Arsini, A., Prastyo, I., & Fitra, I. (2024). Critical Thinking Skills (Cts) Through Augmented Reality Worksheets Using The Inquiry-Scaffolding Models. Physics Education Research Journal, 6(1), 21–28. Https://Doi.Org/10.21580/Perj.2024.6.1.19657

Sari, D. N. (2022). Analysis Of Students' Higher-Order Thinking Skills In Chemical Bonding. Journal Of Turkish Science Education, 19(4). Https://Doi.Org/10.36681/Tused.2022.162

Sari, R., & Sakhiyya, Z. (2020). The Textbook Analysis On Students' Book Of Symphony 1 English Course Book For Senior High School Grade X Viewed From Higher Order Thinking Skills. Elt Forum Journal Of English Language Teaching, 9(2), 97–106. Https://Doi.Org/10.15294/Elt.V9i2.38711

Setianingrum, D., Ula, E., Pratiwi, S., & Jumadi, J. (2022). Development Of Lkpd With A Contextual Approach Based On Flipbook To Increase Science Learning Motivation. Jurnal Pendidikan Sains Indonesia, 10(4), 833–848. Https://Doi.Org/10.24815/Jpsi.V10i4.26098

Shidqi, L., Trisniawati, T., & Rhosyida, N. (2023). The Development Of Kobatar Learning Media For Learning Mathematics In Elementary School. Advances In Mobile Learning Educational Research, 3(2), 886–892. Https://Doi.Org/10.25082/Amler.2023.02.015

Socrates, T., & Mufit, F. (2022). The Effectiveness Of Using Augmented Reality-Based Learning Media In Physics Learning: Literature Study. Electrolyte, 1(02). Https://Doi.Org/10.54482/Electrolyte.V1i02.160

Sudrajat, Y. (2022). Development Of A Motivational-Base For Household Waste Management Training Model. International Journal Of Trends In Mathematics Education Research, 5(3), 315–327. Https://Doi.Org/10.33122/Ijtmer.V5i3.120

Sugiyono. (2016). Metode Penelitian Dan Pengembangan (Research And Development/R&D). Alfabeta.

Suharno, P. (2023). Effect Of Digital Learning Media On Students' Higher-Order Thinking Skills And Learning Outcomes. Heliyon, 9(4). Https://Doi.Org/10.1016/J.Heliyon.2023.E15754

Sulindra, E., Cendra, A., & Hartani, T. (2024). Utilization Of Instructional Technology In English Language Teaching (Elt) Based On Constructivism: A Literature Review. English Education And Literature Journal (E-Jou), 4(02), 141–153. Https://Doi.Org/10.53863/Ejou.V4i02.1150

Sun, J. (2023b). A Project-Based Learning (Pbl) Event In A Chinese Rural School: How Can Pbl Help Teachers And Students Accomplish Deep Learning? Research And Advances In Education, 2(4), 59–68. Https://Doi.Org/10.56397/Rae.2023.04.06

Sung, R., Wilson, A., Lo, S., Crowl, L., Nardi, J., Clair, K., & Liu, J. (2019). Biochemar: An Augmented Reality Educational Tool For Teaching Macromolecular Structure And Function. Journal Of Chemical Education, 97(1), 147–153. Https://Doi.Org/10.1021/Acs.Jchemed.8b00691

Talib, C., Romainor, N., & Aliyu, F. (2022). Augmented Reality In Chemistry Education: A Literature Review Of Advantages On Learners. Journal Of Natural Science And Integration, 5(1), 126. Https://Doi.Org/10.24014/Jnsi.V5i1.16805

Tuela, A., & Palar, Y. (2022). Analysis Of Higher Order Thinking Skills (Hots) Based On Bloom Taxonomy In Comprehensive Examination Questions. Jurnal Kependidikan Jurnal Hasil Penelitian Dan Kajian Kepustakaan Di Bidang Pendidikan Pengajaran Dan Pembelajaran, 8(4), 957. Https://Doi.Org/10.33394/Jk.V8i4.5885

Utamiani, N., & Parmiti, D. (2022). Student Learning Activity Assessment Instruments In Civics Learning For Fifth Grade Elementary School. Mimbar Pgsd Undiksha, 10(2), 416–423. Https://Doi.Org/10.23887/Jjpgsd.V10i2.49300

Utaminingsih, S., Amalia, I., & Sumaji, S. (2024). Management Of Mathematics Learning Based On Interactive Digital Worksheets To Improve Students' Critical Thinking Ability. Journal Of Curriculum And Teaching, 13(1), 159. Https://Doi.Org/10.5430/Jct.V13n1p159

Waliyuddin, D., & Sulisworo, D. (2022). High Order Thinking Skills And Digital Literacy Skills Instrument Test. Ideguru Jurnal Karya Ilmiah Guru, 7(1). Https://Doi.Org/10.51169/Ideguru.V7i1.310

Wang, J. (2023b). The Teaching Practice Of Ideological And Political Courses In College Based On Deep Learning. J. Comb. Math. Comb. Comput., 118, 49–63. Https://Doi.Org/10.61091/Jcmcc118-04

Warnida, Y., Zaini, M., & Suyidno, S. (2023). Feasibility Of Student Worksheets Based On Critical Thinking Skills On The Topic Of Heat And Temperature. Jurnal Ilmiah Pendidikan Fisika, 7(1), 110. Https://Doi.Org/10.20527/Jipf.V7i1.7496

Wei, X., Wang, L., Lee, L., & Liu, R. (2024). Multiple Generative Ai Pedagogical Agents In Augmented Reality Environments: A Study On Implementing The 5e Model In Science Education. Journal Of Educational Computing Research, 63(2), 336–371. Https://Doi.Org/10.1177/07356331241305519

Wicaktini, A., Juanengsih, N., & Noor, M. (2020). Problem Based Learning Models With Student Worksheets: Effect On Higher Order Thinking Skills In Digestive System Concept. Https://Doi.Org/10.4108/Eai.30-9-2019.2291129

Widyaningrum, S., & Parmiti, D. (2024). Contextual Teaching And Learning-Based E-Worksheet On Science Subjects For Fourth Grade Elementary Schools. Mimbar Ilmu, 29(1), 173–184. Https://Doi.Org/10.23887/Mi.V29i1.64644

Wiranata, D., Widiana, I., & Bayu, G. (2021). The Effectiveness Of Learning Activities Based On Revised Bloom Taxonomy On Problem-Solving Ability. Indonesian Journal Of Educational Research And Review, 4(2), 289. Https://Doi.Org/10.23887/Ijerr.V4i2.37370

Yakin, İ., & Tinmaz, H. (2015). Theoretical Guidelines For The Utilization Of Instructional Social Networking Websites. Turkish Online Journal Of Distance Education, 0(0). Https://Doi.Org/10.17718/Tojde.81802

Yang, S., Mei, B., & Yue, X. (2018). Mobile Augmented Reality Assisted Chemical Education: Insights From Elements 4d. Journal Of Chemical Education, 95(6), 1060–1062. Https://Doi.Org/10.1021/Acs.Jchemed.8b00017

Yaseen, H., Alrawadieh, S., & Çakir, A. (2025). The Impact Of Adaptive Learning Technologies, Personalized Feedback, And Interactive Ai Tools On Student Engagement. Sustainability, 17(3). Https://Doi.Org/10.3390/Su17031133

Yulkifli, Y., Jaafar, R., & Resnita, L. (2020). Developing Student Worksheets Using Inquiry-Based Learning Model With Scientific Approach To Improve Tenth Grade Students' Physics Competence. Jurnal Penelitian Fisika Dan Aplikasinya (Jpfa), 10(1), 56. Https://Doi.Org/10.26740/Jpfa.V10n1.P56-70

Yusnaeni, Y., Lika, A., & Hiul, S. (2019). Human Respiratory System: Designing Student Worksheet Based On Inquiry To Promote 21st-Century Skills. Biosfer, 12(1), 34–44. Https://Doi.Org/10.21009/Biosferjpb.V12n1.34-44

Zamzam, G., Komarayanti, S., & Mahfud, M. (2023). The Effect Of Using Liveworksheets Learning Media On Student Interests And Learning Outcomes In Ecosystem Material. International Social Sciences And Humanities, 2(2), 491–494. Https://Doi.Org/10.32528/Issh.V2i2.249