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AN INQUIRY–STEM MODEL FOR STRENGTHENING 21ST-CENTURY SKILLS IN JUNIOR SECONDARY SCIENCE EDUCATION

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ABSTRACT

This study aims to develop an inquiry-based STEM-integrated learning model to enhance students' 21st-century skills in junior secondary science education. The research employed an educational design research approach consisting of three phases: preliminary research, prototyping, and assessment. Data were collected through expert validation sheets, practicality questionnaires administered to teachers and students, and performance-based assessments using observation rubrics. Data analysis was conducted using descriptive statistics for validity and practicality. At the same time, effectiveness was evaluated using a quasi-experimental design with pretest–posttest comparisons, N-gain analysis, and independent-samples t-tests. The findings indicate that the developed model meets high-quality criteria for validity, practicality, and effectiveness. All components were categorized as very valid, demonstrating strong theoretical alignment and internal consistency. The model was also highly practical and easily implemented in classroom settings. Moreover, it significantly improved students' 21st-century skills, critical thinking, creativity, communication, and collaboration with moderate but consistent gains and statistically significant differences compared to conventional learning. These results imply that integrating inquiry and STEM provides an effective framework for fostering higher-order thinking and collaborative skills. This study contributes a validated and applicable learning model that supports student-centered, competency-based science education aligned with global trends.

KEYWORDS: Inquiry-Based Learning; STEM Integration; 21st-Century Skills; Science Education; Instructional Design; Educational Design Research; Junior Secondary School; Learning Model Development.

1. INTRODUCTION

The challenges of 21st-century education demand a generation that is adaptive, creative, and innovative. (Trilling & Fadel, 2009) assert that individuals in the 21st century must possess competencies in information, media, and technology literacy, as well as life and career skills, and the capacity for learning and innovation. This perspective aligns with the Kurikulum Merdeka (Wahyudin et al., 2024), which emphasizes contextual learning, critical thinking, collaboration, and learner autonomy. Consequently, schools are required to provide learning experiences that stimulate these competencies (Van Laar et al., 2020), implying a necessary shift in instructional systems from teacher-centered to student-centered approaches (Redhana, 2019); (Junedi et al., 2020);(Fitriani et al., 2023).

However, empirical evidence indicates that Indonesian graduates still demonstrate relatively low mastery of 21st-century skills (OECD, 2018); (Trilling & Fadel, 2009). The PISA 2022 results reveal that Indonesia's scores remain significantly below the OECD average, with 359 in reading, 366 in mathematics, and 388 in science, compared to OECD averages of 476, 472, and 485, respectively. Recent studies further confirm that students' critical thinking, creativity, communication, and collaboration skills have not developed optimally (Tohani & Aulia, 2022); (Pangestu & Firdaus, 2024). This condition is largely attributed to science instruction that continues to rely on conventional approaches, thereby limiting higher-order thinking and the application of contextual concepts (Thornhill-Miller et al., 2023).

This phenomenon is also evident in several junior high schools in Dharmasraya Regency, namely SMPN 1 Koto Baru, SMPN 1 Sitiung, and SMPN 1 Koto Besar. Interviews with science teachers indicate that lecture-based instruction and individual assignments still dominate classroom practices, largely because of limited familiarity with innovative pedagogical models. Questionnaire data further reveal that students' 21st-century skills remain low, with average scores of 41.86% for critical thinking, 43.15% for creative thinking, 43.28% for communication, and 44.35% for collaboration. These findings are consistent with (Susetyarini et al., 2022) and (Bahtiar* et al., 2023), who argue that conventional instruction inhibits active participation, creativity, and students' problem-solving abilities.

One instructional model considered relevant to addressing this issue is inquiry-based learning, which positions students at the center of the learning process through questioning, investigation, and independent concept discovery (Sanjaya, 2013; Pedaste et al., 2015; Bell, 2010; Stohlmann et al., 2012; Wannapiroon, 2014). Inquiry-based learning has been empirically shown to enhance critical thinking and conceptual understanding in science (Fitriani et al., 2023); (Arifin, 2020); (Prayogi et al., 2024). Nevertheless, this model has certain limitations: its procedural stages tend to be general, it lacks interdisciplinary integration, often terminates at the data collection phase, and does not fully facilitate creativity and collaboration (Isabirye et al., 2025).

To address these limitations, the STEM (Science, Technology, Engineering, and Mathematics) approach is considered highly relevant, as it emphasizes interdisciplinary integration and collaborative, creative problem-solving in real-world contexts (Abdurrahman et al., 2019); (Acikara et al., 2023). STEM integration fosters critical thinking, innovation, and collaboration through project-based activities and the engineering design process (Prayogi et al., 2024). The integration between inquiry-based learning and STEM creates a meaningful learning environment in which students design experiments, analyze data, and communicate solutions grounded in authentic problems (Asy'ari et al., 2019); (Aditomo et al., 2011).

The inquiry–STEM integrated model is grounded in constructivist theory and experiential learning, in which knowledge is constructed through reflection and active engagement with real-world environments. This approach not only strengthens cognitive competencies but also cultivates scientific attitudes and adaptive capabilities (Abdurrahman et al., 2019); (Ramadhan & Umamah, 2024), making it highly relevant to the demands of 21st-century competencies. Based on these considerations, this study aims to develop a STEM-integrated inquiry learning model to enhance students' 21st-century skills in junior high school science education, thereby preparing a generation that is critical, creative, communicative, and collaborative, in alignment with national education policy.

Based on the aforementioned background, the research question is: How can a STEM-integrated, inquiry-based learning model be designed to enhance students' 21st-century skills in junior high school science education? In alignment with the formulated research question, this study aims to develop a design of a STEM-integrated inquiry-based learning model that is valid, practical, and effective in improving students' 21st-century skills, namely critical thinking, creative thinking, communication, and collaboration in junior high school science learning.

2. RELATED WORK

Previous studies relevant to the development of an inquiry-based STEM-integrated learning model design can be classified into three main themes: (1) inquiry-based learning models and 21st-century skills, (2) STEM approaches in education, and (3) the integration of inquiry and STEM and the positioning of this study.

1. Inquiry-Based Learning Models And 21st-Century Skills

A substantial body of research has demonstrated that inquiry-based learning is effective in fostering 21st-century skills. (Tohani & Aulia, 2022) and (Pangestu & Firdaus, 2024) found that inquiry-based approaches significantly enhance students' collaboration and communication skills. Gibson (2017) emphasized that processes such as problem identification, hypothesis formulation, and evidence-based conclusion drawing consistently promote critical thinking (Akpur, 2020). (Aditomo et al., 2011) argued that the stages of inquiry enable students to integrate new knowledge with existing cognitive structures, thereby facilitating meaningful intellectual development.

Furthermore, (Prayogi et al., 2024) reported that inquiry-based learning enhances creativity by providing opportunities for open-ended exploration. Studies by Sinha et al. (2015), Xing et al. (2019), and Chen et al. (2018) confirmed that group-based inquiry activities significantly improve communication and collaboration. More recent studies by (Fitriani et al., 2023) and (Prayogi et al., 2024) also demonstrated improvements in higher-order thinking skills through inquiry.

However, inquiry-based learning in isolation remains limited in comprehensively facilitating creativity and collaboration, as its stages tend to be general and lack interdisciplinary integration.

2. STEM Approaches in Education

Research by (Abuhay et al., 2020) demonstrated that integrated STEM learning has long-term positive effects on 21st-century skills by encouraging interdisciplinary thinking and real-world problem solving. (Kelley & Knowles, 2016) highlighted that integrating STEM disciplines enhances both student motivation and conceptual understanding while promoting higher-order thinking skills.

Jolly (2014) identified six key characteristics of STEM education aligned with 21st-century skills: a focus on real-world problems, the engineering design process, productive teamwork, direct inquiry, integration of science and mathematics, and openness to creative solutions (Benek & Akçay, 2022). (Bramastia et al., 2023)confirmed that STEM is highly compatible with inquiry-based models.

(Ehsan et al., 2023) demonstrated that the engineering design process within STEM effectively trains students to design solutions, test outcomes, and perform iterative improvements, thereby strengthening creativity and systematic thinking. Additionally, Khoiriyah et al. (2018) and Erlinawati et al. (2019) reported that STEM implementation in junior secondary science education simultaneously enhances students' confidence, curiosity, communication, and collaboration skills.

3. Integration Of Inquiry and STEM And the Position of This Study

(Sulaeman et al., 2024) found that integrating inquiry into STEM creates a learning environment that promotes more complex scientific exploration, in which students not only collect data but also design experiments, analyze findings, and communicate scientifically grounded solutions to real-world problems. Asghar et al. (2012) showed that STEM learning, combined with active learning elements such as communication, collaboration, problem-solving, and creativity encourages experiential and inquiry-based learning.

(Bevins & Price, 2016) emphasized that inquiry integrated with interdisciplinary approaches develops three essential dimensions: scientific knowledge, useful procedures, and the personal dimension, positioning students as active agents in the learning process. Furthermore, (Bahtiar* et al., 2023) demonstrated that STEM integration in junior secondary science education enhances learning efficiency, meaningfulness, and students' ability to analyze real-world issues and systematically design solutions.

Despite the established benefits of inquiry-based learning and STEM approaches when implemented separately, there remains a lack of research specifically focused on developing a standardized, valid, practical, and effective design of an inquiry-based STEM-integrated learning model to simultaneously enhance the four core 21st-century skills: critical thinking, creative thinking, communication, and collaboration within the context of junior secondary science education.

Therefore, this study makes a clear contribution by developing an inquiry-based STEM-integrated learning model explicitly designed to improve students' 21st-century skills in a comprehensive, measurable manner within junior secondary science learning contexts.

2. RESEARCH METHODOLOGY

2.1. Research Design and Procedure

This study employed a design research approach based on the framework proposed by Plomp & Nieveen, (2013), consisting of three phases: Preliminary Research, Prototyping, and Assessment.

In the Preliminary Research phase, activities included needs analysis, literature review, and conceptual framework development. This phase involved curriculum analysis, concept analysis, identification of student characteristics, and examination of relevant learning models. Theoretical foundations were derived from constructivist learning theory, inquiry-based learning, STEM education, and 21st-century skills.

The Prototyping phase involved iterative design, formative evaluation, and revision of learning materials, including the model book, teacher guide, and student book. Validation was conducted by five expert validators. Practicality testing was carried out through one-to-one and small-group evaluations. Field testing was conducted over four instructional sessions at SMPN 1 Koto Baru, Dharmasraya, focusing on the topic of Earth Structure and Its Development.

The Assessment phase consisted of summative evaluation, including practicality and effectiveness testing. Effectiveness was evaluated using a quasi-experimental pretest–posttest control group design to measure students' 21st-century skills.

2.2. Research Subject

The participants were eighth-grade students at SMPN 1 Koto Baru, Dharmasraya Regency, during the second semester of the 2024/2025 academic year.

Sampling was conducted using a cluster random sampling technique, where intact classes were selected. Class VIIIB was assigned as the experimental group (inquiry-based STEM-integrated model), while Class VIIIA served as the control group (conventional instruction).

The total number of participants was N = 59 consisting of 30 students in the experimental group and 29 students in the control group.

2.3. Instruments And Data Collection

The research instruments were categorized into validity, practicality, and effectiveness instruments. All instruments were validated by experts and tested for reliability using the Intraclass Correlation Coefficient (ICC) with SPSS version 20.

2.4. Validity Instruments

Validity instruments included validation sheets for the model book, teacher guide, and student book. These instruments assessed three aspects: (a) construct validity (components, consistency, illustration, graphical design), (b) content validity (rationale, theoretical foundation, syntax, social system, reaction principles, support system, instructional and nurturant effects, curriculum alignment, and 21st-century skills), and (c) language clarity.

Five expert validators conducted validation. The results indicated validity percentages ranging from 85.42% to 90.63% (highly feasible), Aiken's V values between 0.81 and 0.88 (very valid), and ICC values ranging from 0.77 to 0.85 (reliable). Data were collected using a Likert scale questionnaire (1–4).

2.5. Practicality Instruments

Practicality instruments consisted of questionnaires assessing the practicality of the student book (16 items), teacher guide (12 items), and model book (21 items). These instruments evaluated ease of implementation, usefulness, applicability, and time allocation.

Practicality testing was conducted during the one-to-one evaluation phase (three students representing high, medium, and low ability levels) and small-group evaluation (nine students). Validation results indicated percentages ranging from 83.33% to 88.10% (highly feasible), with ICC values of 0.81-0.84 (high stability and reliability) (Creswell, 2019).

2.6. Effectiveness Instruments

a) The effectiveness instrument consisted of a holistic rubric for assessing 21st-century skills, adapted from the Partnership for 21st Century Skills (2015). The rubric covered four dimensions: critical thinking (providing explanations, applying systems thinking, decision-making, and problem solving); creative thinking (idea generation, collaborative creativity, and innovation implementation);
b) communication (effective idea delivery, use of media, and active listening); and
c) collaboration (productive teamwork, cooperation, and responsibility)

Validation results showed an Aiken's V value of 0.87 (very valid) and an ICC value of 0.85 (highly reliable). Data were collected through observation and direct assessment during the learning process.

2.7. Data Analysis Techniques

Validity and practicality data were analyzed descriptively using percentage calculations

a) Effectiveness analysis involved four procedures:
b) Normality Test using the Kolmogorov–Smirnov test (SPSS 20), with data considered normal if $p > 0.05$;
c) Homogeneity Test using Levene's Test (SPSS 20), with data considered homogeneous if $p > 0.05$;
d) Improvement Measurement using the N-Gain formula:

$\langle N\text{-Gain}\rangle = \frac{\langle S_{post}\rangle - \langle S_{pre}\rangle}{S_{max} - \langle S_{pre}\rangle}$ with categories: high (> 0.7), medium (0.3–0.7), and low (< 0.3);

e) Hypothesis Testing using an independent samples t-test (SPSS 20). The null hypothesis (H_0) was rejected if $p < 0.05$, indicating a significant difference in 21st-century skills between students taught using the inquiry-based STEM-integrated model and those receiving conventional instruction.

Ethical considerations were addressed by obtaining permission from the school and ensuring that student data were used solely for research purposes.

2.8. Research Schedule

The study was conducted during the second semester of the 2024/2025 academic year, specifically in May 2025, over 4 weeks. The implementation included four instructional sessions on "Earth Structure and Its Development" at SMPN 1 Koto Baru in Dharmasraya Regency.

3. RESULT

This section presents the study's findings on the development of an inquiry-based STEM-integrated learning model designed to enhance students' 21st-century skills in junior secondary science education. The results are organized according to the key criteria of educational design research, namely validity, practicality, and effectiveness. The model's validity was examined through expert review to ensure theoretical soundness and internal consistency. The practicality was evaluated through implementation trials involving teachers and students to assess the usability and feasibility of the developed materials. Furthermore, the model's effectiveness was analyzed using a quasi-experimental design by comparing students' pretest and posttest scores on 21st-century skills, including critical thinking, creative thinking, communication, and collaboration. The findings are presented in the following tables and are discussed in detail to provide a comprehensive understanding of the quality and impact of the developed learning model.

Table 1: Validity Results of the Learning Model Design.

No	Component	Result (%)	Category	Interpretation
1	Model Book	90.04%	Very Valid	Demonstrates strong theoretical alignment and consistency of model components
2	Teacher Book	87.67%	Very Valid	Content structure and implementation align with instructional needs
3	Student Book	88.67%	Very Valid	Language, content, and layout support the learning process
	Average	**88.79%**	**Very Valid**	The model is feasible without substantial revision

Table 1 indicates that all components of the learning model design fall within the very valid category. It suggests that the model fulfills the criteria of construct, content, and language validity. The high validity scores reflect a strong theoretical foundation and internal consistency among the model components. Therefore, the model is conceptually sound and suitable for implementation in learning without requiring major revisions.

These high validity scores (average = 88.79%) indicate strong alignment between theoretical constructs and the developed model components, confirming that the model is conceptually robust and internally consistent.

Table 2: Practicality Results of the Learning Model Design.

No	Component	Result (%)	Category	Interpretation
1	Model Book	92%	Very Practical	Easy to use and implement in classroom settings
2	Teacher Book	85%	Very Practical	Provides clear guidance for teachers
3	Student Book	90%	Very Practical	Supports active and independent learning activities
	Average	**89%**	**Very Practical**	The model is easily applicable in real classroom contexts

Table 2 demonstrates that the learning model design has a very high level of practicality. It indicates that the developed instructional materials are easy to use by both teachers and students in real classroom situations. The practicality is reflected in the ease of implementing the model syntax, the clarity of the instructional guidelines, and the materials' ability to support active, efficient, and well-structured learning activities.

The high practicality score (average = 89%) indicates that the model is feasible for classroom implementation, with clear instructional guidance and manageable learning procedures.

Table 3: Effectiveness Results of the Learning Model Design.

No	Skills	Experiment	Category	Interpretation (Experimental Class)	Control	Category	Interpretation (Control Class)
1	Critical Thinking	0.70	High	High improvemen, indicating the model is highly effective in enhancing critical thinking skills	0.23	Low	Low improvement, indicating the learning has not significantly improved critical thinking skills
2	Creativity	0.53	Medium	Moderate improvemen, showing the model is sufficiently effective in fostering creativity	0.22	Low	Low improvement, indicating minimal development of students' creativity
3	Communication	0.57	Medium	Moderate improvemen, meaning students' communication skills are fairly improved	0.23	Low	Low improvement, indicating limited enhancement in communication skills
4	Collaboration	0.66	Medium	Moderate improvemen, indicating the model supports teamwork and collaboration	0.21	Low	Low improvement, showing collaboration skills are not well developed
	Statistical Test	Sig < 0.05	Significant	Indicates a significant difference from conventional learning			
	Conclusion	-	**Effective**	The model significantly improves 21st-century skills.			

Table 3 indicates that the inquiry-based STEM-integrated learning model is effective in improving students' 21st-century skills. This is evidenced by the N-Gain scores in the experimental class, which range from moderate to high across the four skill domains (4C). Critical thinking skills show a high level of improvement, while creativity, communication, and collaboration fall within the moderate category, indicating a consistent and meaningful enhancement of students' competencies. In contrast, the control class demonstrates low N-Gain scores across all skill aspects, suggesting minimal improvement under conventional instruction.

Furthermore, the results of the statistical test reveal a significance value of less than 0.05, indicating a statistically significant difference between students taught using the inquiry-based STEM-integrated model and those receiving traditional learning. This finding confirms that the developed model is empirically effective in enhancing students' 21st-century skills.

The synthesis of these findings, supported by recent international literature, suggests that the developed learning model demonstrates strong validity, practicality, and effectiveness. The model's high validity is reflected in its solid theoretical foundation and the coherent integration of STEM and inquiry-based learning principles. In terms of practicality, the model is adaptable to real classroom contexts and aligns with the demands of technology-enhanced 21st-century education. Moreover, its effectiveness in improving students' competencies is consistent with global empirical evidence highlighting the benefits of integrating inquiry-based approaches with STEM education. Therefore, this study not only contributes to the local educational context but also aligns with global trends in STEM education and 21st-century skills development, demonstrating its relevance and potential for international publication.

The higher N-Gain scores in the experimental class compared to the control class indicate that the inquiry–STEM model provides a more effective learning environment for developing students' 21st-century skills.

4. DISCUSSION

The validity results indicate that the inquiry-based STEM-integrated learning model falls within the very valid category (average = 88.79%), demonstrating strong theoretical alignment and internal consistency. This suggests that the model components are well-structured and coherent, which is essential in instructional design.

This finding is supported by previous studies. Moore et al., (2020) highlight that valid STEM learning design should integrate engineering design processes, authentic contexts, and structured learning activities. Similarly, (Dare et al., 2021) emphasize the importance of explicitly connecting interdisciplinary concepts in STEM learning. In addition, (Margot & Kettler, 2019) state that effective instructional design must address both teacher usability and student learning needs. Therefore, the high validity of this model reflects strong theoretical robustness and its relevance to contemporary STEM and inquiry-based educational practices.

The practicality results reveal that the learning model falls within the very practical category, reflecting its ease of implementation in real classroom settings. This finding aligns with instructional design principles that emphasize usability and implement ability as key indicators of a successful learning model. Empirical evidence from recent studies supports this result. For instance (Deehan et al., 2025) argued that the successful implementation of STEM education depends on the clarity of the model structure and the usability of instructional materials. In addition, (Falloon et al., 2020) found that practical STEM learning models significantly enhance student engagement and learning effectiveness. Moreover (Van Laar et al., 2020)v emphasized that learning environments designed to support 21st-century skills must be flexible and easily implemented by educators. Thus, the high practicality observed in this study indicates that the model is not only conceptually sound but also highly applicable in junior secondary science classrooms.

The effectiveness results show that the model significantly improves students' 21st-century skills, as evidenced by moderate to high N-Gain scores and statistically significant differences ($p < 0.05$). The highest improvement was observed in critical thinking skills, indicating that inquiry-based STEM learning effectively promotes higher-order thinking processes.

This finding is consistent with previous studies showing that integrated STEM learning enhances students' cognitive and problem-solving skills. Falloon et al., (2020) ound that STEM-integrated learning contributes significantly to student achievement and higher-order thinking. Compared to conventional instruction, the inquiry–STEM model provides more opportunities for active engagement, collaboration, and real-world problem-solving, which are essential for developing 21st-century competencies.

However, this study is limited to a specific context and sample size. Therefore, future research is recommended to implement the model across broader educational settings to further validate its effectiveness.

5. CONCLUSION

This study concludes that an inquiry-based STEM-integrated learning model for junior secondary science was successfully developed, demonstrating high quality and feasibility for implementation. The model is systematically structured, incorporating learning syntax (orientation, conceptualization, investigation, conclusion, and discussion), a student-centered social system, teacher facilitation principles, and supporting materials including the model book, teacher guide, and student book.

In terms of quality, the model fulfills the criteria of validity, practicality, and effectiveness. The validity results indicate strong theoretical alignment and internal consistency across all components. The practicality findings show that the model is easy to implement in real classroom settings by both teachers and students. Furthermore, the effectiveness results reveal that the model significantly improves students' 21st-century skills critical thinking, creativity, communication, and collaboration with moderate yet consistent gains.

It is recommended that teachers apply this model consistently while enhancing their competence in inquiry- and STEM-based instruction. Schools should provide adequate support and training to facilitate implementation. Future research should expand the model to different topics, integrate digital technologies, and examine long-term impacts. Policymakers may use these findings to support the development of STEM-based, competency-oriented educational policies aligned with global trends.

Author Contributions: For research articles with multiple authors, a short paragraph outlining each author's individual contributions must be provided. The following statements should be used: "Conceptualization, I.S. and I.S.; methodology, I.S.; software, Y.A.; validation, L.F., Y.A. and I.S.; formal analysis, R.W.; investigation, R.D.; resources, I.S.; data curation, I.S.; writing—original draft preparation, Y.A.; writing—review and editing, I.S.; visualization, Y.A.; supervision, I.S.; project administration, Y.A.; funding acquisition, I.S. All authors have read and agreed to the published version of the manuscript.

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REFERENCES

Abdurrahman, Ariyani, F., Maulina, H., & Nurulsari, N. (2019). Design and validation of inquiry-based STEM learning strategy as a powerful alternative solution to facilitate gifted students facing 21st century challenging. *Journal for the Education of Gifted Young Scientists*, *7*(1), 33–56. https://doi.org/10.17478/jegys.513308

Abuhay, T. M., Metsker, O. G., Yakovlev, A. N., & Kovalchuk, S. V. (2020). Constructing Holistic Patient Flow Simulation Using System Approac. *Computational Science – ICCS 202020th International Conference, Amsterdam, The Netherlands, June 3–5, 2020, Proceedings, Part IV*, *12140*, 418–429.

Acikara, T., Xia, B., Yigitcanlar, T., & Hon, C. (2023). Contribution of Social Media Analytics to Disaster Response Effectiveness: A Systematic Review of the Literature. *Sustainability*, *15*(11), 1–50. https://doi.org/10.3390/su15118860

Aditomo, A., Goodyear, P., Bliuc, A.-M., & Ellis, R. A. (2011). Inquiry-based learning in higher education: Principal forms, educational objectives, and disciplinary variations. *Studies in Higher Education*, *38*(9), 1239–1258. (world). https://doi.org/10.1080/03075079.2011.616584

Akpur, U. (2020). Critical, Reflective, Creative Thinking and Their Reflections on Academic Achievement. *Thinking Skills and Creativity*, *37*, 100683. https://doi.org/10.1016/j.tsc.2020.100683

Arifin, Z. (2020). Teori Perkembangan Sosial Anak dan Pengaruhnya bagi Pendidikan. *TADARUS: Jurnal Pendidikan Islam*, *9*(1), 119–132.

Asy'ari, M., Ikhsan, M., & Muhali. (2019). The Effectiveness of Inquiry Learning Model in Improving Prospective Teachers' Metacognition Knowledge and Metacognition Awareness. *International Journal of Instruction*, *12*(2), 455–470. https://doi.org/10.29333/iji.2019.12229a

Bahtiar*, B., Maimun, M., & Ibrahim, I. (2023). Analysis of Collaboration, Communication, Critical Thinking, and Creative Thinking Ability of Students in Solving Science Problems in Terms of Gender. *Jurnal Pendidikan Sains Indonesia*, *11*(2), 379–400. https://doi.org/10.24815/jpsi.v11i2.29065

Benek, İ., & Akçay, B. (2022). The effects of socio-scientific STEM activities on 21st century skills of middle school students. *Participatory Educational Research*, *9*(2), 25–52. https://doi.org/10.17275/per.22.27.9.2

Bevins, S., & Price, G. (2016). Reconceptualising Inquiry in Science Education. *International Journal of Science Education*, *38*(1), 17–29. https://doi.org/10.1080/09500693.2015.1124300

Bramastia, B., Suciati, S., Nugraheni, F. S. A., Sari, M. W., Wati, I. K., Antrakusuma, B., & Masithoh, D. F. (2023). Effectiveness of EthnoSTEM-Based Science Learning to Improve Junior High School Students' Science Literacy Ability. *Jurnal Penelitian Pendidikan IPA*, *9*(SpecialIssue), 332–337. https://doi.org/10.29303/jppipa.v9ispecialissue.5710

Care, E., Kim, H., Vista, A., & Anderson, K. (2018). *Education System Alignment for 21st Century Skills: Focus on Assessment*. Center for Universal Education at The Brookings Institution. https://eric.ed.gov/?id=ED592779

Creswell, J. W. (2019). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. In *Sage Publication*. Sage Publications. https://doi.org/10.1002/tl.20234

Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F. (2021). Beyond Content: The Role of STEM Disciplines, Real-World Problems, 21st Century Skills, and STEM Careers within Science Teachers' Conceptions of Integrated STEM Education. *Education Sciences*, *11*(11), 737. https://doi.org/10.3390/educsci11110737

Deehan, J., Redshaw, S., Danaia, L., Postlethwaite, F., Donnelly, A., & Morris, C. (2025). Understanding STEM beyond the cities: A comprehensive review of non-metropolitan STEM education research. *International Journal of Educational Research Open*, *9*, 100496. https://doi.org/10.1016/j.ijedro.2025.100496

Ehsan, H., Quintana-Cifuentes, J. P., Purzer, S., & Rehmat, A. P. (2023). Engineering Design and Children: A Systematic Literature Review. *International Journal of Education in Mathematics, Science and Technology*, *11*(3), 775–803. https://doi.org/10.46328/ijemst.2669

Falloon, G., Hatzigianni, M., Bower, M., Forbes, A., & Stevenson, M. (2020). Understanding K-12 STEM Education: A Framework for Developing STEM Literacy. *Journal of Science Education and Technology*, *29*(3), 369–385.

Fitriani, R., Asyhar, R., Hariyadi, B., Hasibuan, H. E., & Javed, M. A. (2023). Urgensi Pembelajaran Abad 21 Model Pembelajaran berbasis Inkuiri: Tinjauan Pustaka. *EduFisika: Jurnal Pendidikan Fisika*, *8*(3), 406–512.

Isabirye, A. K., Moloi, K. C., Lebelo, R. S., & Khan, S. (2025). Cultivating Creativity and Innovation in the School Curriculum for the 21st Century: Opportunities and Challenges. *Journal of Ecohumanism*, *4*(3), 334–348. https://doi.org/10.62754/joe.v4i3.6647

Junedi, B., Mahuda, I., & Kusuma, J. W. (2020). Optimalisasi Keterampilan Pembelajaran Abad 21 dalam Proses Pembelajaran pada Guru MTs Massaratul Mut'allimin Banten. *Transformasi Jurnal Pengabdian Masyarakat*, *16*(1), 63–72.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1). https://doi.org/10.1186/s40594-016-0046-z

Margot, K. C., & Kettler, T. (2019). Teachers' Perception of STEM integration and Education: A Systematic Literature Review. *International Journal of STEM Education*, *6*(2), 1–16. https://doi.org/10.1186/s40594-018-0151-2

Moore, T. J., Johnston, A. C., & Glancy, A. W. (2020). STEM Integration: A Synthesis of Conceptual Frameworks and Definitions. In *Handbook of Research on STEM Education*. Routledge.

OECD, P. (2018). The Future of Education and Skills: Education 2030. *The Future of Education and Skills: Education 2030*, (1), 23.

Pangestu, A., & Firdaus, F. M. (2024). Optimizing Collaboration Skills in the 21st Century: Recent Innovations in Project Model Differentiated Learning. *Jurnal Ilmiah Sekolah Dasar*, *8*(1), 34–44. https://doi.org/10.23887/jisd.v8i1.64923

Plomp, T., & Nieveen, N. (2013). Educational Design Research: An Introduction. In *Educational Design Research* (pp. 10–51). Netherlands Institute for Curriculum Development (SLO).

Prayogi, S., Bilad, M. R., Verawati, N. N. S. P., & Asy'ari, M. (2024). Inquiry vs. Inquiry-Creative: Emphasizing Critical Thinking Skills of Prospective STEM Teachers in the Context of STEM Learning in Indonesia. *Education Science*, *14*(593), 1–14. https://doi.org/10.3390/educsci14060593

Ramadhan, H. B. W., & Umamah, N. (2024). Application of Constructivist and Experiential Learning Theory in Social Studies Learning: Theoretical and Practical Perspectives. *International Journal of Academic Pedagogical Research*, *8*(12), 71–76.

Redhana, I. W. (2019). Mengembangkan Keterampilan Abad ke 21 dalam Pembelajaran Kimia. *Jurnal Inovasi Pendidikan Kimia*, *13*(1), 2239–2252.

Sulaeman, N., Nuryadin, A., Subagiyo, L., Zulhiyah, F., & Dinurrohmah, S. (2024). Science Teacher Development in STEM for Indonesia's Curriculum Change: *Proceedings of the 4th International Conference on Humanities Education, Law, and Social Science*, 527–532. https://doi.org/10.5220/0013421800004654

Susetyarini, E., Nurohman, E., & Husamah, H. (2022). Analysis of Students' Collaborative, Communication, Critical Thinking, and Creative Abilities through Problem-Based Learning. *Jurnal Penelitian Dan Pengkajian Ilmu Pendidikan: E-Saintika*, *6*(1), 33–42. https://doi.org/10.36312/esaintika.v6i1.584

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J.-M., Morisseau, T., Bourgeois-Bougrine, S., Vinchon, F., El Hayek, S., Augereau-Landais, M., Mourey, F., Feybesse, C., Sundquist, D., & Lubart, T. (2023). Creativity, Critical Thinking, Communication, and Collaboration: Assessment, Certification, and Promotion of 21st Century Skills for the Future of Work and Education. *Journal of Intelligence*, *11*(3), 54. https://doi.org/10.3390/jintelligence11030054

Tohani, E., & Aulia, I. (2022). Effects of 21st Century Learning on the Development of Critical Thinking, Creativity, Communication, and Collaboration Skills. *Journal of Nonformal Education*, *8*(1), 46–53. https://doi.org/10.15294/jne.v8i1.33334

Trilling, B., & Fadel, C. (2009). *21st Century Skills: Learning for Life in Our Times*. John Wiley & Sons.

Van Laar, E., Van Deursen, A. J. A. M., Van Dijk, J. A. G. M., & De Haan, J. (2020). Measuring the levels of 21st-century digital skills among professionals working within the creative industries: A performance-based approach. *Poetics*, *81*, 101434. https://doi.org/10.1016/j.poetic.2020.101434

Wahyudin, D., Subkhan, E., Malik, A., Hakim, Moh. A., Sudiapermana, E., Alhapip, L., Anggraena, Y., Maisura, R., Amalia, N. R. A. S., Solihin, L., Ali, N. B. V., & Krisna, F. N. (2024). *Kurikulum Merdeka*. Pusat Kurikulum dan Pembelajaran.