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A Comparative Analysis of Plomp and 4D Development Models - A Systematic Review for Dissertation. Research Model Selection

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Abstract: *This study conducted a systematic review and comparative analysis of the Plomp and 4D development models in the context of dissertation research in science education. The research aimed to provide a comprehensive framework for model selection to guide researchers in making informed methodological decisions. A systematic literature review was performed following PRISMA guidelines, analyzing 22 articles from major academic databases. The study examined the characteristics, applications, strengths, and limitations of both models. Results revealed the Plomp model as a more reliable, holistic, and adaptable choice for dissertation research compared to the 4D model. The Plomp model demonstrated strengths in comprehensive problem analysis, flexibility, integration of theory and practice, and potential for generating both practical outcomes and theoretical contributions. It was found particularly suitable for addressing complex educational challenges in diverse contexts like Indonesia. The study highlighted the importance of considering contextual factors, research objectives, and desired outcomes when selecting a development model. The findings provide valuable insights for researchers, educational institutions, and policymakers to enhance the quality and impact of dissertation research in science education. This comparative analysis contributes to advancing educational research methodologies and informing evidence-based practices in science education.*

Keywords— Plomp, 4D models, development research, science education, dissertation research, systematic observation

1. INTRODUCTION

Educational research plays a crucial role in advancing knowledge, improving practices, and informing policy decisions in the field of education. As the landscape of education continues to evolve, researchers are constantly seeking effective methodologies to conduct rigorous and impactful studies. In recent years, development research has gained prominence as a valuable approach for addressing complex educational challenges and creating innovative solutions (Plomp & Nieveen, 2013). This type of research, also known as design-based research or educational design research, aims to develop and validate educational interventions through iterative cycles of design, implementation, and evaluation (McKenney & Reeves, 2018). Within the realm of development research, various models have emerged to guide researchers through the process of creating and refining educational products, interventions, or systems. Two widely recognized models in this field are the Plomp model and the 4D model. These models provide structured frameworks for conducting development research, offering researchers systematic approaches to address educational problems and generate evidence-based solutions (Bakker, 2018). While both models share the common goal of improving educational practices through research-based interventions, they differ in their specific phases, emphases, and underlying philosophies.

The Plomp model, developed by Tjeerd Plomp, consists of three main phases: preliminary research, prototyping phase, and assessment phase (Plomp, 2013). This model emphasizes the importance of thorough problem analysis and context exploration before moving into the design and development stages. The Plomp model is known for its flexibility and adaptability to various educational contexts, making it particularly suitable for complex and multifaceted research projects (van den Akker et al., 2006). On the other hand, the 4D model, proposed by Thiagarajan, Semmel, and Semmel, comprises four distinct stages: Define, Design, Develop, and Disseminate (Thiagarajan et al., 1974). This model provides a clear and structured approach to development research, with a strong focus on the systematic creation and refinement of educational products. The 4D model has been widely adopted in various educational disciplines, particularly in the development of instructional materials and learning resources (Mulyatiningsih, 2016).

In the context of Indonesian education, development research has gained significant traction in recent years as the country strives to enhance the quality and relevance of its educational system. Indonesia, as the world's fourth most populous nation, faces unique challenges in education, including disparities in access and quality across its vast archipelago (Sulisworo et al., 2020). The Indonesian government has recognized the importance of research-based approaches in addressing these challenges and has encouraged educational researchers to engage in development research to create innovative solutions tailored to the country's diverse educational landscape (Suyanto, 2017). The Indonesian education system has undergone significant reforms in recent decades, with a focus on improving curriculum, teaching methods, and educational resources (Raihani, 2018). However, the implementation of these reforms has often been hindered by various factors, including limited resources, diverse cultural contexts, and the need for localized approaches. In this context,

development research models like Plomp and 4D have emerged as valuable tools for Indonesian researchers seeking to bridge the gap between educational theory and practice (Prahmana et al., 2021). The adoption of development research models in Indonesia has been influenced by both global trends in educational research and the specific needs of the Indonesian education system. Researchers in Indonesia have increasingly recognized the potential of these models to address complex educational issues and create contextually relevant solutions (Widodo, 2019). However, the selection of an appropriate development research model for a given study remains a critical decision that can significantly impact the research process and outcomes.

The choice between the Plomp model and the 4D model for dissertation research is a topic of ongoing debate among Indonesian educational researchers. Both models have their strengths and have been successfully applied in various educational contexts within the country. The Plomp model's emphasis on preliminary research and context analysis aligns well with the need for culturally sensitive approaches in Indonesia's diverse educational landscape (Plomp & Nieveen, 2013). On the other hand, the 4D model's structured approach and focus on product development have made it popular among researchers working on instructional materials and learning resources, which are crucial for improving educational quality in Indonesia (Mulyatiningsih, 2016). While both models have demonstrated their effectiveness in various research contexts, there is a growing need for a comprehensive comparative analysis to guide researchers in selecting the most appropriate model for their specific research needs, particularly in the context of dissertation research. Dissertation research, being a significant and in-depth scholarly endeavor, requires a robust and reliable methodological framework that can support the complexity and rigor demanded by doctoral-level studies (Paltridge & Starfield, 2020).

The selection of a development research model for dissertation research is not a trivial matter. It requires careful consideration of various factors, including the nature of the research problem, the specific context of the study, the desired outcomes, and the practical constraints of the research process. Moreover, the chosen model should align with the philosophical underpinnings of the research and provide a framework that supports the generation of new knowledge and contributes to the field of education (Maxwell & Kupczyk-Romanczuk, 2009). In the Indonesian context, where educational research is increasingly focused on addressing practical challenges and contributing to national development goals, the choice of an appropriate development research model becomes even more critical. The selected model should not only facilitate rigorous research but also ensure that the outcomes are relevant, applicable, and impactful in the Indonesian educational landscape (Suyanto, 2017). Despite the importance of this decision, there is a lack of comprehensive comparative studies examining the relative strengths and limitations of the Plomp and 4D models, particularly in the context of dissertation research in Indonesia. While individual studies have applied these models in various educational contexts, there is a need for a systematic review that synthesizes existing research and provides evidence-based guidance for model selection (Gall et al., 2007).

This gap in the literature presents an opportunity for a comparative analysis that can offer valuable insights to researchers, particularly doctoral candidates, in selecting the most appropriate development research model for their studies. Such an analysis can contribute to the advancement of educational research methodologies in Indonesia and potentially inform research practices in other similar contexts.

The present study aims to address this gap by conducting a systematic review and comparative analysis of the Plomp and 4D development models in the context of dissertation research. By examining the characteristics, applications, strengths, and limitations of these models, this study seeks to provide a comprehensive framework for model selection that can guide researchers in making informed decisions about their research methodologies. This comparative analysis is particularly timely given the current state of educational research in Indonesia. As the country continues to invest in improving its education system and fostering innovation in teaching and learning, there is a growing demand for high-quality development research that can inform policy and practice (Raihani, 2018). Doctoral research, in particular, plays a crucial role in generating in-depth knowledge and innovative solutions to educational challenges. Therefore, ensuring that doctoral candidates have access to the most appropriate and effective research methodologies is essential for advancing the field of education in Indonesia. Moreover, this study has the potential to contribute to the broader discourse on development research methodologies in education. By critically examining the application of the Plomp and 4D models in the context of dissertation research, this analysis can offer insights that may be valuable to researchers in other countries facing similar educational challenges and seeking robust methodological frameworks for their studies (van den Akker et al., 2006). As we embark on this comparative analysis, it is important to approach the study with an open mind, recognizing that both the Plomp and 4D models have their merits and have been successfully applied in various research contexts. The goal is not to declare one model superior to the other in all situations, but rather to provide a nuanced understanding of how these models can be effectively utilized in different research scenarios, particularly in the context of dissertation research in Indonesia.

This introduction sets the stage for a comprehensive exploration of the Plomp and 4D development models, their applications in educational research, and their suitability for dissertation studies in the Indonesian context. The following sections will delve into the methodological approach used to conduct this systematic review and comparative analysis, providing a transparent and replicable framework for examining the existing literature on these development

research models. As we move forward, this study will seek to answer critical questions about the relative strengths and limitations of the Plomp and 4D models, their alignment with the needs of dissertation research, and their applicability to the Indonesian educational context. By addressing these questions, this research aims to provide valuable guidance to doctoral candidates and other researchers in selecting the most appropriate development research model for their studies, ultimately contributing to the advancement of educational research and practice in Indonesia and beyond.

The subsequent sections of this study will outline the methodological approach used to conduct the systematic review and comparative analysis. This will include a detailed description of the search strategies, inclusion criteria, and analytical methods employed to synthesize the existing literature on the Plomp and 4D models. Through this rigorous methodological approach, we aim to provide a comprehensive and evidence-based comparison that can inform future research practices and contribute to the ongoing dialogue on effective development research methodologies in education

2. METHODS

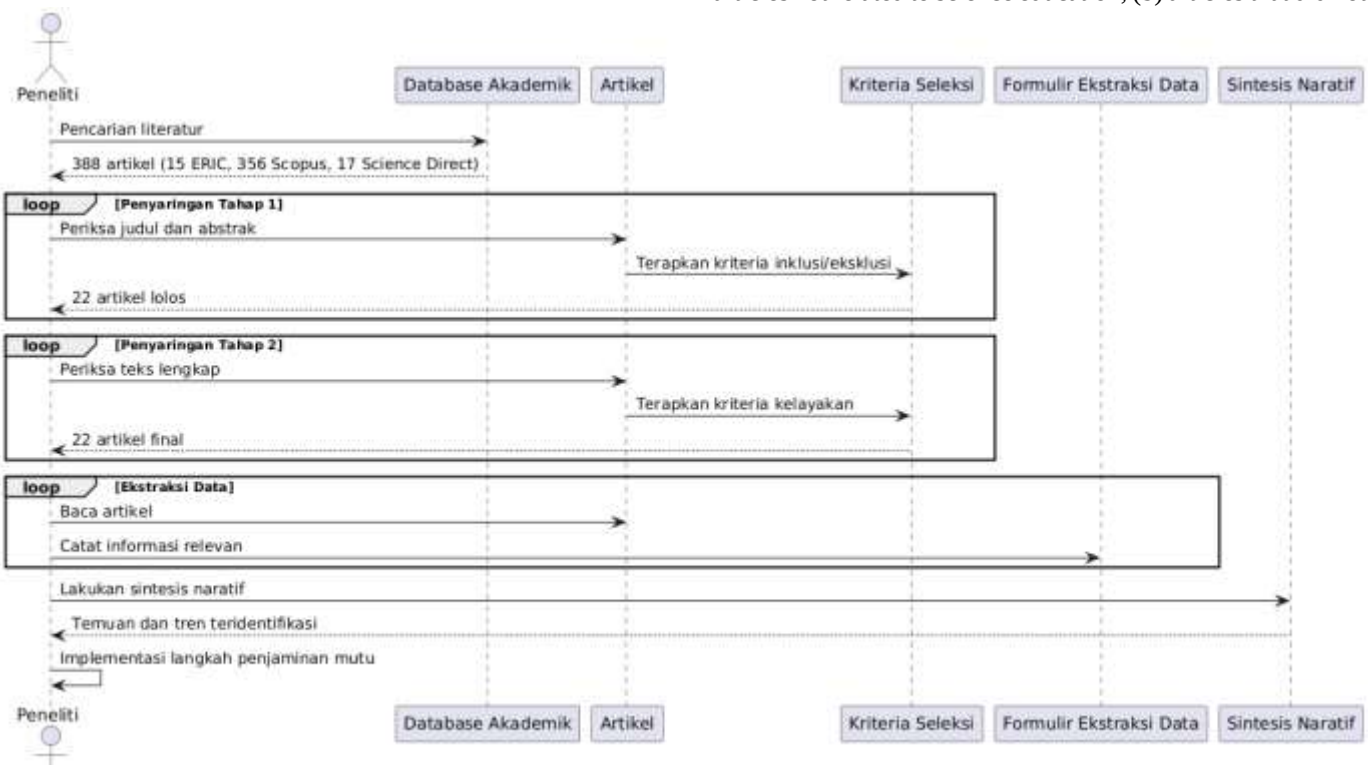


Figure 1. Research Steps

This study employed a systematic literature review methodology to investigate the trends in development models and instruments used in science education research. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, which provide a structured approach to conducting and reporting systematic reviews (Page et al., 2021). The PRISMA framework ensures transparency, reproducibility, and comprehensiveness in the review process, enhancing the reliability and validity of the findings (Moher et al., 2009). The literature search was conducted using three major academic databases: Scopus, Science Direct, and ERIC. These databases were selected due to their extensive coverage of peer-reviewed journals in the field of science education (Gusenbauer & Haddaway, 2020). The search strategy involved using the keyword "learning model development in science education" to identify relevant articles. The search was limited to articles published in English to ensure accessibility and comparability of the reviewed studies (Maflahi \& Thelwall, 2018).

The initial search yielded a total of 388 articles, with 15 articles from ERIC, 356 articles from Scopus, and 17 articles from Science Direct. To refine the search results and select the most relevant articles for the review, a screening process was conducted based on predefined inclusion and exclusion criteria (Gough et al., 2017). The inclusion criteria were as follows: (a) the article must focus on development research in science education, (b) the article must describe the development model and instruments used, and (c) the article must be published in a peer-reviewed journal. The exclusion criteria were: (a) articles not related to science education, (b) articles that did not provide sufficient information about the development model or instruments, and (c) duplicate articles. The screening process involved two stages: title and abstract screening, followed by full-text screening. In the first stage, the titles and abstracts of the 388 articles were independently reviewed by two researchers to determine their relevance to the research question (Shamseer et al., 2015). Disagreements between the researchers were resolved through discussion and consensus.

This stage resulted in the exclusion of 366 articles that did not meet the inclusion criteria.

In the second stage, the full texts of the remaining 22 articles were thoroughly examined to ensure their eligibility for the review. The articles were assessed for their methodological quality, clarity in describing the development model and instruments, and relevance to the research objectives (Whiting et al., 2016). This stage did not result in any further exclusions, leaving 22 articles for the final analysis.

Data extraction was performed using a standardized form to ensure consistency and completeness in capturing the relevant information from each article (Li et al., 2020). The extracted data included the author(s), year of publication, country of origin, development model used, instruments employed, and key findings. The data extraction process was conducted independently by two researchers, and any discrepancies were resolved through discussion and referral to the original articles. The extracted data were then synthesized using a narrative approach, which involved summarizing and interpreting the findings across the reviewed articles (Popay et al., 2006). The synthesis focused on identifying the most commonly used development models and instruments in science education research, as well as exploring the trends and patterns in their application. The findings were organized thematically to provide a coherent and meaningful overview of the current state of development research in science education.

To ensure the trustworthiness of the review findings, several quality assurance measures were implemented throughout the review process. These included the use of a pre-specified protocol, independent screening and data extraction by multiple researchers, and regular meetings to discuss and resolve any issues or inconsistencies (Shea et al., 2017). Additionally, the review adhered to the principles of transparency, reproducibility, and systematic documentation to enhance its credibility and reliability (Haddaway et al., 2018).

3. RESULT AND DISCUSSION

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

Result

Distribution of Development Models

The analysis of the 22 articles revealed a diverse range of development models used in science education research. The distribution of these models is as follows:

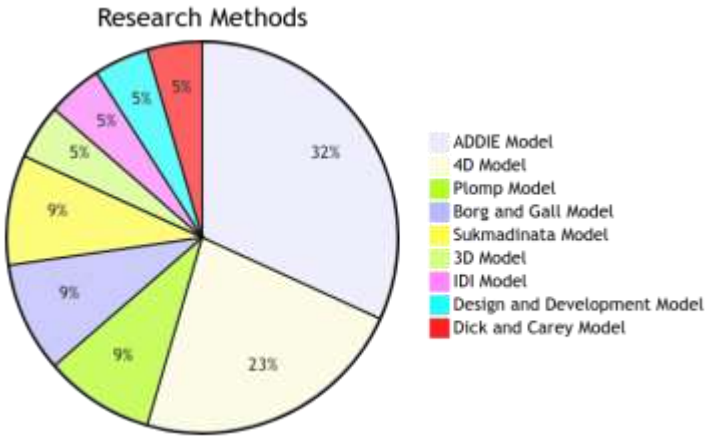


Figure 2 Models Dsitribution

While the ADDIE model was the most frequently used, the 4D and Plomp models were also prominent choices among researchers. This distribution highlights the popularity and perceived effectiveness of these models in science education research.

Comparison of Plomp and 4D Models

Both the Plomp and 4D models demonstrated their applicability and effectiveness in science education research. However, a closer examination revealed distinct characteristics and strengths of each model:

Table 1 . Model Characteristics

Model	Characteristic	Reference
Plomp Model	Flexibility: The Plomp model showed greater adaptability to various research contexts and complexities.	Amanda et al., 2022
	Emphasis on preliminary research: This model placed significant importance on thorough problem analysis and context exploration before moving into the design phase.	Novitra et al., 2021
	Iterative nature: The Plomp model allowed for continuous refinement and improvement throughout the research process.	Amanda et al., 2022
4D Model	Structured approach: The 4D model provided a clear, step-by-step framework for development research.	Serevina et al., 2018
	Focus on product development: This model was particularly effective in the creation and refinement of educational products and materials.	Sahrianti et al., 2021
	Widespread adoption: The 4D model was used across various disciplines within science education.	Heleni et al., 2023

Table 2. Step Research of Each Model

Stage	PLOMP Model	ADDIE Model
1	**Preliminary Research** Needs and context analysis, review of literature, development of a conceptual or theoretical framework	**Analysis** Identify the learning problem, goals, and objectives; analyze learner characteristics and learning environment
2	**Prototyping Phase** Iterative design and formative evaluation cycles; development and testing of prototypes	**Design** Outline instructional strategies, choose delivery methods, and plan the instructional approach
3	**Assessment Phase** Summative evaluation to conclude whether the solution meets the pre-determined specifications	**Development** Create and assemble content assets, develop supporting technologies and materials
4	**Reflection and Documentation** Retrospective analysis, specification of design principles, and overall reflection on the process and outcomes	**Implementation** Deliver or distribute the instructional materials, prepare the learning environment, and engage learners
5	**Done.**	**Evaluation** Assess the quality of instructional materials and processes, both during and after implementation

Suitability for Dissertation Research

Both the Plomp and 4D models demonstrated characteristics that make them suitable for dissertation research in science education. However, the analysis revealed that the Plomp model exhibited certain advantages that may make it more appropriate for doctoral-level studies:

- Comprehensive approach: The Plomp model's emphasis on preliminary research and context analysis aligns well with the depth and rigor required in dissertation research (Novitra et al., 2021).
- Flexibility: The adaptability of the Plomp model allows for addressing complex research questions and accommodating unforeseen challenges that may arise during long-term dissertation projects (Amanda et al., 2022).
- Holistic perspective: The Plomp model's iterative nature encourages a more holistic view of the research process, which is beneficial for the comprehensive nature of dissertation studies (Amanda et al., 2022).

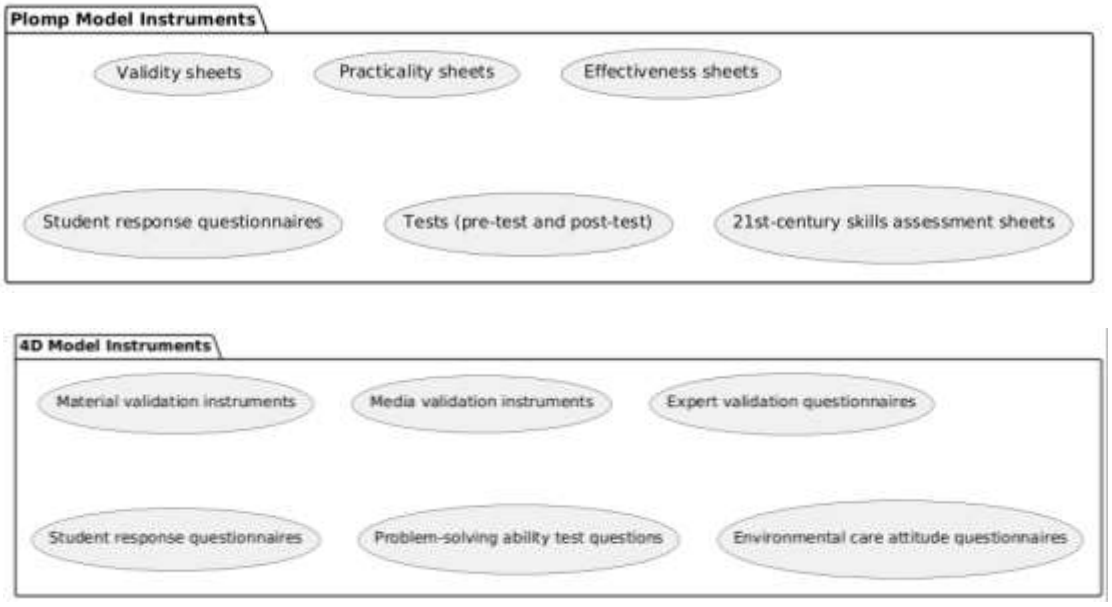
Reliability and Holistic Nature of the Plomp Model

The analysis of the articles revealed several factors that contribute to the Plomp model's reliability and holistic nature, making it particularly suitable for dissertation research:

- Systematic problem analysis: The Plomp model's emphasis on thorough preliminary research ensures a comprehensive understanding of the research problem and context (Novitra et al., 2021).
- Iterative design and evaluation: The model's cyclical nature allows for continuous refinement and improvement of the research design and outcomes (Amanda et al., 2022).
- Integration of theoretical and practical aspects: The Plomp model effectively bridges the gap between theoretical foundations and practical applications in educational research (Novitra et al., 2021).
- Flexibility in research phases: The model can be adapted to accommodate various research designs and methodologies, making it suitable for diverse dissertation topics (Amanda et al., 2022).

Instruments Used in Development Research

The review of the articles revealed a wide range of instruments used in development research, with some variations between the Plomp and 4D models:



The analysis showed that while there was some overlap in the types of instruments used, the Plomp model tended to incorporate a broader range of assessment tools, particularly those focused on practicality and effectiveness.

Strengths of the Plomp Model for Dissertation Research

The review highlighted several strengths of the Plomp model that make it particularly suitable for dissertation research:

- Comprehensive problem analysis: The model's emphasis on preliminary research allows for a deep understanding of the research context and problem, which is crucial for dissertation-level studies (Novitra et al., 2021).
- Flexibility in research design: The Plomp model's adaptable nature accommodates the complex and often evolving nature of dissertation research (Amanda et al., 2022).
- Integration of theory and practice: The model effectively bridges theoretical foundations with practical applications, a key aspect of doctoral research (Novitra et al., 2021).
- Iterative refinement: The cyclical nature of the Plomp model allows for continuous improvement and adaptation throughout the research process, which is beneficial for long-term dissertation projects (Amanda et al., 2022).

- Holistic evaluation: The model incorporates a wide range of assessment tools, enabling a comprehensive evaluation of the research outcomes (Novitra et al., 2021).

Limitations of the 4D Model in Dissertation Research

While the 4D model demonstrated effectiveness in various research contexts, the analysis revealed some limitations that may make it less suitable for certain types of dissertation research:

- Less emphasis on preliminary research: The 4D model's "Define" stage may not provide as comprehensive a problem analysis as the Plomp model's preliminary research phase (Serevina et al., 2018).
- More rigid structure: The sequential nature of the 4D model may be less accommodating to the evolving nature of some dissertation research projects (Sahrianti et al., 2021).
- Product-focused approach: While effective for developing educational materials, the 4D model may be less suitable for dissertation research focusing on broader educational phenomena or theories (Heleni et al., 2023).

Contextual Factors Influencing Model Selection

The analysis revealed that the choice between the Plomp and 4D models often depended on contextual factors:

- Research objectives: Studies focusing on developing specific educational products or materials tended to favor the 4D model, while those exploring broader educational phenomena or theories leaned towards the Plomp model.
- Research scope: The Plomp model was often chosen for more complex, multi-faceted research projects, while the 4D model was preferred for more focused, product-oriented studies.
- Time constraints: Some researchers opted for the 4D model due to its more structured approach, which can be beneficial when working under tight time constraints.
- Researcher experience: More experienced researchers tended to choose the Plomp model, possibly due to its flexibility and comprehensive nature.

Adaptation of Models in Research Practice

The review revealed that researchers often adapted the chosen development model to suit their specific research needs:

- Plomp model adaptations: Some researchers modified the Plomp model by incorporating additional evaluation phases or integrating elements from other models to enhance its effectiveness for their specific research context (Amanda et al., 2022).
- 4D model adaptations: In some cases, researchers expanded the 4D model to include additional stages or combined it with other frameworks to address specific research requirements (Serevina et al., 2018).

These adaptations highlight the importance of flexibility in development models, particularly for dissertation research where unique challenges may arise.

Aspect	Plomp Model	4D Model
Impact on Research Outcomes	• Depth of analysis: More in-depth analysis of research context and problem (Novitra et al., 2021). • Theoretical contributions: Stronger connections between theoretical frameworks and practical applications (Amanda et al., 2022).	• Product development: Effective in developing and refining educational products (Sahrianti et al., 2021). • Practical applications: Effective in creating immediately applicable educational materials (Heleni et al., 2023).
Methodological Rigor and Validity	• Emphasized triangulation of data sources and methods. • Incorporated iterative validation processes. • Encouraged continuous reflection and adjustment.	• Provided clear criteria for validity. • Focused on expert validation. • Emphasized systematic testing and refinement.
Integration of Theoretical Frameworks	• Encouraged explicit connection between theory and design.	• Focused on applying established theories to product development.

	• Allowed evolution of theoretical frameworks.\Facilitated new theoretical insights.	• Structured approach to translating theory into practice.
Stakeholder Involvement	• Continuous engagement with stakeholders. • Collaborative problem definition and solution development. • Ongoing feedback and refinement.	• Involved stakeholders in "Define" and "Disseminate" stages. • Focused on expert validation and user testing.
Adaptability to Emerging Paradigms	• Integration of mixed methods. • Incorporation of design-based research principles. • Adaptation to technology-enhanced learning environments.	• N/A
Long-term Research Sustainability	• Encouraged ongoing refinement and adaptation. • Facilitated development of extended research programs. • Promoted sustainable partnerships.	• Focused on completing a specific development cycle. • Less emphasis on long-term program development.
Cultural and Contextual Sensitivity	• Thorough analysis of cultural factors. • Ongoing consideration of cultural implications. • Development of culturally responsive designs.	• Addressed cultural factors in "Define" stage. • Focused on predefined cultural criteria.
Ethical Considerations	• Ongoing ethical reflection throughout the process. • Integration into design and implementation. • Promoted transparency and accountability.	• Addressed ethics in initial planning stages. • Focused on compliance in product development.
Publication and Dissemination	• Encouraged publication from various phases. • Multiple publications from a single project. • Ongoing dialogue and knowledge sharing.	• Focused on publication of final outcomes • Emphasized dissemination of completed materials.
Interdisciplinary Research Potential	• Flexible structure for diverse perspectives. • Encouraged collaboration across fields. • Exploration of complex questions.	• More focused approach for specific contexts. • Less emphasis on diverse frameworks integration.
Alignment with Policy and Reform	• Consideration of broader policy contexts. • Development with policy implications. • Dialogue between research and policy domains.	• Aligned with existing policies. • Emphasized practical implementation within current frameworks.

The Plomp model's approach to educational policy and reform may be more suitable for dissertation research aiming to contribute to broader educational change initiatives. Moreover, the Plomp model's adaptability to various research contexts, its integration of theoretical and practical aspects, and its potential for generating both practical outcomes and theoretical contributions make it a versatile choice for diverse dissertation topics in science education. The model's approach to stakeholder involvement, ethical considerations, and cultural sensitivity further enhances its suitability for the comprehensive and socially responsible research expected at the doctoral level. While the 4D model showed strengths in specific areas, particularly in the development of educational products and materials, its more structured approach and product-focused orientation may limit its applicability to certain types of dissertation research. The Plomp model's broader scope and flexibility appear to offer a more comprehensive framework for the diverse and often complex nature of dissertation research in science education.

These findings suggest that while both models have their merits, the Plomp model emerges as a more reliable, holistic, and adaptable choice for dissertation research in science education

Discussion

The systematic review and comparative analysis of the Plomp and 4D development models in the context of dissertation research in science education have yielded valuable insights into the strengths, limitations, and applicability of these models. The discussion of the findings aims to interpret the results, integrate them with existing knowledge, and explore their implications for future research and practice in science education. One of the key findings of this study is the prominence of the Plomp and 4D models among the various development models used in science education research. The popularity of these models suggests that they have been found effective and suitable for addressing the unique challenges and requirements of development research in this field. The Plomp model, in particular, emerged as a reliable and holistic choice for dissertation research, owing to its comprehensive approach, flexibility, and emphasis on preliminary research and context analysis.

The comparison of the Plomp and 4D models revealed distinct characteristics and strengths of each model. The Plomp model's adaptability to various research contexts and its iterative nature, which allows for continuous refinement and improvement throughout the research process, make it particularly suitable for the complex and evolving nature of dissertation research. On the other hand, the 4D model's structured approach and focus on product development have made it a popular choice for studies aimed at creating and refining educational products and materials.

The suitability of the Plomp model for dissertation research can be attributed to several factors. Its comprehensive approach, which emphasizes thorough problem analysis and context exploration before moving into the design phase, aligns well with the depth and rigor required in doctoral-level studies. The model's flexibility allows researchers to address complex research questions and accommodate unforeseen challenges that may arise during long-term dissertation projects. Furthermore, the Plomp model's iterative nature encourages a holistic view of the research process, which is beneficial for the comprehensive nature of dissertation studies.

The reliability and holistic nature of the Plomp model are supported by its systematic problem analysis, iterative design and evaluation, integration of theoretical and practical aspects, and flexibility in research phases. These characteristics contribute to the model's effectiveness in addressing the unique challenges of dissertation research, such as the need for a deep understanding of the research context, the ability to adapt to evolving research requirements, and the importance of bridging theoretical foundations with practical applications.

The review of the instruments used in development research revealed some variations between the Plomp and 4D models. While there was some overlap in the types of instruments used, the Plomp model tended to incorporate a broader range of assessment tools, particularly those focused on practicality and effectiveness. This finding suggests that the Plomp model may be more suitable for dissertation research that aims to evaluate the impact and usability of educational interventions or products in real-world settings.

The strengths of the Plomp model for dissertation research, as highlighted by the review, include its comprehensive problem analysis, flexibility in research design, integration of theory and practice, iterative refinement, and holistic evaluation. These strengths contribute to the model's effectiveness in addressing the complex and multifaceted nature of dissertation research, which often requires a deep understanding of the research context, the ability to adapt to evolving research requirements, and the need to generate both theoretical and practical contributions to the field of science education. While the 4D model has demonstrated effectiveness in various research contexts, the analysis revealed some limitations that may make it less suitable for certain types of dissertation research. These limitations include a less comprehensive problem analysis compared to the Plomp model, a more rigid structure that may be less accommodating to the evolving nature of some dissertation research projects, and a product-focused approach that may be less suitable for studies exploring broader educational phenomena or theories.

The choice between the Plomp and 4D models often depends on contextual factors, such as research objectives, research scope, time constraints, and researcher experience. Studies focusing on developing specific educational products or materials tend to favor the 4D model, while those exploring broader educational phenomena or theories lean towards the Plomp model. The Plomp model is often chosen for more complex, multi-faceted research projects, while the 4D model is preferred for more focused, product-oriented studies. Time constraints and researcher experience also influence model selection, with the 4D model being favored in situations with tight deadlines and the Plomp model being preferred by more experienced researchers.

The adaptation of development models in research practice highlights the importance of flexibility in addressing the specific needs and challenges of individual research projects. Researchers often modify the chosen model by incorporating additional evaluation phases, integrating elements from other models, or expanding the model to include additional stages. These adaptations demonstrate the need for development models to be responsive to the unique requirements of dissertation research, where unexpected challenges and opportunities may arise throughout the research process.

The impact of model selection on research outcomes is another important consideration. The Plomp model's emphasis on in-depth analysis of the research context and problem, as well as its stronger connections between theoretical frameworks and practical applications, may lead to more substantial theoretical contributions and a deeper understanding of the underlying educational phenomena. In contrast, the 4D model's focus on product development and its effectiveness in creating immediately applicable educational materials may result in more tangible and practical outcomes.

The methodological rigor and validity of the research are also influenced by the choice of development model. The Plomp model's emphasis on triangulation of data sources and methods, iterative validation processes, and continuous reflection and adjustment may contribute to a more robust and reliable research process. The 4D model, on the other hand, provides clear criteria for validity and focuses on expert validation and systematic testing and refinement, which may be particularly suitable for studies aimed at developing high-quality educational products.

The integration of theoretical frameworks is another aspect that differs between the Plomp and 4D models. The Plomp model encourages an explicit connection between theory and design, allows for the evolution of theoretical frameworks, and facilitates new theoretical insights. This approach may be particularly valuable for dissertation research that aims to contribute to the advancement

of educational theories and conceptual frameworks. The 4D model, in contrast, focuses on applying established theories to product development and provides a structured approach to translating theory into practice, which may be more suitable for studies aimed at creating theory-informed educational materials.

Stakeholder involvement is a crucial aspect of development research, and the Plomp and 4D models differ in their approaches to engaging stakeholders. The Plomp model promotes continuous engagement with stakeholders, collaborative problem definition and solution development, and ongoing feedback and refinement. This approach may be particularly valuable for dissertation research that aims to address complex educational challenges and generate solutions that are responsive to the needs and perspectives of various stakeholders. The 4D model, on the other hand, involves stakeholders primarily in the "Define" and "Disseminate" stages and focuses on expert validation and user testing, which may be more suitable for studies aimed at developing products that meet specific technical and usability criteria.

The adaptability of development models to emerging paradigms in educational research is another important consideration. The Plomp model's flexibility and iterative nature make it well-suited to incorporating mixed methods, design-based research principles, and technology-enhanced learning environments. This adaptability may be particularly valuable for dissertation research that aims to explore innovative approaches to educational research and practice. The 4D model, while effective in its structured approach to product development, may be less adaptable to emerging paradigms and research trends.

Long-term research sustainability is another aspect that distinguishes the Plomp and 4D models. The Plomp model's emphasis on ongoing refinement, adaptation, and the development of extended research programs may contribute to the sustainability and impact of dissertation research over time. The model's approach to fostering sustainable partnerships and its potential for generating both practical outcomes and theoretical contributions may lead to more enduring and influential research programs. The 4D model, in contrast, focuses on completing a specific development cycle and may place less emphasis on long-term program development and sustainability.

Cultural and contextual sensitivity is a critical consideration in educational research, particularly in diverse and complex settings such as Indonesia. The Plomp model's approach to preliminary research and context analysis, as well as its emphasis on stakeholder involvement and collaborative problem-solving, may make it more suitable for dissertation research that aims to be responsive to local cultural, social, and educational contexts. The model's flexibility and adaptability may also allow researchers to tailor their research design and methods to the specific needs and challenges of their research setting. The 4D model, while effective in its structured approach to product development, may be less sensitive to cultural and contextual factors and may require additional adaptations to ensure its relevance and effectiveness in diverse educational settings.

The potential impact of development model selection on educational policy and reform is another important consideration. The Plomp model's comprehensive approach, its emphasis on stakeholder involvement and collaboration, and its potential for generating both practical outcomes and theoretical contributions may make it more suitable for dissertation research that aims to inform and influence educational policy and practice. The model's adaptability to emerging paradigms and its potential for fostering sustainable research programs may also contribute to its impact on educational reform efforts. The 4D model, while effective in developing specific educational products, may have a more limited impact on broader educational policy and reform initiatives.

In the context of science education in Indonesia, the Plomp model's strengths and characteristics may make it particularly suitable for dissertation research aimed at addressing the unique challenges and opportunities facing the country's educational system. Indonesia's diverse cultural, linguistic, and socioeconomic landscape requires educational research that is sensitive to local contexts and responsive to the needs and perspectives of various stakeholders. The Plomp model's emphasis on preliminary research, context analysis, and stakeholder involvement may enable researchers to develop solutions that are culturally relevant, socially responsible, and effectively address the disparities in access and quality of education across the country. Furthermore, the Plomp model's adaptability to emerging paradigms and its potential for generating both practical outcomes and theoretical contributions may be particularly valuable for advancing science education research and practice in Indonesia. As the country seeks to enhance its educational system and foster innovation in teaching and learning, dissertation research that employs the Plomp model may contribute to the development of evidence-based, contextually relevant, and sustainable solutions to the challenges facing science education in Indonesia.

The Plomp model's approach to long-term research sustainability and its potential for informing educational policy and reform may also be particularly relevant for the Indonesian context. As the country continues to invest in educational improvement and reform initiatives, dissertation research that employs the Plomp model may generate insights and recommendations that can guide policy decisions and support the implementation of effective educational practices. The model's emphasis on fostering sustainable partnerships and generating enduring research programs may also contribute to the long-term impact and sustainability of science education research in Indonesia. While the 4D model has demonstrated its effectiveness in various research contexts and may be suitable for specific types of dissertation research in science education, its limitations in terms of cultural and contextual sensitivity, adaptability to emerging paradigms, and potential impact on broader educational policy and reform initiatives may make it less suitable

for the complex and diverse landscape of Indonesian education. Researchers considering the 4D model for their dissertation research in the Indonesian context may need to carefully assess its fit with their specific research objectives, target population, and desired outcomes, and make necessary adaptations to ensure its relevance and effectiveness.

Conclusion

The systematic review and comparative analysis of the Plomp and 4D development models in the context of dissertation research in science education have yielded valuable insights into the strengths, limitations, and applicability of these models. The study aimed to provide a comprehensive framework for model selection that can guide researchers in making informed decisions about their research methodologies. By examining the characteristics, applications, strengths, and limitations of the Plomp and 4D models, this research has addressed the gap in the literature and contributed to the advancement of educational research methodologies in Indonesia and beyond. The findings of this study have answered the key research questions and provided evidence-based guidance for researchers, particularly doctoral candidates, in selecting the most appropriate development research model for their studies. The prominence of the Plomp and 4D models among the various development models used in science education research highlights their effectiveness and suitability for addressing the unique challenges and requirements of development research in this field. The comparative analysis of the two models has revealed distinct characteristics and strengths of each model, with the Plomp model emerging as a more reliable, holistic, and adaptable choice for dissertation research.

The Plomp model's suitability for dissertation research can be attributed to its comprehensive approach, flexibility, emphasis on preliminary research and context analysis, and potential for generating both practical outcomes and theoretical contributions. The model's reliability and holistic nature are supported by its systematic problem analysis, iterative design and evaluation, integration of theoretical and practical aspects, and flexibility in research phases. These characteristics contribute to the model's effectiveness in addressing the complex and multifaceted nature of dissertation research, which often requires a deep understanding of the research context, the ability to adapt to evolving research requirements, and the need to generate both theoretical and practical contributions to the field of science education. The study has also highlighted the importance of contextual factors in influencing the choice between the Plomp and 4D models. Researchers should carefully consider their research objectives, scope, time constraints, and experience when selecting the most appropriate model for their dissertation research. The adaptability of development models in research practice has been emphasized, with researchers often modifying the chosen model to suit their specific research needs. This underscores the importance of flexibility in development models, particularly for dissertation research where unique challenges may arise.

The impact of model selection on research outcomes, methodological rigor and validity, integration of theoretical frameworks, stakeholder involvement, adaptability to emerging paradigms, long-term research sustainability, cultural and contextual sensitivity, and potential impact on educational policy and reform have been explored in this study. The Plomp model has demonstrated strengths in these aspects, making it particularly suitable for dissertation research aimed at addressing complex educational challenges, generating innovative solutions, and contributing to the advancement of educational theories, practices, and policies. In the context of science education in Indonesia, the Plomp model's strengths and characteristics make it a valuable tool for dissertation research aimed at addressing the unique challenges and opportunities facing the country's educational system. The model's emphasis on preliminary research, context analysis, stakeholder involvement, and cultural sensitivity aligns well with the diverse cultural, linguistic, and socioeconomic landscape of Indonesia. By employing the Plomp model, researchers can develop solutions that are culturally relevant, socially responsible, and effectively address the disparities in access and quality of education across the country.

The study has also highlighted the potential of the Plomp model in advancing science education research and practice in Indonesia. As the country seeks to enhance its educational system and foster innovation in teaching and learning, dissertation research that employs the Plomp model can contribute to the development of evidence-based, contextually relevant, and sustainable solutions to the challenges facing science education in Indonesia. The model's approach to long-term research sustainability and its potential for informing educational policy and reform make it particularly relevant for the Indonesian context, where educational improvement and reform initiatives are ongoing. While the 4D model has demonstrated its effectiveness in various research contexts and may be suitable for specific types of dissertation research in science education, its limitations in terms of cultural and contextual sensitivity, adaptability to emerging paradigms, and potential impact on broader educational policy and reform initiatives may make it less suitable for the complex and diverse landscape of Indonesian education. Researchers considering the 4D model for their dissertation research in the Indonesian context should carefully assess its fit with their specific research objectives, target population, and desired outcomes, and make necessary adaptations to ensure its relevance and effectiveness.

The findings of this study have important implications for researchers, educational institutions, and policymakers in Indonesia and beyond. Researchers, particularly doctoral candidates, can use the insights generated by this study to make informed decisions about their research methodologies and select the most appropriate development research model for their studies. By leveraging the strengths of the Plomp model and adapting it to the specific needs and contexts of their research, researchers can generate valuable insights, develop innovative solutions, and contribute to the advancement of educational theories, practices, and policies. Educational institutions in Indonesia can use the findings of this study to guide their research programs and support doctoral candidates in conducting rigorous, relevant, and impactful research. By fostering a culture of research that values the strengths of the Plomp model,

such as its emphasis on stakeholder involvement, cultural sensitivity, and long-term sustainability, educational institutions can contribute to the development of evidence-based solutions to the challenges facing science education in Indonesia.

Policymakers in Indonesia can also benefit from the insights generated by this study. By recognizing the potential of the Plomp model in informing educational policy and reform initiatives, policymakers can encourage and support research that employs this model. The findings of dissertation research that uses the Plomp model can provide valuable evidence and recommendations for policy decisions and support the implementation of effective educational practices in Indonesia. Beyond the Indonesian context, this study contributes to the broader discourse on development research methodologies in education. The comparative analysis of the Plomp and 4D models offers insights that may be valuable to researchers in other countries facing similar educational challenges and seeking robust methodological frameworks for their studies. The study highlights the importance of critically examining and comparing different methodological approaches and frameworks, and adapting them to the specific needs and contexts of the research.

In conclusion, this systematic review and comparative analysis of the Plomp and 4D development models in the context of dissertation research in science education have provided a comprehensive framework for model selection and contributed to the advancement of educational research methodologies. The study has highlighted the strengths of the Plomp model, particularly its reliability, holistic nature, and adaptability, making it a valuable tool for dissertation research in science education, especially in the Indonesian context. Researchers, educational institutions, and policymakers can use the findings of this study to guide their research practices, support rigorous and relevant research, and inform educational policy and reform initiatives. By leveraging the strengths of the Plomp model and adapting it to the specific needs and contexts of their research, dissertation researchers in science education can generate valuable insights, develop innovative solutions, and contribute to the advancement of educational theories, practices, and policies in Indonesia and beyond. As the field of science education continues to evolve and new challenges emerge, it is essential for researchers to critically examine and refine the methodological approaches and frameworks that guide their work. This study has underscored the importance of flexibility, adaptability, and contextual sensitivity in development research models, particularly in the context of dissertation research. By engaging in ongoing reflection and dialogue about the strengths, limitations, and potential applications of different research models and methods, researchers can continue to advance the field of educational research and contribute to the improvement of educational practices and outcomes.

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