

Development of a Desmos-Assisted Planar Analytic Geometry Textbook to Support High Order Thinking Skills

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ABSTRACT

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The study focuses on improving higher-order thinking skills (HOTS) in mathematics students using a Desmos-assisted planar analytic geometry course. Analytic geometry, which is essential for understanding geometric properties using analytic methods, requires students to develop problem-solving, analysis, assessment, and creativity abilities. However, current educational practices fall short of acquiring these abilities due to insufficient instructional techniques, textbooks, and a lack of integration with information and communication technologies. To address these shortcomings, the study proposes a Desmos-assisted textbook meant to increase students' HOTS through the use of interactive Desmos platform tools such as graphic depiction, experimentation, simulation, and collaborative learning. The textbook development followed the PLOMP model, which included preliminary research, prototyping, and assessment phases, ensuring the textbook's validity and practicality through reiterated evaluations. The findings show that the textbook is highly valid and practical for instructional purposes, improving students' knowledge of mathematical concepts and ability to engage in HOTS processes. Despite some difficulties with HOTS-related practice questions, generally student feedback was positive, emphasizing the textbook's function in supporting a deeper understanding of analytic geometry and encouraging problem-solving skills. The study indicates that integrating technology such as Desmos into mathematics education can greatly contribute to the development of students' HOTS, and recommends its use in teaching techniques as well as additional research on its implementation in educational contexts.



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A. INTRODUCTION

Analytic geometry is a mandatory course for mathematics students. This subject is a branch of mathematics that studies the relationship between geometric objects using analytic methods, especially by utilizing the coordinates of points within a coordinate system (Khalil & Khalil, 2019). It is crucial for students because it allows them to analyse and understand the geometric properties of these objects mathematically (Hua et al., 2019). One of the goals of learning analytic geometry in higher education is to help students understand concepts, have effective problem-solving skills, and develop the ability to participate in higher order thinking skills (HOTS) (Marasigan, 2019). Anderson and Krathwohl (Samo, 2019) define high-order thinking as (1) analyzing; (2) assessing; and (3) creating. Analyzing entails the cognitive processes of attribution, organization, integration, and validation. Evaluating entails investigating, criticizing, hypothesizing, and experimenting. Creating includes generating, designing,

producing, and planning. These are classified as high-order since they encompass all non-algorithmic cognitive abilities.

HOTS refers to an individual's logical thinking, reasoning, analysis, evaluation, creation, problem solving, and decision-making abilities. Brookhart Setiawati et al. (2019) defines HOTS as the process of transfer (learners' ability to apply what they have learned to new situations without direction or hints from educators or others); HOTS also includes critical thinking. HOTS is a component of both creative and critical thinking skills. When students can engage both skills, it indicates that they have successfully employed high-order thinking skills. This ability is extremely useful for students who want to be competitive in today's world (Akpur, 2020; Dondi et al., 2021). However, reality shows that the HOTS of Indonesian students has not yet reached a suitable level. This is aligned with the mention Samo (2019) that the HOTS of students, particularly in analytic geometry, remains low. Many students struggle to answer issues that require high-order thinking or problem-solving (Kholid et al., 2022; Masfingatin et al., 2021; Purwati et al., 2022).

Furthermore, Samo (2019); Wang (2021) indicates that this condition is produced by a number of variables. For example, analytic geometry instructions do not prioritize the development of high-order thinking skills. Second, textbooks do not support the development of advanced thinking skills. Third, there is no integrated media with information and communication technology (ICT) used in learning, which can help students understand the subject and facilitate problem-solving activities. Every student is capable of thinking, but the majority of them require encouragement, instruction, and assistance in the process of high-order thinking (Fatimah et al., 2019). This skill can develop when someone is confronted with uncommon difficulties, conditions, or phenomena that they have never faced before. As a result, in order to increase students' high-order thinking skills in analytic geometry classes, researchers are going to conduct analytic geometry instruction that is centered on developing students' HOTS and aided by technology.

Regarding the use of technology, researchers choose to use Desmos. Desmos is an online mathematics platform that offers a variety of interactive tools for math education. This platform can be used to teach mathematics and analytic geometry in a variety of ways and has been identified as very engaging (Ebert, 2014). Here are several applications of Desmos in mathematics and analytic geometry learning: (1) Graphic Visualization: users may simply and interactively build graphs representing mathematical functions. This allows pupils to see the relationship between algebra and geometry more clearly. Desmos can be used in analytic geometry to depict graphs of line equations, circles, and other curves, hence improving conceptual understanding; (2) Exploration and Experimentation: Desmos allows students to experiment with parameters in mathematical functions; (3) Simulation: Desmos also offers mathematical simulation tools, which enable students to conduct virtual experiments within a mathematical setting. For example, in analytic geometry, students can use Desmos to create and manipulate geometric objects such as triangles, rectangles, and other geometric forms; and (4) Collaboration and Project-Based Learning: Desmos enables students to collaborate on mathematical learning. They can share graphs, problem-solving techniques, and mathematical projects with other students or teachers (Chorney, 2022).

Moreover, Desmos has a unique feature: it has slides that can help teachers provide student learning activity paths (Gulli, 2021). Desmos allows learners to examine graphs, tables, and significant statements all on one screen, making it easier for them to solve problems (Handayani et al., 2017; Montijo, 2017). Desmos' function for adding pictures or images to the Cartesian plane is also said to be easier and more practical (Chechan et al., 2023). Desmos has been shown in prior research to improve learners' HOTS. According to (Lawalata & Pratini, 2023; Simanungkalit & Rajagukguk, 2022), using Desmos can help students enhance their critical thinking skills when working with Pythagorean. Furthermore, several research suggest that using Desmos can improve students' comprehension of function (Chechan et al., 2023), linear programming (Safarini & Herman, 2020). None of these studies employed Desmos to train learners' HOTS in planar analytic geometry.

As a result, further study into the development of a Desmos-assisted planar analytic geometry textbook is necessary. Students that use Desmos in study are intended to gain a deeper comprehension of mathematical topics, improve their high-order thinking skills, and acquire good problem-solving abilities. The purpose of this study is to determine the validity and practicality of a Desmos-assisted planar analytic geometry textbook produced to support students' HOTS.

B. METHODS

This research is a design research study of the validation study type. The research subjects were 24 students of 2nd grade mathematics education. The development research utilizes the PLOMP model (Plomp, 2013). The phases of development, criteria, and a brief description of the activities of this model can be seen in Table 1.

Table 1. The PLOMP Development Model

Phase	Criteria	Short description of activities
Preliminary research	Emphasis mainly on content validity	Examination of existing literature and (past and/or current) projects that explore questions akin to those posed in this research. This leads to the creation of (guidelines for) a foundational framework and initial design for the intervention
Development or Prototyping phase	Initially: consistency (construct validity) and practicality. Later on, mainly practicality and gradually attention for effectiveness.	Development of a sequence of prototypes that will be tried out and revised on the basis of formative evaluations. Early prototypes can be just paper-based for which the formative evaluation takes place via expert judgments resulting in expected practicality
Assessment phase	Practicality and effectiveness	Evaluate whether target users can work with intervention (actual practicality) and are willing to apply it in their teaching (relevance & sustainability). Also whether the intervention is effective.

Based on Table 1, during the preliminary research stage, researchers conduct a literature review and analysis concerning the needs for a Desmos-assisted planar analytic geometry textbook in supporting students' HOTS. This forms the basis for creating the textbook. The next stage is the development or prototyping phase, where researchers test the validity of the

created textbook and make revisions. The final phase is the assessment phase, where researchers evaluate the practicality and effectiveness of the developed textbook and make necessary revisions. This research's development is limited to the practicality testing stage. The formative evaluation used in this model refers to Tessmer (Nieveen & Folmer, 2013), with stages presented in Figure 1.

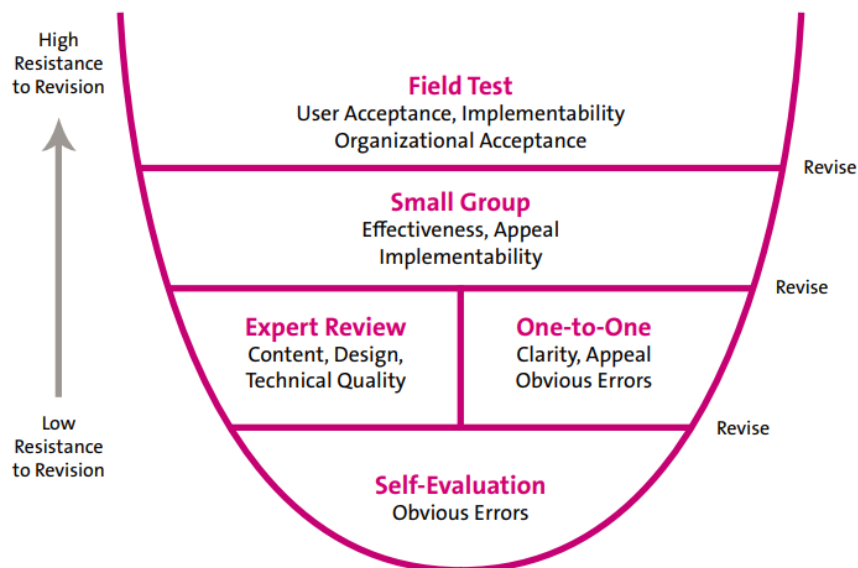


Figure 1. Formative Evaluation Illustrated

The data collection techniques used in this research were validation assessment sheets, response questionnaires, and HOTS tests. This validation assessment sheet is addressed to experts and is used to measure the validity of the textbooks produced. The assessment given on this sheet determines whether the textbooks and lecture tools produced are suitable for testing without revision, with revisions, or not suitable for testing. The response questionnaire is used to determine student responses related to the practicality of textbook. The practicality of textbooks is seen in the convenience and helpfulness of students in the learning process. A test is several questions that must be answered or responded to to measure a student's level of ability or to reveal certain aspects. Data were analysis descriptive qualitatively to obtain textbooks that meet the criteria of being valid, and practical.

C. RESULT AND DISCUSSION

The development of this textbook was carried out through three main phases, namely the preliminary research (preparation and design stage), development or prototyping phase (self-evaluation, expert review, and one-to-one), and the assessment phase (small group and field test). These phases are description bellows:

1. Preliminary research

Activities at this preliminary research include research preparation, namely analysis and design of Desmos-assisted planar analytic geometry textbook. Analysis at this stage include: (1) Curriculum analysis; the results of the curriculum analysis show that the Mathematics Education uses a "Merdeka" curriculum starting from 2021. The planar analytic geometry

topics are: (a) coordinate systems; (b) circles; (c) parabolas; (d) ellipses; and (e) hyperbole; (2) Needs analysis; The results of the analysis carried out by researchers showed that the book available was analytic geometry with GeoGebra integration, no one had used the Desmos application. Textbook that can train students' HOTS skills are very necessary because they are in line with the demands of the 21st century skills that students must master; (3) Analysis of student characteristics; Based on the results of the analysis of student characteristics, according to Piaget learning theory, students at this age stage are able to use their reasoning on something abstract. This shows that student logic at this level is appropriate to be able to participate in HOTS-based learning.

At this phase, the researcher also succeeded in designing a Desmos-assisted planar analytic geometry textbook which developed to train HOTS students. The design carried out includes: (1) preparing the framework for the HOTS component in textbook. The book consists of 3 parts, namely: (a) the preliminary of the book which consists of the cover, foreword and table of contents; (b) the contents of the book which is divided into 5 chapters on planar analytic geometry textbook; and (c) the end of the book which contains bibliography; (2) collection and selection of book references; and (3) preparing instruments to measure the achievements of planar analytic geometry textbook in training students' HOTS.

2. Development or Prototyping Phase

Activities at this prototyping phase is formative evaluation to test the validity of the textbook. At this phase the evaluation conducted are: self-evaluation, expert review, and one to one.

a. Self-Evaluation

At this stage the researcher re-evaluated the textbook that the researcher had designed both in terms of content and language used. Self-evaluation is also carried out to check whether the textbooks prepared contain HOTS indicators. The resulting Desmos-assisted planar analytic geometry textbook was called the first prototype, and was then submitted to experts for validation.

b. Expert Review

The first prototype design is given to experts for validation. The experts involved as validators in this research consisted of 2 lecturers and 1 teacher. At this stage, the validity of the textbook is carried out qualitatively, and its suitability is checked with the HOTS indicators and the language used. At this stage, input is obtained from the validator in the form of comments about the textbook.

c. One-to-one

At this stage, the first prototype was tested on 3 students of 3th grade mathematics education. The three students had high, medium, and low mathematics abilities. This stage held on August 23, 2023. The result of one-to-one test can be seen in Table 2.

Table 2. Student Comments at One-To-One

Date	Validator	Comments
23 August 2023	ASY	1. Question number 1 regarding the circle of sentences is difficult to understand 2. I don't understand question number 9 about circles
23 August 2022	AP	1. The activity of matching circle images with their equations is quite time consuming 2. Provide an option to view completion steps on Desmos activities
23 August 2022	AST	1. Some questions and activities have high complexity

Validator comments and suggestions at the expert reviews stage as well as comments and suggestions from students at the one-to-one stage are important information for researchers which will be used as material for revising the first prototype. This revision was carried out to correct deficiencies in the first prototype in order to produce a better second prototype. Changes before and after revision based on validation and one-to-one results are generally presented in Table 3.

Table 3. Before and After Revision

No	Before Revision	Validator Comments and One to One	After Revision
1.	Writing the words "Collect Coconuts"	a) What do the words "gather coconuts" mean? b) There are no instructions yet	Additional explanations and activity instructions are provided.
2.	Learning objectives	a) Add learning objectives for drawing parabola graphs on page 75 b) Add the learning objective of describing hyperbolas on page 154	Learning objectives on circle and hyperbola material were added
3.	Exercise	For each practice question, give the HOTS level code	The HOTS level in the practice questions is written at the end of the sentence

After going through the expert review and one-to-one stages, the first prototype was revise to become the second prototype. This second prototype is then reassessed by the validator for review via a validation sheet. The results of the validator's assessment of the second prototype can be seen in the following Figure 2.

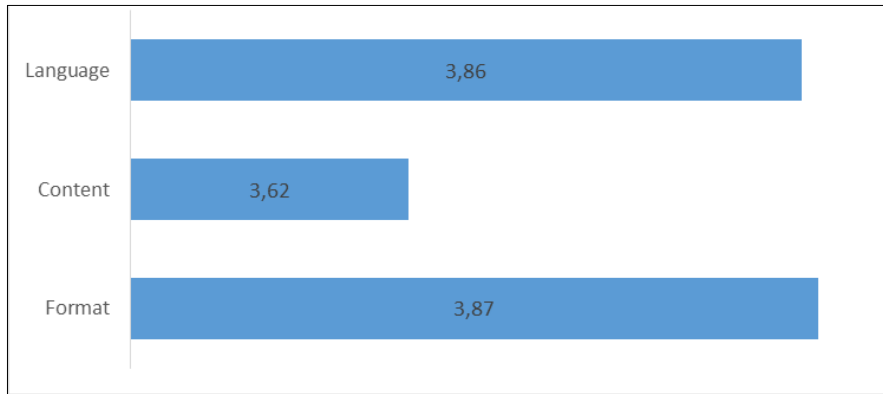


Figure 2. Validator Assessment Results

Based on the validator's assessment, the total average was 3.71, with a very valid category. Thus it can be concluded that the second prototype is suitable for further testing. Based on the textbook assessment, an average score of 3.71 out of a maximum score of 4.00 was obtained with a very valid classification. This shows that the textbook developed meets the requirements for developing a valid textbook (Siregar, 2018). Providing texts alone is not enough, because students must actually use textbooks and teaching staff know how to incorporate the material into learning process (Utami et al., 2020).

3. Assessment Phase

This phase is intended to see the practicality of the second prototype. It is tested on 24 students of 2nd grade mathematics education. Small group activities were held on August 28 to September 11, 2023. Students complete the planar analytic geometry activities that are available in the textbook using Desmos. The example of students' activities in Desmos can be seen in Figure 3.

Settle a dispute.

Alma's solution to Challenge #3 is shown in purple.

Alma tells Axel that she can add a fifth circle to the pattern by using the next point, $(11,5)$, and using the radius of 2 to write the equation below.

$$(x - 11)^2 + (y - 5)^2 = 4$$

Axel thinks that Alma made a mistake.

Who is correct?

Figure 3. Example of Students' Activities in Desmos

After the learning process, the researcher conducted written interviews and asked students to fill out a response questionnaire. This interview was used to find out students' difficulties. The results of the interviews at this phase were also used for revising the textbook. Student comments at the small group stage can be seen in Table 4.

Table 4. Student Comments at the Small Group

Date	Name	Comments
13 September 2023	SW	The practice questions have been made easier and there are more curve-making questions
13 September 2023	AS	So that the example questions are more varied and equipped with more detailed explanations
13 September 2023	ART	The questions shouldn't be too difficult and should be made sequentially from easiest to most difficult

The comments and suggestions given by students at the small group are important information that researchers need to revise the second prototype. Based on student suggestions and comments, there were several questions that were incomprehensible or confusing. Therefore, the researcher re-checked some of the practice questions and made revisions. The examination results for practice questions are arranged sequentially according to the difficulty level of the questions. At this phase the researcher also evaluated the practicality of the textbook. This is obtained from the response questionnaire that has been filled out by students. The questionnaire consists of 13 statements on a scale of 1-4. The results of the questionnaire can be seen in Figure 4.

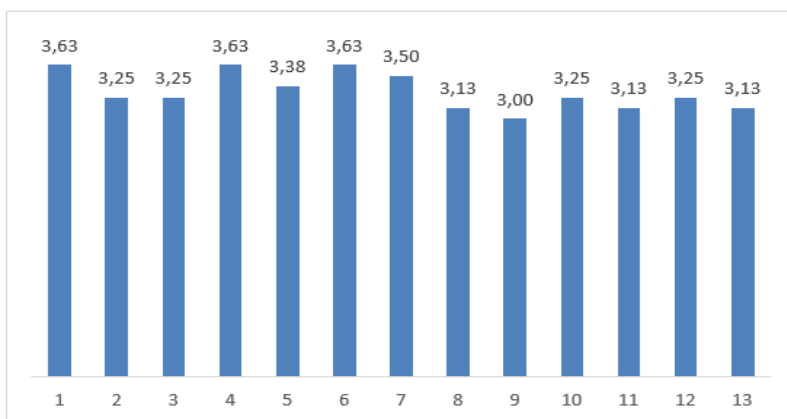


Figure 4. Results of Student Response Questionnaires

The highest score is in statements 1, 4, and 6. This shows that the majority of students think that this textbook helps students understand analytic geometry material, the example questions and practice questions in the textbook are able to develop HOTS abilities, and learning using Desmos provides new experiences for students. However, the lowest score was in statement 9, which stated that the problems in the practice questions were difficult to understand. This is because the questions contain HOTS elements consisting of levels C4 (Analysing), C5 (Evaluating), and C6 (Creating).

Based on the results of this response questionnaire, it is known that the average student response to using the Desmos-assisted planar analytic geometry textbook is 3.32. Thus, this textbook can be categorized as practical. Based on the questionnaire responses given by students, a score of 3.63 was obtained from the maximum score in the practical category. This shows that textbooks help and make it easier for students to understand the material and develop HOTS skills.

The next result of student responses is that students feel that the practice questions are difficult to do. This is because the example questions and practice questions are prepared based on the HOTS indicator. These student difficulties are caused by students still not being familiar with critical thinking practice questions that require explanations, algorithms, generalizations, and problem solving. This feeling of difficulty in learning mathematics is due to students' misconception and low critical thinking skills (Ancheta, 2022; Anggara & Wandari, 2021; Barut & Retnawati, 2020).

D. CONCLUSION AND SUGGESTIONS

Based on the results of research regarding the development of the Desmos-assisted planar analytic geometry textbook for supporting HOTS that has been carried out, it can be concluded that: (1) Desmos-assisted planar analytic geometry textbook for supporting student's HOTS which was developed based on the PLOMP development model was declared very valid as shown by the average score of 3.71 out of a maximum score of 4. (2) Desmos-assisted planar analytic geometry textbook to support student's HOTS which was developed is stated to be practical as indicated by the average score of 3.63 out of a maximum score of 4. Moreover, the researcher can offer the following recommendations: (1) for future research, this textbook can be implemented in lectures, in order to see the effectiveness; and (2) It is recommended for educators to utilize the textbook produced in this study as a learning resource to train students' HOTS abilities and to be proactive in integrating technology into mathematics teaching.

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