

## Promoting Mathematical Literacy Using Desmos Polygraph

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### Abstract

Language plays a fundamental role in the teaching and learning of mathematics. Students rely on their literacy skills to comprehend problem-solving situations before applying their mathematical knowledge. Unfortunately, there have been numerous reports of illiteracy, particularly in the area of communication, which is one of the most important skills in mathematical literacy. The students' lack of experience connecting formal mathematical language with their everyday language is one factor contributing to their communication illiteracy. To address this issue, the current study uses Desmos Polygraph as a tool to promote mathematical literacy by encouraging a thorough understanding of formal language. Desmos Polygraph's effective use encourages students to use formal language and understand the relationship between formal and informal language. This study, on the other hand, is solely concerned with analyzing the language used in the activity. Further research could assess the student-teacher interaction during the Desmos Polygraph activity to determine other potential in enhancing mathematical literacy.

**Keywords:** mathematical literacy, formal language, Desmos, Desmos Polygraph

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### Introduction

The use of language in mathematics instruction and learning is becoming increasingly important. Language has enabled access to understanding concepts and providing mathematical instruction. Furthermore, students' mathematical performance success can be predicted by their general knowledge of how to use language (Jourdain & Sharma, 2016; van der Walt et al., 2009). The more frequently students understand and utilize mathematical language, the better performance of students in mathematics.

National Research Council (2001) elaborated that there are five strands in mathematical proficiency encompassing (a) conceptual understanding, (b) procedural fluency, (c) strategic competence, (d) adaptive reasoning, and (e) productive disposition. It is critical to foster language comprehension to not only comprehend the concept but also to justify and communicate the reason effectively. All four strands (a-d) are interconnected together with the use of language, because one student can grasp the concept, know how to compute fluently by following the proper procedure, and there is a need for them to justify and communicate the appropriateness of the procedure. Additionally, cultivating a productive disposition toward mathematics, which entails believing that mathematics is meaningful and useful, is accomplished through active engagement and continuous communication using Mathematics. Furthermore, Riccomini et al. (2015) defined mathematics proficiency as the integrated connection and combination of concepts, procedures, problem-solving, and language. Both the NRC (2001) and Riccomini (2015) definitions of mathematical proficiency emphasize the importance of language in learning mathematics.

Language comprehension plays a crucial role in the process of learning mathematics, especially in problem-solving (Doyle, 2005). This connection between language and mathematics is evident in the emphasis on literacy skills, which focuses on reading, writing, speaking, and listening, all with the objective of achieving specific objectives. Individuals with strong literacy skills have certain characteristics, such as the ability to persuade others of the accuracy of the information, highlight key points, effectively explain concepts, and transform ideas into different forms of language (Gardner, 2011). Recognizing the significance of literacy in mathematics, it becomes essential to promote mathematical reading, writing, and discourse as a means of improving problem-solving skills (Beaudine, 2018; Hillman, 2014). NCTM emphasizes the link between literacy and Mathematics in their Connection and Communication standard (Altieri, 2009), while the OECD has focused on the relationship between mathematics and literacy through PISA Mathematical Literacy, (OECD, 2018). Both of them, as well as many researchers, believe that by combining mathematics and literacy, not only the way to comprehend the problem but also the way to communicate the strategy to solve the problem, can be enhanced (OECD, 2018; Ojose, 2011; Sumirattana et al., 2017).

Individuals who are mathematically literate can estimate, comprehend facts, solve everyday problems, reason in numerical, graphical, and geometric contexts, and communicate effectively using mathematics (OECD, 2018). These abilities and knowledge are critical in today's society. As a result, the OECD established the PISA test to ensure that 15-year-olds who have completed compulsory schooling have these skills, including mathematical literacy.

The most recent PISA Mathematics 2018 results revealed that Indonesia is at level 2 out of 6 levels (Schleicher, 2019). Indonesia received a score of 379, while the average OECD member score is 489. Indonesia's PISA Mathematics score remains below average. Although the PISA Mathematics Framework has established six levels of mathematics proficiency, all OECD members can only reach level four. Levels 5 and 6 represent the ability to mathematically communicate their actions as follows:

***“Level 5: ..... They begin to reflect on their work and can formulate and communicate their interpretations and reasoning”.***

***Level 6: “.....can reflect on their actions, and can formulate and precisely communicate their actions .....”.***

Furthermore, mathematical communication competency is essential because anyone learning or practicing mathematics must engage in receptive or constructive communication about mathematical matters. It can be accomplished by attempting to comprehend written, oral, figurative, or gestural mathematical communication, or by communicating one's mathematical ideas and reasoning to others in similar ways. Furthermore, communication is one of the 21<sup>st</sup> century competencies embedded in the PISA mathematics literacy assessment (OECD, 2018). It will be required of the student for him or her to recognize and comprehend a problem situation. Reading, decoding, and interpreting statements, questions, tasks, or objects allows the student to form a mental model of the situation, which is an important step in comprehending, elaborating, and formulating. During the solution process, it may be necessary to summarize and present intermediate results. Later, once a solution has been discovered, the problem-solver may need to communicate the solution to others, along with an explanation or justification (OECD, 2018).

Mathematical communication competence in mathematical literacy emphasizes the significance of formal and technical language and multiple mathematics representations (Stacey & Turner, 2015). Selecting, interpreting, translating between, and employing a variety of representations, as well as using formal and technical mathematical language to capture a situation, interact with a problem, or present one's work, may be required. Several studies also discovered that students frequently make literacy mistakes before attempting to use their mathematical abilities. These literacy errors are mostly related to communication issues, such as describing a situation or presenting a solution (Fitriani et al., 2018; Schüler-Meyer et al., 2019; Simpson & Cole, 2015; Thompson & Rubenstein, 2014). Because their everyday language differs from mathematical language, students are perplexed when it comes to selecting the appropriate mathematical representation and formal language to describe the situation (Simpson & Cole, 2015). This problem is associated with the mathematical literacy challenge, which is the multimodal formulation (i.e., language, mathematical symbolism, and images) of mathematical knowledge and the complex linguistic structures found in mathematical discourse (O'Halloran, 2015). Furthermore, this research's pre-study survey reveals that students with high scores in certain mathematical concepts do not guarantee that they have consistently used precise mathematical formal language in work. To avoid confusion, it recommends the practice of instruction that promotes the consistent use of formal mathematical language by bridging it into everyday language.

The objective of this research is to introduce the Desmos Polygraph activity as a tool for encouraging the consistent use of mathematical formal language and its relationship to everyday language. Desmos Polygraph is a Desmos platform activity that is designed to engage students in mathematical conversation. Students are paired up for this activity, with one acting as the picker and the other as the guesser. There are sixteen cards with various mathematical representations related to a specific topic. The picker selects one card, and the guesser attempts to identify it by asking questions.

Students are encouraged to describe mathematical representations using formal language when using Desmos Polygraph, allowing them to observe the connection between everyday language and formal mathematical language. This practice also allows students to interact with and comprehend the reasoning of their peers. By consistently implementing these practices, the mathematics classroom transforms into a community of mathematical discourse in which students and teachers collaborate to construct mathematical knowledge and improve mathematical literacy (Thompson & Rubenstein, 2014)

This study acknowledges the significance of using Desmos Polygraph and its relationship to mathematical literacy, an aspect that previous research has not extensively emphasized (Caniglia et al., 2017; Chorney, 2022; Danielson & Meyer, 2016). The studies by Caniglia et al., (2017) and Danielson and Meyer (2016) used Desmos Polygraph to strengthen the students' oral language, but the connection to the mathematical literacy process was not discussed when students needed to formulate, employ, and interpret the information. Furthermore, the study by Chorney (2022) focuses more on how to integrate Desmos in the classroom to see the challenges in crafting the knowledge. This study aims to shed light on the importance of incorporating this tool into educational practices by investigating the potential of Desmos Polygraph in enhancing mathematical understanding and communication, two aspects of mathematical literacy. As a result, the following research questions are proposed:

1. How is the development of formal language acquisition when utilizing Desmos polygraph activity in the classroom activities?
2. How do Desmos polygraph activities help to promote mathematical literacy?

### **Methods**

This study employed a content analysis technique. Content analysis is a suitable technique as it allows the researcher to examine the communication that occurred (Fraenkel et al., 2018). Three classroom meetings were conducted with 11th grade mathematics students who had finished studying limit and continuity. Students were divided into three groups based on their level of competence, as determined by their most recent Limit and Continuity assessment scores: High competence for those who received an A, Middle competence for those who received a B, and Low competence for those who received a C. Students used the Desmos polygraph in the following three meetings, which could involve multiple sessions, with 15 minutes of discussion following each session. Students were informed prior to the activities that they would be divided into three groups (A, B, and C), but the reason for grouping based on competence was not stated. To ensure pairings among students of the same competence level, three consecutive Desmos polygraph codes were utilized.

The first research question is concerned with the progression of formal language acquisition when using the Desmos polygraph. The recorded responses on the Desmos polygraph teacher dashboard will be analyzed to answer this question. The terms in the questions are classified into two categories: formal language and everyday language. A mathematical formal language question is one that contains a mathematical term. During the three-day activities, the frequency of formal language occurrence is then counted. Analyzing data by looking at the frequency is a common practice in content analysis techniques (Fraenkel et al., 2018). The researcher further examined the trends, such as the most commonly used mathematical formal language on a daily basis by different competence levels. The researcher summarized the terms used, including formal and informal (everyday language), and informed the teacher so that the teacher could emphasize the material that students had learned to bridge the gap between everyday and formal language. Finally, the researcher discusses how the development of formal language acquisition differs depending on the three levels of competence.

The second research question investigates how the Desmos polygraph aids in the promotion of mathematical literacy. The qualitative descriptions of the Desmos polygraph activities will be employed to determine which activities align with the PISA Mathematics framework, with a focus on the communication component. The activities are evaluated utilizing the framework outlined below:

Table 1  
*Content, Process, and Context of Desmos Polygraph Activity based on PISA Mathematical Literacy Framework (OECD, 2021)*

Content	Process			Context
	A. Formulating	B. Employing	C. Interpreting	
Change and relationship	A1. Translating a problem into mathematical language or a representation			Scientific
	A2. Understanding and explaining the relationships between a problem's context-specific language and the symbolic and formal language required to mathematically represent it;	B.1 Using and switching between different representations while finding solutions	C1. Interpreting information presented in graphical and/or diagram form	

### Result and Discussion

#### Number of Success

Students were divided into three distinct competency levels during the meetings: low, medium, and high. Participants in each group were paired to participate in the Desmos polygraph activity. One student selected a mathematical image, while the other asked yes/no questions to guess which representation was chosen. The guesser correctly recognizing the chosen mathematical representation determined the activity's success. The Desmos teacher dashboard displayed the number of successful pairs as well as a list of questions asked. Figure 1 depicts the number of victories from Day 1 to Day 3.

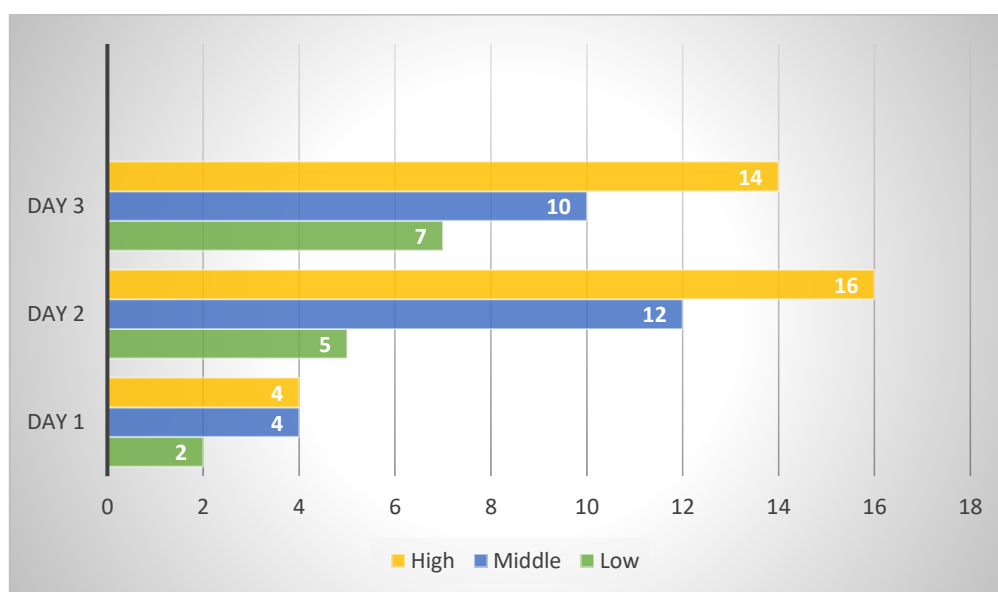


Figure 1. The Number of Success of Desmos Polygraph from Day 1-3.

Regardless of competence, the number of successes increases from Day 1 to Day 3. On Day 3, it became clear that the most successful pairs were made up of students with high levels of competency, whereas on Day 1, the proportions of success were nearly equal across the three competence levels. While the number of successes indicated the ability of the pairings to identify the chosen image, it does not always indicate progress in formal language acquisition. To further investigate this, we are categorizing the terminology used in the questions to determine the extent of formal language acquisition.

### Formal Language Acquisition

We counted how many formal languages were used during the questioning activity to guess which picture was chosen at each meeting. The result is illustrated in Figure 2.

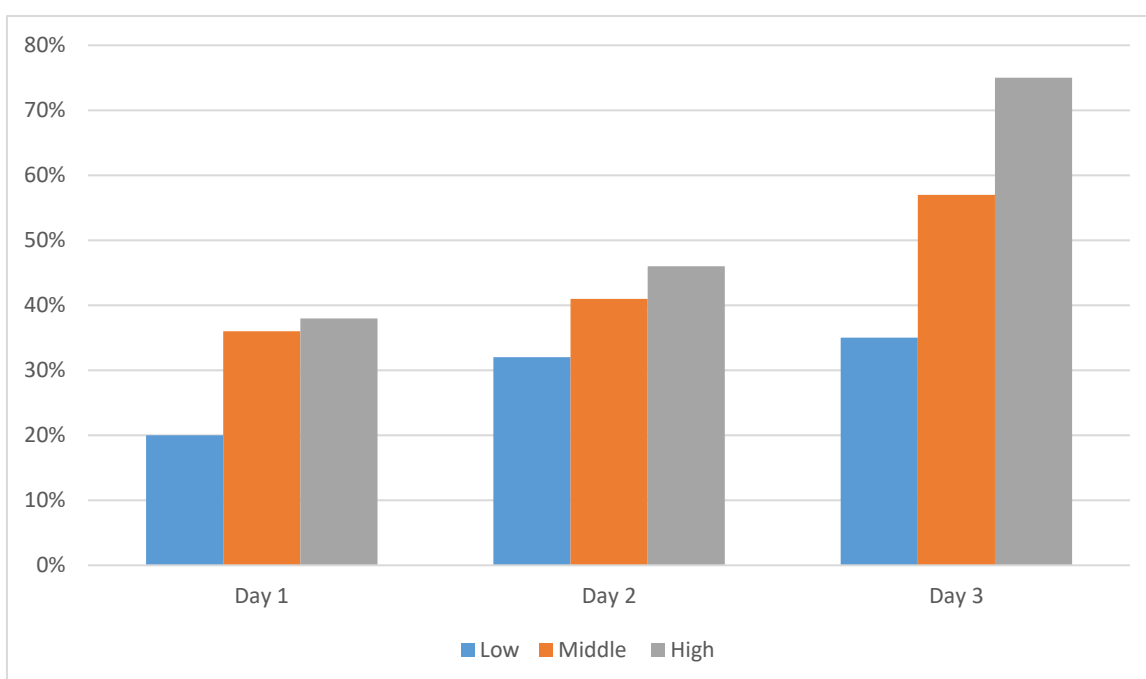


Figure 2. The Trend of Formal Language Acquisition in percentages.

The figure demonstrates that on day one, the formal language acquisition used by all three groups is nearly identical. The highly competent group, on the other hand, quickly adopts the use of formal mathematical language. Although low competence is slow to adopt formal mathematics vocabulary, there is evidence of a shift in how they select the appropriate words to depict a mathematical representation. Table 2 compiles the most formal language used over three days.

Table 2  
*The Most Formal Language Used*

Day	Level of Competence		
	Low	Middle	High
Day 1	passes (0,0)	Y value approaches a certain value at $x=a$	The line crosses the x-axis at point (a,b) passes (0,0)
	function continues	function value defined	limit exists
Day 2	passes (0,0)	passes (0,0) limit exists	function continues function discontinues
	function continues	function value defined	limit exists
Day 3	passes (0,0)	passes (0,0) limit exists	function continues function discontinues
		y value approaches a certain value at $x=a$	passes (0,0) asymptote
			function value undefined

The development of formal language acquisition observed from Table 2 is the result of a three-day activity that combined the use of Desmos Polygraph with intensive discussions between teacher and student to build a bridge between the everyday language they used to describe the image and the formal mathematical language. Table 3 summarizes the relationship between informal and formal language during the teacher-student discussion.

Table 3  
*Everyday Terms vs Formal Language*

Everyday Term	Formal Language
“garis menyambung”	Function continues
Break apart in the middle of the graph	Function discontinues
The graph has 3 lines	Function discontinues/left limit $\neq$ right limit/the function value is undefined
Point outside of the line	Limit value $\neq$ function value
There is hole	Limit exists, but function value undefined
Graph has a black dot on the graph	The function value is defined

This finding is consistent with Simpson and Cole's (2015) findings that the higher the students' competence, the faster they acquire formal language. Furthermore, the greater the acquisition of formal language and exposure to the relationship between formal and informal language, the greater the development of conceptual knowledge (Simpson et al., 2014). Furthermore, as Mathematics is also developed through social and cultural activity, there is an

urgency to bridge the context of mathematics with everyday activities (Alex et al., 2021; Solomon, 2008). It should be highlighted that using Desmos activity should be followed by active discussion (Haryani & Hamidah, 2022). The Desmos polygraph activity, followed by discussion, consistently assists students in bridging the gap between everyday language and formal mathematics language. To build more mathematical sense and elaborate the clarification of the concept meaning, it is necessary to engage in a complex process of crossing over or code-switching between formal and informal language and creating a bridge between them (Solomon, 2008).

### **The PISA Process Indicator**

As demonstrated in Table 1, the PISA process indicator used in this study focuses specifically on the communication component. The PISA process indicator will be employed to evaluate the Desmos polygraph activities. Students are paired in the Desmos polygraph activity, with one serving as the picker and the other as the guesser. There were 16 mathematical representations of Limit and Continuity, and the picker chose one while the guesser posed questions to guess the chosen image.

The guesser who formulated the questions by selecting the appropriate formal language to translate the symbol or mathematical figure was successful in achieving the A1 process indicator. Students must identify distinguishing characteristics of the representations and use them in their questions in the Desmos polygraph activity. Students who recognize the opportunity to apply mathematical content by using appropriate mathematical terminology demonstrate proficiency in question formulation (OECD, 2021). Students may not realize that the problem can be solved using mathematics if they focus solely on the physical characteristics without connecting them to the mathematical content they have learned. For instance, Student A's question demonstrates a lack of understanding that the graph's characteristics can be linked to the concepts of limit and continuity. Student B, on the other hand, recognizes that a graph breaking apart can be related to the continuity concept.

**Student A: “Does the graph break apart?”**

**Student B: “Is it a continuous function graph?”**

Both the guesser and the picker meet the A2 indicator after each round of discussion with the teacher. The Desmos polygraph activity allows students to review and identify reasons for unsuccessful pairings. More information about this indicator will be presented in a separate scholarly publication.

The picker then achieves the B1 indicator by correctly responding to the guesser by translating the question "Is the graph continuous?" back to the chosen mathematical representation (see figure where a chosen image is highlighted in a blue box).



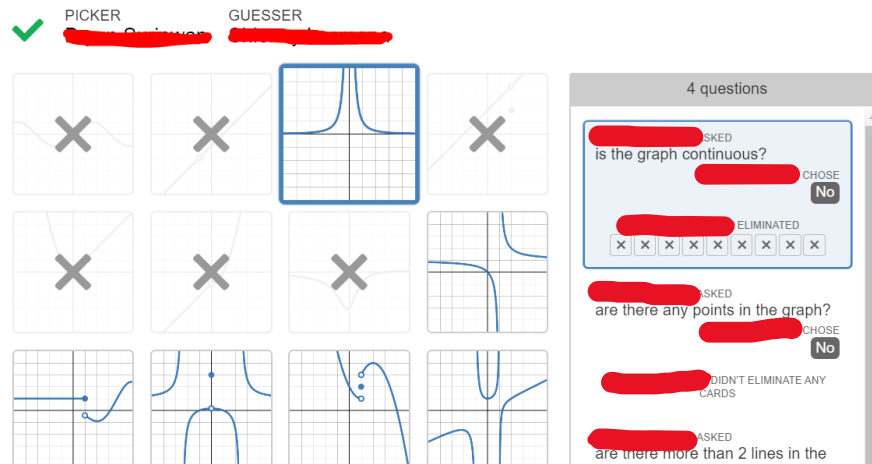


Figure 3. The Situation on Desmos Polygraph which Tells about B1 and C1 Indicator.

Finally, during this polygraph activity, the C1 indicator is attained by the guesser, when they correctly interpret the answer from the picker into the decision on which representation needs to be eliminated. Figure 3 showed us how the picker said no, answering the question, “Is the graph continuous?”. The guesser then interprets the no-answer to the decision on eliminating the representation of the continuous graph.

This activity concentrated on the PISA knowledge areas where students have the most difficulty (PISA, 2018). This practice can help students incorporate everyday language into formal languages, such as "*garis menyambung*" (connected line) to "*fungsi kontinu*," (continuous function). Desmos Polygraph's method provides multiple representations of mathematics and allows students to switch between them, assisting them in developing their formal language. This result is aligned with the study of Herbel-Eisenmann (2002) which used multiple representations to build the students' formal language. Desmos polygraph also improves students' mathematical flexibility when translating mathematical images to formal language or vice versa. When it comes to problem solving, flexibility is essential (Haryani, 2020). Furthermore, because mathematical literacy emphasizes the importance of problem-solving and communication, this practice encourages students to engage in mathematical discourse (Casey & Ross, 2022; OECD, 2021; Ojose, 2011; Ripley, 2013; Wilkinson, 2019).

## Conclusion

This teaching approach with Desmos Polygraph must be continued since it promotes an increased significance on formal language in mathematics. In addition, it enables pupils to understand the relationship between the formal language of mathematics and their everyday English. It promotes mathematical literacy and enhances the conceptual understanding of mathematics. Future research may examine the teacher-student interaction in the discussion after the activity that may promote better mathematical literacy using the Desmos polygraph.

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