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## Didactic Contributions of Massive Open Online Courses (MOOCs) to Mathematics Education: A Pedagogical Proposal for Teaching the Sine Function

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**Abstract:** This study explores the pedagogical benefits of integrating Massive Open Online Courses (MOOCs) in teaching the sine function within a specific educational setting. Drawing on a comprehensive approach, this study combines socio-constructivist principles with theories of autonomous, collaborative, and problem-based learning, along with Van Hiele's levels theory. At the heart of the investigation lies the meticulous design and implementation of a MOOC as a pivotal element in the didactic sequence, all conducted within a virtual learning environment. To assess its effectiveness, classroom sessions were closely observed and analyzed through the lenses of prominent teaching theories such as technological pedagogical content knowledge (TPACK), mathematical knowledge for teaching (MKT), and Knowledge Quartet (QK). The findings underscore the remarkable potential of leveraging MOOCs to foster a deeper understanding and practical application of the sine function, thereby enriching the overall learning experience. By providing students with accessible and flexible learning opportunities, this approach enhances engagement and encourages active participation. The integration of MOOCs empowers students to take ownership of their learning journey while benefiting from collaborative and problem-solving activities. Ultimately, this research sheds light on the valuable contributions that MOOCs can make to mathematics education, revolutionizing the traditional teaching paradigm and paving the way for more inclusive and effective learning environments.

**Keywords:** Massive Open Online Courses, socio-constructivism, Van Hiele, autonomous learning, collaborative learning, problem-based learning, technological pedagogical content knowledge, mathematical knowledge for teaching, Knowledge Quartet.

### 大规模在线开放课程（慕课）对数学教育的教学贡献：教授正弦函数的教学建议

**摘要：**本研究探讨了在特定教育环境中整合大规模开放在线课程(慕课)教授正弦函数的教学效益。本研究采用综合方法，将社会建构主义原则与自主、协作和基于问题的学习理论以及范希勒的水平理论相结合。调查的核心在于慕课的精心设计和实施，作为教学序列中的关键要素，所有这些都发生在虚拟学习环境中进行。为了评估其有效性，通过技术教学内容知识 (TPACK)、教学数学知识 (MKT) 和知识四重奏 (QK) 等著名教学理论的视角对课堂进行了密切观察和分析。研究结果强调了利用慕课促进对正弦函数的更深入理解和实际应用的巨大潜力，从而丰富了整体学习体验。通过为学生提供方便且灵活的学习机会，这种方法增强了参与度并鼓励积极参与。慕课的整合使学生能够掌控自己的学习旅程，同时从协作和解

决问题的活动中受益。最终，这项研究揭示了慕课可以对数学教育做出的宝贵贡献，彻底改变传统的教学模式，并为更具包容性和有效的学习环境铺平道路。

**关键词：**大规模开放在线课程，社会建构主义，范希勒，自主学习，协作学习，基于问题的学习，技术教学内容知识，教学数学知识，知识四重奏。

## Introduction

This research is part of a macroproject on the didactics of mathematics with the use of ICTs (MOOC) [4], which scrutinizes the didactic contributions that digital tools offer mathematics teachers throughout the entire teaching process, from planning and intervention to evaluation and respective analysis of teaching practices. On this occasion, it was conducted with university students attending the first mathematics course, specifically focusing on the sine function [6]. To achieve this, a pedagogical design is implemented that encompasses socio-constructivism [2] as a pedagogical approach that establishes real, proximal, and distal development zones, where the teacher's intervention through mediation and scaffolding strengthens students' abilities to learn mathematics. The theories of autonomous learning [7, 8] correspond to the possibility of providing strategies for students to acquire strength in self-regulation for learning mathematics. Collaborative learning [1] serves as an interactive scenario in which students identify their own prior knowledge and learn from others. Problem-based learning [3] aids in recognizing how students approach a math problem and solve it using their knowledge. Van Hiele's theory [11] is used both in designing learning activities according to their levels and in guiding teacher actions throughout the teaching process. This pedagogical design is proposed to establish relationships that best fit the context, students' prior knowledge, and conditions for teaching mathematics. Based on this, a MOOC was created to teach the sine function [6], supported by the GeoGebra tool. The MOOC concept is used as a strategy for building an online learning environment controlled by students' profiles and coverage. Consequently, the resources generated are used to teach the sine function, creating a virtual space where students encounter content and systematized learning activities supported by digital resources such as videos and exercises in GeoGebra. For classroom intervention, a didactic sequence is elaborated for teaching the sine function, linking resources from the MOOC, and obtaining information about teacher-student-content interaction through technological mediation. This information is

then analyzed using pedagogical knowledge of the content [12], mathematical knowledge for teaching mathematics [9], the Knowledge Quartet [10], and pedagogical and technological knowledge of the content [5].

## 1. Methodology

This research was conducted within the framework of mathematics didactics using ICTs. This is a qualitative study with an analytical and interpretative approach, focusing on the development of a pedagogical design based on socio-constructivism (Vygotsky) and Van Hiele's model (Van Hiele's marriage). This design is juxtaposed with theories of learning (collaborative, autonomous, and problem-based) to establish relevant connections between these theories and the research context.

Table 1 Didactic contributions (Developed by the authors)

		Socio-Constructivism				Van Hiele's T.		
		Scaffolding	Scaffolding	ZDP	CCS	Level I	Level II	
THEORIES OF LEARNING	A. L	Self-regulation	5	4	3	3	4	1
		Autocontrol y	3	4	5	2	1	1
		Assessment and Positive interdependence	2	4	3	5	4	4
		Interdependence	1	4	5	5	1	1
	C.L	Tutoring	1	5	5	3	1	1
		Collaboration through technological support	1	5	5	2	5	5
	P.B.L	Problem-solving	3	5	4	4	5	2
		Investigative / Informative	3	3	5	5	2	2
		Solution-oriented	3	3	5	1	5	4
		Productive	4	3	1	5	4	5

Notes: AL - autonomous learning; CL - collaborative learning; PBL - problem-based learning; ZPD - zone of proximal development; CCS - common construct of significance

The relationships valued with a score of 5 generate the pedagogical design to be considered in this context and under the conditions diagnosed in the research problem. This design will guide the construction of the MOOC and each of the learning activities in the didactic sequence, as well as the dynamics of teaching mathematics using the MOOC.

The most relevant relationships determining this pedagogical design can be explained as follows:

Table 2 The most relevant relationships (Developed by the authors)

Relevant Relationship	Argumentation
Scaffolding and ZPD, self-	Reference is made to the importance of self-regulation for students in using tools and strategies to

control and monitoring	progress toward their goals, experiencing for themselves the possibilities and limitations they face when engaging in a learning activity. This requires the teacher to provide support and control in aspects of the activity that are beyond the student's current abilities. In this way, the student can focus on mastering the relevant aspects of a strategy or skill through feedback and teacher support when necessary.
ZPD and positive interdependence	Self-control and monitoring contribute to students in their zone of proximal development (ZPD) by allowing them to acquire skills and knowledge to solve mathematical problems with greater autonomy. By internalizing a strategic approach, students can learn to plan, solve mathematical problems, make decisions independently, and adapt to the learning context.
Positive interdependence and joint construction of meanings	When involving students in the process of knowledge construction within a social environment, they receive constant feedback on their understanding and progress from both the teacher and their peers, enabling joint adjustments and improvements in their learning. Additionally, designing assessments before the learning activities ensures that the objectives are aligned with the activities, and students receive feedback on their progress toward those objectives.
ZPD and tutoring	When working together, students support each other to advance in their zone of proximal development (ZPD) by providing assistance and guidance to overcome difficulties during the development of activities and making individual progress. Teamwork fosters social and emotional skills such as effective communication, conflict resolution, and collaboration.
Positive interdependence and joint construction of meanings	Working together, students support each other to advance in their ZPD, providing guidance and support to overcome difficulties during the development of activities and to progress individually. Teamwork develops social and emotional skills such as effective communication, conflict resolution, and group work.
Adjusted assistance and tutoring	Through collaborative group work to construct meanings, students question each other's ideas, leading to a deeper and more critical understanding of the topic. This relationship also impacts emotional and social aspects such as empathy, cooperation, and leadership.
ZPD and tutoring	Personalized assistance tailored to the student's needs increases the possibility of learning and developing new skills. Both Adjusted Assistance and Tutoring can be used in individual or group contexts. Tutoring is used to identify skills that a student has not yet acquired and that are within their ZPD, providing the necessary help to develop them.
Adjusted assistance and collaboration through technological support	Digital materials are used to support participants in generating knowledge, developing products, solving relevant problems, and acquiring specific competencies established within the context of mathematics education.
Van Hiele's Level 1 and the problematic phase of problem-based learning (PBL)	During the problematic phase of Problem-Based Learning (ABP), students apply some characteristics of Van Hiele's Level 1, such as recognizing and analyzing particular properties of the problem. Additionally, ABP can be an effective methodology for developing cognitive skills and advancing through Van Hiele's levels of understanding as students work together to solve problems.
ZPD and the investigative phase of PBL	Working in collaboration with more experienced peers during the investigative phase of ABP, students leverage their ZPD to acquire new knowledge and skills to effectively address the problem. Furthermore, by receiving feedback and guidance during this phase, students develop their capacity for self-regulation and autonomous learning.
Joint construction of meanings and the investigative phase of PBL	Students work in groups and share their findings and interpretations with other group members. Through this process, they discuss different perspectives and construct shared meanings based on the collected information.
Joint construction of meanings and the investigative phase of PBL	Collaborating to find solutions to the proposed problem allows students to interact socially and learn from each other.
Van Hiele's Level 1 and the solution-oriented phase of PBL	Students actively participate in the construction of their knowledge and development of skills through problem-solving and concept exploration. Both theories promote a student-centered approach, encouraging active participation and the ability to relate content to their context and experiences.
Joint construction of meanings and the productive phase of PBL	As they progress into the productive phase, students also work together to identify specific learning goals they want to achieve through the project. Again, this involves joint construction of meanings to ensure that everyone is working toward the same objectives.

### 1.1. Design and Creation of the MOOC

In the first instance, the decision was made to use the Thinkific.com platform to host the MOOC because of its flexibility, customization options, and tools necessary for implementing the didactic sequence activities. If needed, Wix will be employed as an alternative platform for hosting the course because of its flexibility and ability to customize the visual interface and incorporate useful tools for the development, analysis, and interpretation of the didactic sequence.

The purpose of the MOOC is to provide students with autonomous and collaborative opportunities to

acquire knowledge about the sine function. It will include all the activities outlined in the didactic sequence, structured as follows:

On the main page, an infographic created in Canva will display the content of the MOOC.

Five tabs will be placed in the top-right corner, providing access to all materials prepared for the didactic sequence, including:

*Initial evaluation* consisting of a series of questions related to the mathematical concept implemented through a Google Form to gather information about student's prior knowledge.

*Three units:*

*Unit on trigonometric ratios:* This unit will begin with an introductory text followed by an explanatory video created by the teacher, which presents concepts related to trigonometric ratios. The unit will continue with a group activity in which students will define roles and invent a problem related to trigonometric ratios using GeoGebra for its solution. Afterward, they will present their solutions to the group, and a video tutorial on using GeoGebra, created by the teacher, will be provided. Following the activity, a virtual meeting on Google Meet will be conducted to reinforce the acquired knowledge.

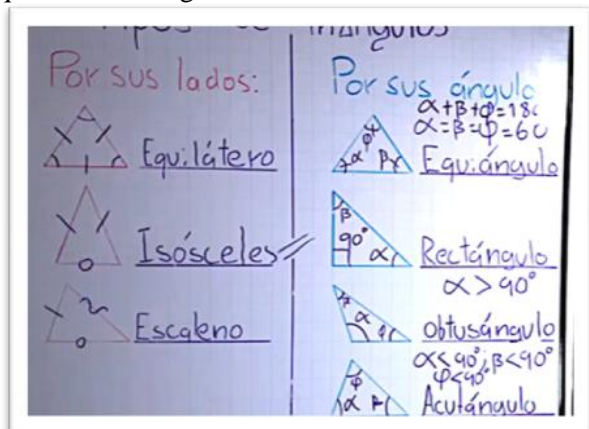


Fig. 1 Screenshot of the video of trigonometric ratios (<https://n9.cl/n6ju8>)

*Unit on functions:* Similar to the first unit, this unit will include an introductory text, a teacher-created video on functions, an individual activity in which students will create a video on a topic related to functions chosen by the teacher, and a video example of the activity created by the teacher on periodic functions. The final activity involves students asking questions and providing comments related to the content of each other's videos.

## ACTIVIDAD

MÓDULO II

### VIDEO SOBRE FUNCIONES

ACTIVIDAD DE TIPO INDIVIDUAL

Observa el video I correspondiente a la unidad 2 de funciones

Realiza un video de 3 minutos en el cual expliques un poco mas en profundidad un concepto de sobre funciones escogido para ti, por el profesor.

Fig. 2 Screenshot of Module II functions (<https://n9.cl/wsgxh>)

*Unit on trigonometric functions:* For the last unit, the teacher will create two videos, the first on the trigonometric circle and the second on the sine function. This unit will also feature a group activity with the same roles as the first activity, where students will create an explanatory text on constructing the sine function on the Cartesian plane using GeoGebra.

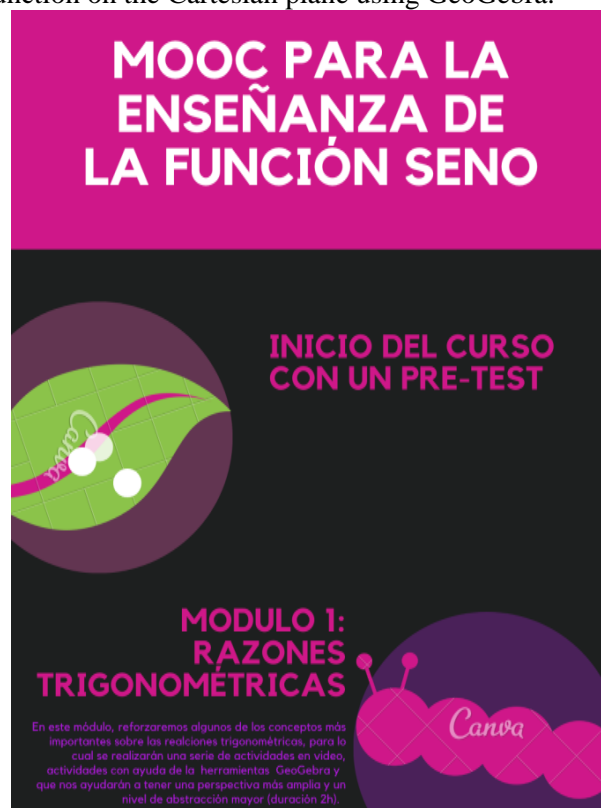


Fig. 3 Screenshot of the video of trigonometric functions (<https://n9.cl/dk9dg>)

*Final evaluation:* The last tab of the MOOC will contain an evaluation similar to the initial one, aiming to assess the knowledge acquired throughout the application of the didactic sequence.

### 1.2. Didactic Sequence

With the pedagogical design as a guide, a didactic sequence is structured, presenting learning activities ordered according to the theoretical framework. It is divided into three main moments:

- 1) Initial activities, including course introduction, initial evaluation, and interesting facts about the MOOC;
- 2) Development, which presents step-by-step explanations of each level. The MOOC's structure is divided into four parts constructed using the same methodological approach, making the sequence adaptable to any of these parts;
- 3) Closing activities, including the final evaluation.

This didactic sequence, combined with the MOOC platform, promotes autonomous and collaborative learning, fostering students' acquisition of knowledge and skills related to the sine function. By using both

pedagogical theories and technological tools, this study enhances mathematics education and student learning experiences.

This work introduces a comprehensive pedagogical design aimed at structuring an effective Massive Open Online Course (MOOC) that focuses on teaching the mathematical concept of the sine function. The didactic sequence is carefully organized into three main stages. It starts with initial activities involving course presentations, pretesting to assess students' prior knowledge, and providing intriguing insights about MOOCs to foster engagement. Moving on to the development stage, the sequence encompasses four modules with a meticulous breakdown of each level, allowing for adaptability and personalized learning paths based on individual student requirements. Throughout the process, the teacher demonstrates a deep understanding of the content and students' needs. Technological tools such as Google Meet are employed for video sessions, and captivating introductory talks are created to elucidate the significance of the MOOC. To make abstract concepts of trigonometric ratios accessible and relatable, the course content is presented using carefully crafted YouTube videos that embed these concepts in real-life applications and contemporary mathematical contexts. The teacher's keen awareness of students' misconceptions and struggles with trigonometric concepts facilitates the design of pedagogical strategies to address specific learning barriers. The research highlights the teacher's expertise in integrating technology, resulting in an engaging and interactive learning experience. Students are provided with opportunities to explore educational platforms such as GeoGebra, enabling them to interact with graphical representations of trigonometric ratios and fostering spatial understanding and conceptualization of the sine function. The use of diverse technological resources ensures comprehensive learning support, thereby helping students acquire a solid foundation in trigonometry. Overall, this research serves as an exemplary model for designing pedagogically sound MOOCs that effectively leverage technology to cater to diverse student needs, promote meaningful engagement, and enhance the understanding and application of complex mathematical concepts, such as the sine function. Regarding the implementation of a didactic sequence focused on trigonometric functions, specifically the sine function ( $\sin(x)$ ), using GeoGebra as a supporting tool, the series is divided into three units: "Trigonometric Ratios," "Functions," and "Sine Function ( $\sin(x)$ )." Each unit involves practical activities, explanatory videos, and evaluations to measure student progress. GeoGebra was extensively used to support teaching and learning, enabling students to interact with mathematical concepts and visualize function graphs. Collaborative learning was

encouraged through group work, assigning specific roles to each group member, and promoting active participation. The concept of self-regulated learning was observed among students with varying levels of autonomy. Some students demonstrated higher independence in learning, whereas others required more guidance from the teacher. The report emphasizes the importance of considering the transition between the levels of Van Hiele's understanding in activity design to ensure students' progression in mathematical comprehension. Formative and summative assessments were employed to measure student progress throughout the didactic sequence. The report acknowledges certain challenges in planning and executing the activities, emphasizing the need to address these contingencies to improve future implementations. In conclusion, the report highlights efforts to implement a well-structured didactic sequence supported by technological tools to facilitate learning trigonometric functions, particularly the sine function ( $\sin(x)$ ). Reflections on the results and identification of areas for improvement aim to enhance future implementations and design a more effective learning experience for students.

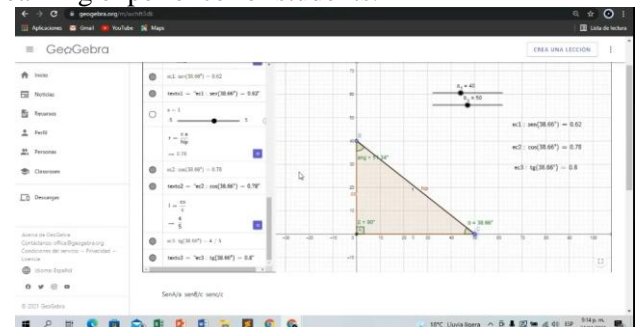


Fig. 4 Screenshot of the interaction between the tutor and one student using the Geogebra software online

## 2. Results

- The teacher explored multiple platforms for creating the MOOC.
- The teacher found the GeoGebra tool useful for conducting learning activities.
- The didactic sequence was adjusted as the students progressed.
- The roles assigned to students facilitated the completion of activities, especially collaborative and problem-solving tasks.
- Students accessed the MOOC for both completing activities and interacting with their peers and the teacher.
- The creation and editing of videos allowed the teacher to continuously reflect on communicative and media-related aspects and develop skills in video production.
- The pedagogical design guided the entire process, from the MOOC design to the implementation of learning activities based on the didactic sequence.
- These results demonstrate the successful

implementation of the pedagogical design and MOOC platform in teaching the sine function. The adaptation of the didactic sequence based on students' progress ensured a personalized and effective learning experience. The use of GeoGebra and video creation enhanced the learning environment, enabling the students to actively interact with the content and peers. The teacher's continuous reflection on the instructional process contributed to the improvement of teaching practices and communication strategies.

- Overall, the study's outcomes highlight the significance of integrating technology, pedagogy, and mathematics education, fostering a dynamic and supportive learning environment through the use of MOOCs and digital tools.

### 3. Conclusions

There are several important conclusions that stand out in this research, considering the context in which it was conducted, making it a significant contribution to the teaching of mathematics through MOOCs. First, a high level of student participation and motivation in the online course was observed, indicating that MOOCs can be an effective tool for promoting interest in mathematical learning. In addition, it was found that MOOCs allow for reaching a broader and more diverse audience, including students from different regions and varied academic backgrounds, thus contributing to democratizing access to mathematical education. Another relevant finding was the possibility of using various interactive resources and technologies in MOOCs to facilitate a more dynamic and engaging teaching environment for students. Finally, the importance of feedback and personalized monitoring provided to students through online platforms was highlighted, enhancing the learning process and promoting greater success in achieving educational objectives. Taken together, these results endorse the efficacy and potential of MOOCs as a valuable tool for enhancing the teaching and learning of mathematics in the digital era.

*C1:* The teacher gained new pedagogical insights by gathering essential information about the students, analyzing their sociocultural context, and exploring their existing knowledge about the mathematical object. Based on these initial conditions, the teacher developed a pedagogical design that integrated various learning theories and the socio-constructivist approach. Additionally, the interaction with the first two levels of Van Hiele's theory contributed to relevance and enriched the teacher's pedagogical knowledge of the content, leveraging the geometric nature of the mathematical object. This provided the teacher with pedagogical resources to determine which relationships between these theories were relevant for addressing the learning situation of the sine function in this research context. The dynamic interplay between pedagogical

and mathematical content knowledge enhanced the teacher's pedagogical capabilities to navigate different classroom situations, such as adapting to attendance patterns and addressing unforeseen contingencies. Finally, the teacher acquired didactic and technological knowledge of the content, as the pedagogical design had to be adapted to the MOOC's structure and didactic sequence.

*C2:* The creation of didactic materials in various formats using ICTs for structuring and creating a MOOC for teaching the sine function was evident. This process allowed the teacher to acquire greater technological and pedagogical knowledge of the content. During the MOOC creation, the pedagogical design guided the adaptation of each resource and possible interactions to enable students to engage in the learning activities of the didactic sequence. The teacher faced different situations during the process, such as addressing content asynchronously and modifying the course content based on time constraints, which demonstrated the teacher's knowledge of content and teaching, enabling the selection of effective strategies and the structuring of learning spaces. The MOOC's activities empowered the teacher to guide students interactively, using mediators such as GeoGebra, fostering an environment where students could observe and learn concepts about the sine function actively. Thus, the implementation of the MOOC for teaching the sine function enriched the teacher's didactic knowledge.

*C3:* The teacher, armed with didactic content knowledge, skillfully planned the teaching, selected effective strategies, organized the classroom, promoted interaction and communication with students, and designed the didactic sequence for teaching the sine function. During the development of activities proposed throughout the didactic sequence's application, the teacher exhibited specialized mathematical knowledge for teaching by developing activities, choosing examples, and assigning tasks that explored concepts related to the sine function while identifying relationships between the concepts that formed the mathematical object. Notably, the teacher encountered contingency situations during the didactic sequence's application due to scheduling and time constraints, which further enhanced pedagogical capabilities by adapting to these challenges, modifying planned activities, and providing tailored support during the didactic sequence's development. The teacher successfully achieved the pedagogical design goals by using technological tools enabling communication, interaction, and the construction of the MOOC.

*General Conclusion:* Following the application of the didactic sequence with the aid of the MOOC for teaching the sine function, based on a socio-constructivist pedagogical design, it became evident

that the interaction with the MOOC provided didactic contributions. The teacher, leveraging technological resources, transformed their curriculum knowledge into more accessible forms for teaching the sine function. The teacher organized topics, content, concepts, and explanations in ways that aligned with students' learning needs, using videos, infographics, and interactive activities in GeoGebra, among others. Thus, the teacher acquired greater technological and didactic knowledge of the content while addressing classroom situations, such as time-related contingencies, resource limitations, and student attendance intermittence. The teacher applied tailored strategies for each situation, drawing on specialized knowledge for teaching mathematics, horizon knowledge, and curriculum and student knowledge, all of which played a crucial role in how these strategies were implemented to showcase the teacher's pedagogical, didactic, and technological knowledge in action.

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