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Dynamic Hypermedia Aids for Teaching the Sine Theorem

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Abstract: This unique research in our region presents the findings of a qualitative research study aimed at determining the didactic contributions in the creation of a dynamic hypermedia aid (DHA) for teaching the sine theorem. To achieve this, a pedagogical design was devised to guide the creation of the DHA, based on a conceptual map outlining its structure, as well as the development and integration of digital resources. Subsequently, a teaching sequence was designed and implemented, incorporating the DHA and its associated resources. This sequence was conducted with 10th-grade students at a school in Pereira (Risaralda). The results revealed that the creation and use of the DHA enabled educators to propose alternative instructional frameworks, complementing specialized mathematical knowledge with technological and pedagogical proficiency in using information and communication technologies (ICT). Consequently, the students discovered novel methods of learning and problem-solving. The implementation of the DHA offered educators fresh opportunities and dynamics to engage with students, fostering exchanges of ideas related to the sine theorem.

Keywords: dynamic hypermedia aid, didactic contributions, pedagogical design, information and communication technologies, sine theorem, teaching resources.

动态超媒体辅助正弦定理教学

摘要：我们地区的这项独特研究展示了一项定性研究的结果，旨在确定创建用于教授正弦定理的动态超媒体辅助工具(DHA)的教学贡献。为了实现这一目标，基于概述其结构的概念图以及数字资源的开发和整合，设计了一种教学设计来指导DHA的创建。随后，结合DHA及其相关资源，设计并实施了教学序列。该序列是在佩雷拉（里萨拉尔达）一所学校的十年级学生中进行的。结果显示，DHA的创建和使用使教育工作者能够提出替代的教学框架，通过使用信息和通信技术(信息通信技术)的技术和教学熟练程度来补充专业数学知识。因此，学生们发现了新的学习和解决问题的方法。DHA的实施为教育工作者提供了与学生互动的新机会和动力，促进了与正弦定理相关的思想交流。

关键词：动态超媒体辅助、教学贡献、教学设计、信息和通信技术、正弦定理、教学资源。

Introduction

This research is part of an overarching project in mathematics didactics using ICT (DHA) at the Technological University of Pereira, which explores the didactic contributions that digital tools offer mathematics educators, from the planning stage to intervention, assessment, and subsequent analysis of teaching practice. This study was conducted with high school students attending a trigonometry course, specifically focusing on the sine theorem. To achieve this, a pedagogical design is formulated that incorporates socio-constructivism as the pedagogical approach. This framework establishes real, proximal, and proximate developmental zones within which teacher intervention through mediation and scaffolding enhances students' mathematical learning abilities.

The theories of autonomous learning correspond to opportunities to provide strategies for students to strengthen their self-regulation in learning mathematics. Collaborative learning serves as an environment for interaction among students, aiding in the identification of their prior knowledge and that of their peers. Problem-based learning is employed to recognize how students approach and tackle mathematical problems based on their existing knowledge. Van Hiele's theory is applied both in its levels for designing learning activities and in its phases to discern the teacher's actions in the teaching process.

This pedagogical design aims to establish relationships that closely align with the context, students' prior knowledge, and the conditions for teaching mathematics. Based on this, a DHA is developed for teaching the sine theorem using the CmapTools tool. In this case, the concept of DHA is employed as a strategy to construct a learning environment controlled by both students and the teacher. The resources generated within this environment are used for teaching the sine theorem, serving as a physical space and supporting physical instruction. Students encounter systematized content and learning activities supported by digital resources such as videos and exercises.

To conduct classroom intervention, a didactic sequence for teaching the sine theorem is devised. This sequence integrates the resources embedded in the DHA, extracting information from the interaction between the teacher, student, and content through technological mediation. This analysis is conducted from the perspective of pedagogical content knowledge, mathematical knowledge for teaching mathematics, the quartet of knowledge, and pedagogical and technological content knowledge.

1. Theoretical Framework

1.1. State of the Art

In the book titled "Progressive Inquiry (IP) with Dynamic Hypermedia Aids (DHA) in the School Curriculum of the Archipelago of San Andrés, Providencia, and Santa Catalina," guided by a group of educators from the Technological University of Pereira, the project presents a proposal for pedagogical and didactic teacher training. It compiles experiences from pedagogical practices across various disciplines, including physics, chemistry, biology, philosophy, social sciences, and deontology, all using the concept of DHA, framed within socio-constructivism and the theory of progressive inquiry (IP), mediated through the use of ICT. This approach is structured around DHA [1].

[2] covers the main themes of a six-level training process grounded in socio-constructivism mediated by DHA as a pedagogical proposal in ICT. This approach enables a shift in teachers' educational practices in line with current demands. It is part of the Computers for Education training process at the Technological University of Pereira, making it a valuable resource for our research.

1.1.1. Socio-Constructivist Pedagogical Approach

Socio-constructivism is a psycho-pedagogical theory that seeks to address the influence of action on our reality and the transformations that occur through this interaction. In educational processes, socio-constructivism portrays human development as a gradual construction of learning, in which individuals play an active role, marked by socio-historical-cultural exchange. Vygotsky asserts that a person can feel, imagine, remember, or construct new knowledge if they have a cognitive precedent to anchor it. Thus, prior knowledge is crucial for acquiring learning as it is the product of the influence exerted on it by individuals, culture, and the surrounding environment. Vygotsky refers to these processes of social interaction as interpsychological processes [3].

1.1.2. Autonomous Learning

Autonomous learning is a process that enables individuals to develop independently, becoming the authors of their development. They choose the paths, strategies, tools, and moments they find relevant to learn and autonomously put into practice what they have learned [4].

According to [5], "teaching for autonomy or the didactic method of strategic teaching involves progressively transferring control of the strategy, which initially the teacher exercises, to the student so that the student appropriates it and can begin to use it autonomously".

Strategic use of procedures is a fundamental responsibility of strategic teaching. It transitions from external and teacher-centered control when the strategy is first introduced to a phase where the student can practice the learned strategy under the guidance of the teacher. Finally, the student gains internal self-regulation and autonomy in using the strategy [6].

1.1.3. Collaborative Learning

Collaborative learning occurs within a conversational environment mediated by language and discourse. Participants engage in dialogs, negotiations, and explanations. Shared prior experiences, strategies for obtaining information, ways of presenting ideas and proposals, methods of evaluating contributions, and repeating and reformulating others' statements are essential for successful interaction [7].

Tasks designed for collaborative environments are aimed at achieving the proposed goals. The design serves as the foundation for collaborative knowledge construction. Gulikers et al. (2004) suggested that task or activity design should consider three dimensions: individual responsibility, task nature, and control [8].

1.1.4. Problem-Based Learning (PBL)

This theory is rooted in Barrows' (1986) definition of PBL as a method of learning based on the principle of using problems as a starting point for the acquisition and integration of new knowledge [9]. PBL involves presenting students with a set of situations to stimulate strategies for solving problems and accessing supplementary information.

1.1.5. Technological and Pedagogical Content Knowledge (TPACK)

The TPACK framework explains teachers' understanding of educational technology and the interaction between technological and pedagogical content knowledge (TPCK) to achieve effective teaching using technology. TPCK is an emergent form of knowledge that extends beyond the core components of content, pedagogy, and technology. It arises from the interaction between these three domains. Effective and meaningful technology-enhanced teaching is rooted in TPACK, which requires understanding how to represent concepts using technological and pedagogical skills, employing technologies constructively to teach content, understanding the challenges students face, and employing technologies to address these challenges [10].

The TPACK framework suggests that discipline, pedagogy, technology, and the contexts of teaching and learning play individual and combined roles. Successful teaching using technology necessitates a continuous balance among all components [10].

1.2. The Knowledge Quartet (KQ)

The Knowledge Quartet (KQ) is a framework that describes and analyzes classroom observations that reveal a teacher's knowledge of mathematical content. It is categorized into four units or dimensions: foundation, transformation, connection, and contingency.

1.3. Pedagogical Content Knowledge

Shulman [11] proposes a minimum of knowledge that teachers should possess, which is grouped into three categories: knowledge of the subject matter, pedagogical content knowledge, and curricular knowledge. Shulman expanded the model of pedagogical reasoning in teacher preparation, focusing on the following aspects:

- Content knowledge;
- Pedagogical content knowledge;
- Knowledge of students;
- Curricular knowledge;
- General pedagogical knowledge;
- Knowledge of goals and objectives;
- Knowledge of contexts, frameworks, and educational management.

1.4. The Van Hiele Model

The Van Hiele model features a hierarchical structure that works through levels with a set order that cannot be altered. The levels are recursive, meaning that what is implicit in one level becomes explicit in the next. Progression both within and between the levels is closely related to the enhancement of the mathematical language required for learning. The five levels are typically referred to by numbers 1 to 5, but the notation 0 to 4 is more commonly used. The levels are:

i) *Level 0:* Visualization or recognition;
ii) *Level 1:* Analysis;
iii) *Level 2:* Ordering or classification;
iv) *Level 3:* Formal deduction;
v) *Level 4:* Rigor.

1.5. Adaptive Hypermedia System (AHS)

Brusilovsky (1996) defines an adaptive hypermedia system (AHS) as a system that reflects user characteristics in a user model and applies this model to adapt various visible aspects of the system to the user. For a system to be considered an AHS, it must meet three criteria:

- Be hypermedia-based;
- Have a user model;
- Be able to adapt the hypermedia content to the user model.

The proposal of dynamic hypermedia aids (AHD) as a didactic instrument for teaching and learning aligns with the characteristics of AHS. It is a hypermedia system with the capability to adapt its structure to each user's specific attributes, such as information needs, access conditions, experience, and knowledge. This allows it to provide tailored materials based on the user characteristics and domain being studied.

According to [1], AHD serves as a multimedia product with hypermedia attributes that promote metacognitive processes. It is grounded in socio-constructivism and functions as a psychological instrument. [12] refers to it as a mediator of intra- and inter-mental processes involved in teaching and

learning. It serves as a means of knowledge representation and strategic communication system for implementing ICT in educational processes through the development of a techno-pedagogical design (DTP) aligned with educational goals, thereby modifying and innovating the relationships between the teacher, student, and knowledge.

Therefore, AHD becomes a tool that contributes to the redefinition of the relationships among the elements of the didactic triangle (teacher, student, and knowledge) from a socio-constructivist perspective [12].

1.6. Basic Concepts

In this research, the following concepts are taken into account:

1. Trigonometry;
2. Angles;
3. Pythagorean theorem;
4. Trigonometric ratios;
5. Sine function;
6. Law of sines or sine law.

2. Methodology

2.1. Descriptive Qualitative Design

This study employs a qualitative methodology of a descriptive-interpretive nature to obtain descriptive data. Classroom observations, recordings, and other methods are used to analyze class development when using AHD.

2.2. Research Context

The research was conducted at an educational institution in the municipality of Pereira, Risaralda Department, for secondary school students aged between 14 and 16. Their parents provided consent for their participation in the research and engagement in the planned activities within the didactic sequence.

2.3. Research Techniques and Instruments

2.3.1. Participant Observation Techniques

Distinction is made between observation and participant observation. The former is a technique for collecting data on nonverbal behavior, while the latter involves more than mere observation; it implies the direct involvement of the observer, allowing the researcher to interact directly with the group's life. [13] stated that participant observation refers to a practice that involves living among the people being studied, getting to know them, and understanding their language and ways of life through intrusive and continuous interaction with them in daily life.

In this research, the classroom work was conducted by the investigating teacher. This means direct involvement in various activities during the time dedicated to observing the subjects and participating in their activities to facilitate better understanding. It required preparation, prior design, and organization for fieldwork sessions during the experience.

2.3.2. Videographic Records

Using video as a recording or visual support instrument in the research enabled the acquisition of more information because of the ability to capture both image and sound. For this study, videography records served as the primary observation instrument during the research development. They document the learning environments in the classroom and highlight procedures, situations, expressions, and emotional and expressive behaviors of the students. Multiple recording sessions (classroom filming) necessary for the didactic sequence's development, corresponding to the thematic development of the law of sine, are captured and later analyzed considering the theoretical framework.

2.4. Pedagogical Design

Based on the diagnosis, prior knowledge, and research problem, this pedagogical design showcases relationships from the teacher's perspective that facilitate or are geared toward guiding teaching actions to promote the learning of the sine theorem.

Table 1 Pedagogical design (Developed by the authors)

Pedagogical Model Matrix		**Socio-Constructivism**					
		Characteristics of Socio-Constructivism					
Learning Theories and Characteristics		**Prior Knowledge**	**Adaptive Support to Demonstrate How Students Construct Knowledge**	**Scaffolding to Provide Adequate Support to Students**	**Representation**	**Construction**	**Delegation of Responsibility and Control**
Problem-Based Learning (PBL)	Active Work with Student Engagement						X
	Selected Problems in Achieving Knowledge Objectives			X			
	Student-Centered Learning	X					

	Continuation of Table 1						
	Teacher as Facilitator or Learning Guide	X					
Collaborative Learning	Positive Interdependence						X
	Responsibility and Commitment						X
	Teamwork				X		
	Enhancing Development			X			
Autonomous Learning	Students Learn to Construct Their Knowledge				X		
	Self-Regulation			X			
	Progressively Transferring the Strategy Control						X
	Strategic Use of Procedures				X		

Table 2 Phases of the research (Developed by the authors)

Phases	**Objectives**	**Activities**
Phase I: Characterization	Diagnosing problems of teaching the law or theorem of sines in the classroom	Using the basic learning rights (DBA) established by the Ministry of National Education as a reference, which mentions that students in the tenth grade should be capable of "DBA 12: Understands and applies the law of sines and cosines to solve problems in mathematics and other disciplines involving non-right triangles" (Ministry of National Education, 2016, p. 34), an analysis of the comprehension processes of the law of sines is conducted and diagnosed through the results of the Saber 11th-grade tests (Chapter 1: Description of the Problematic Reality).
Phase II: Research	Identifying the impact of AHD as didactic strategies for teaching and learning the law of sines	We proceed to develop an instrument that allows us to design, implement, and evaluate the content developed in the classroom. Therefore, we will start by: - Literature review on dynamic hypermedia aids (AHD) and the use of information and communication technology (ICT) applied to mathematics teaching; - Literature review on the socio-constructivist pedagogical approach and constructivist learning theories; - Literature review on didactics in teaching the law of sines. This process aims to provide a comprehensive understanding of AHD, ICT integration, socio-constructivist pedagogy, constructivist learning theories, and effective didactic approaches for teaching the law of sines. The information gathered will serve as a foundation for the development of an instrument that facilitates the design, implementation, and evaluation of instructional content in the classroom.
Phase III: Design and Implementation	Creating a dynamic hypermedia aid to facilitate the study of the law of sines	• Construction of a techno-pedagogical design for teaching the law of sines; • Selection, adaptation, and construction of didactic resources for developing thematic units; • Design and construction of a DHA instrument for teaching and learning the law of sines using the CmapTools application.
Phase IV: Applicati	Applying the didactic strategy of DHA in the tenth grade of the educational institution	• Implementation of the didactic sequence using DHA in four 90-minute class sessions in the tenth grade of the educational institution; • Elaboration of student products and presentations that demonstrate autonomous and collaborative work in the activities proposed in the instrument.
Phase V: Analysis and Evaluation	Evaluating the performance of the didactic strategy with students in four predetermined aspects: - Creation of educational material; - Use of educational resources; - Communicative strategies in the classroom; - Adaptation of educational resources to the context. All of these strategies are framed within the socio-constructivist pedagogical approach and theories of problem-based	- Determining the impact of didactic contributions offered by the use of dynamic hypermedia aids to mathematics teachers from the socio-constructivist approach to teaching the law of sines regarding the use and creation of educational material, adaptation of educational resources to the context, and communicative strategies in classrooms with tenth-grade students of the educational institution; - Evaluating the performance achieved during the implementation of the didactic strategy from a curricular perspective.

learning (PBL), collaborative learning, and autonomous learning among tenth-grade students of the educational institution.

3. The Design and Implementation of the DHA

A DHA aims to autonomously and collaboratively build knowledge about the foundations of trigonometry through multimedia resources. In addition, it enhances the classroom experience by implementing ICT in the classroom, facilitating communication between the students and teacher. The creation of a DHA is based on prior knowledge, following the socio-constructivist model, allowing the exploration in various ways and addressing different levels of complexity that may arise during its development.

The instrument is composed of the following parts:

3.1. General Information

This includes buttons located in the upper right corner of the DHA interface: Presentation, Content, Roles, Instructions, and Rules.

3.2. Initial Diagnostic Test for the Students

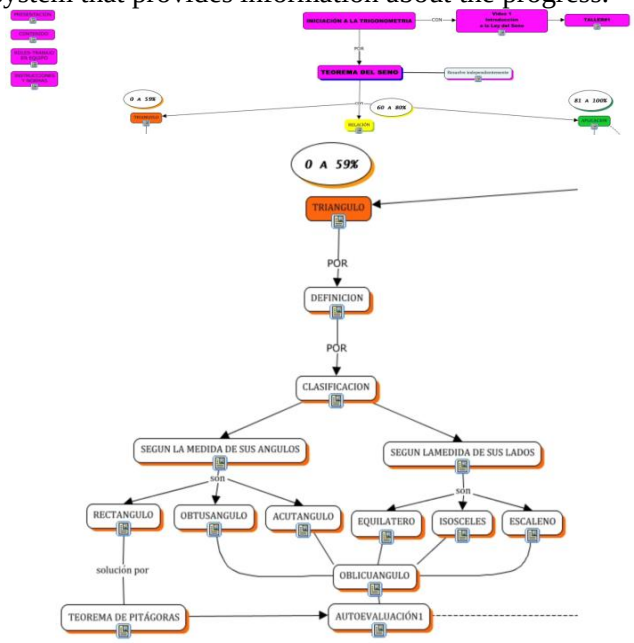
This determines the student's initial state by assessing prior knowledge to adjust routes and activities based on each student's particular situation.

3.3. Thematic Development of the Didactic Unit

This unit consists of four content sections (planned in the didactic sequence) to achieve the proposed objectives.

3.4. Evaluation System

Throughout the DHA, the evaluation system inquires about students' preferences and self-learning progress. It serves as a continuous self-assessment system that provides information about the progress.



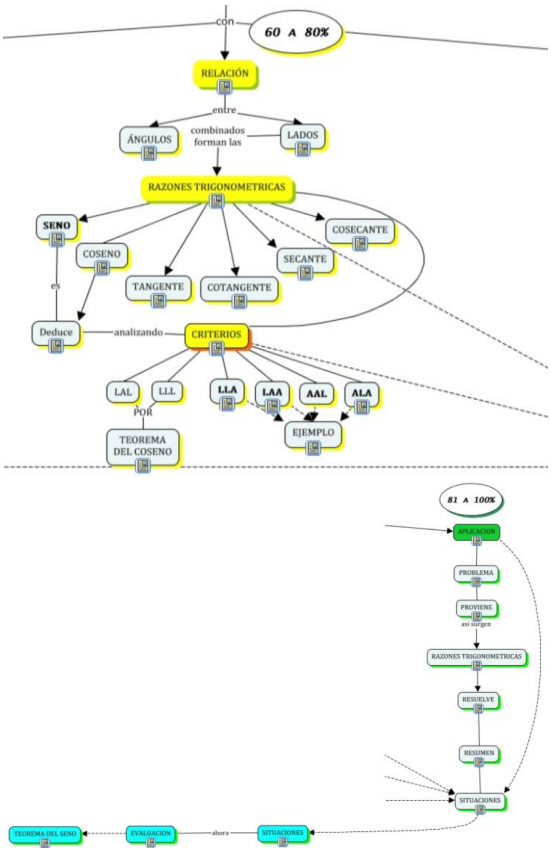


Fig. 1 DHA for the law of sines (Developed by the authors, https://cmapspublic.ihmc.us/rid=1SCHVFRS8-12D3XW9-3394/TEOREMA%20DEL%20SENO.cmap.cmap)

4. Thematic Content Development for Teaching the Law of Sines Is Outlined in the Didactic Sequence

4.1. Design of the Didactic Sequence (DS)

The DS consists of an exploratory section introducing trigonometry, which includes a brief historical overview of the development and evolution of trigonometry, and three sections planned for the thematic development of the didactic unit for learning the law of sines. These sections are as follows:

1st section (fuchsia) introduces trigonometry;

2nd section (orange) addresses prior knowledge;

3rd section (yellow): solving right triangles and trigonometric ratios;

4th section (green): solving oblique triangles using the law of sines and its applications.

The first section covers the historical and introductory components of trigonometry; the second section introduces fundamental concepts about triangles; the third section presents the resolution of right triangles, and the final section develops the resolution of non-right triangles. Each section includes theoretical foundations of the topic, examples, and a series of practical activities aimed at familiarizing

students with triangle concepts. These activities include classical trigonometry exercises and word problems, which aim to enhance students' performances in triangle manipulation.

5. Results

1. The initial diagnosis allowed determining that the students had prior knowledge of angles, triangles, the Pythagorean theorem, and equation solving but displayed low interest in learning trigonometry.

2. A pedagogical design was created on the basis of the conditions found in the diagnosis.

3. A DHA was created for teaching the sine theorem.

4. A didactic sequence was created and used with the use of the DHA for teaching the sine theorem.

5. The class shifted its focus as the DHA was used for both teaching and learning.

6. The pedagogical design provided traceability of the teacher's actions in class.

6. Conclusions

C1: Designing a pedagogical model based on socio-constructivist principles and learning theories (autonomous, collaborative, and problem-based), in addition to using the TPACK theory, enhanced the teacher's pedagogical content knowledge for teaching the sine theorem using a DHA.

C2: The creation and design of a DHA assisted the teacher in developing criteria to select and classify educational material that connects trigonometry with technology and the use of educational platforms focused on applying the sine theorem. This tool allowed the proposal of a working framework where students have the flexibility to learn about the sine theorem by approaching it from various routes according to their capacities.

C3: Creating a DS using the DHA reinforces the teacher's knowledge by employing various teaching strategies for the sine theorem. It enables selecting and optimizing the necessary topics and prior knowledge to address the content, in addition to seeking new sources and resources adapted through a conceptual map. It also supports the teacher in generating innovative and dynamic actions in the classroom compared with traditional practices, contributes to comprehensive, ongoing assessment adapted to new technologies, improves the pace of the class, and provides support for research processes in teaching practice.

7. Recommendations

The pedagogical contributions encompass flexibility in knowledge accessibility through diverse pathways and the construction of a scaffold of prior knowledge that anchors new understanding. The educator imparts knowledge using a digital conceptual map for student engagement. It is advisable for the instructor to adopt diverse teaching approaches to accommodate individual student progress and foster collaborative participation. The pedagogical design led to heightened communication between students and the teacher throughout class evolution. Using the DHA within the didactic sequence further empowered the teacher to effectively address the unique learning needs of her students in mastering the concept of the sine theorem.

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