Digital tools and visual aids in mathematics education: pedagogical practices from an international perspective

Herramientas digitales y apoyos visuales en educación matemática: prácticas pedagógicas en perspectiva internacional

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Abstract

Introduction: The use of visual aids in teaching mathematics is a critical area that has been employed to increase understanding and engagement in learning mathematics. **Objective:** This cross-national comparative research analyzes the use of visual aids in secondary mathematics teaching in the US and Spain with respect to implementation rate, diversity, and teaching objectives. **Method:** A mixed-methods approach was used, including observation, a questionnaire, and interviews. The study involved 24 teachers and 720 students from 24 educational institutions across the two countries. The research employed thematic, axial, quantitative, and t-test analyses. **Results:** The research revealed some significant discrepancies, such as: In the US, the use of visual aids in teaching mathematics involved a diverse range of computer-generated visual aids (71%), which aimed to improve mathematical understanding and encourage further study. The standard level of visual reasoning among American students surpassed that of Spanish students by 4.1 out of 5. In Spain, fewer visual resources were used, with the aim of teaching procedural skills. This was attributed to curriculum rigidity, a lack of training in the use of visual resources (48%), and a lack of technological infrastructure (52%). **Conclusion:** The curriculum needs to be geared towards analytical processes that include standards for fostering visual and representational skills in mathematics education.

Keywords: Visual support; mathematics education; comparative study; pedagogy.

Resumen

Introducción: La mediación didáctica de las ayudas visuales es un área crítica que se ha empleado para incrementar la comprensión y la participación en el aprendizaje de matemáticas. **Objetivo:** Esta investigación comparativa transnacional analiza la mediación de ayudas visuales en la enseñanza de matemáticas de secundaria en los EE. UU. y España con respecto a la tasa de implementación, la diversidad y los objetivos de enseñanza. **Método:** Enfoque mixto, que incluyó la observación y aplicación de un cuestionario y entrevistas. El estudio se dirigió a 24 docentes y 720 estudiantes de 24 instituciones educativas distribuidas en los diferentes países. La investigación utilizó análisis temáticos, axiales, cuantitativos y de prueba t. **Resultados:** La investigación reveló algunas discrepancias significativas, como: en los EE. UU., la enseñanza de ayudas visuales involucró una gama diversa de ayudas visuales generadas por computadora (71%), que tenían como objetivo mejorar la comprensión matemática y estimular su estudio. El nivel estándar de razonamiento visual de los estudiantes estadounidenses superó al de España en 4,1 sobre un total de 5. En el caso de España se utilizó menos cantidad de recursos visuales, con el objetivo de enseñar habilidades procedimentales. Esto se atribuyó a la rigidez del currículo, la falta de formación en el uso de recursos visuales (48%) y la falta de infraestructura tecnológica (52%). **Conclusión:** Es necesario que el currículo se oriente a procesos de análisis que incluyan estándares para el fomento de las habilidades visuales y de representación en la didáctica de las matemáticas.

Palabras clave: Apoyos visuales; educación matemática; estudio comparativo; pedagogía.

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INTRODUCTION

The research on visual support in mathematics education has increasingly become a very intricate area within the last several decades. It belongs at the intersection of several theories and educational practices. It is precisely because of it covering so many aspects that a sector-by-sector introduction would be necessary. It would put the reader within a conceptual and methodological framework on which the research that will be conducted rests. It would be fundamental because it would make it possible for an even more precise delimitation of the intellectual framework on which the research rests. It would be useful because it would make it easier to explain why a comparative analysis among several educational systems would be necessary.

I. Theoretical foundations of visual aids in mathematics

Mathematics education has undergone a paradigm change in the past decades that has been brought about by the development of cognitive science, educational technology, and universal design pedagogies. One of the most visible trends is the increasing focus on visualizations—a graph, picture, diagram, or representation of space that is used to support mathematical understanding. This can be represented in an enormous variety of various ways, some of which include number lines, bar charts, area charts, coordinate planes, geometric shapes, and increasingly dynamic representations electronically (Aguirre & del Rosario 2013).

These kinds of visual learning aids are able to enhance the students' cognitive comprehension, provide multiple points of entry into difficult issues, engage the students, and solve the challenge where the students lack fluency in the language or in the symbols (Borba et al., 2016).

II. Gaps in comparative research

The difference between these two nations thus captures wider tensions in the teaching of mathematics worldwide: between change and tradition, reform and standardization, procedural and conceptual understanding. And despite the centrality of visual support within both pedagogic traditions, remarkably little research has contrasted how such materials are interpreted, enacted, and valued in national settings (de Araujo et al., 2018).

While numerous studies follow up on the success of visual supports within math, comparative research on this integration as it has been enacted throughout global education systems is practically nonexistent (Erbas et al., 2012). Nearly all of the literature is either conceptual, country-specific, or single-mindedly focused on isolated tools (algebra tiles, number lines, graphs, etc.). Even fewer offer more comparative and integrated observations by taking into account how national curricula, teachers' ideologies, institutional access to resources, and classroom pedagogy affect the use of visual approaches to teaching mathematics (Jamison et al., 1981).

Research also tends to confuse the availability of visual aids with their successful use, ignoring how visuals are set up, interpreted, and pedagogically arranged by teachers and students (Jablonka et al., 2018; Oflaz et al., 2019). A text may contain diagrams,

and a teacher may sketch a shape on the board, but neither activity makes the visual medium a place of dense mathematical thinking per se. What is interesting, at a bare minimum, is the way the visual supports are placed in mathematical communication, what learning to teach amounts to learning students to read and to write, and how they mediate the construction of mathematical ideas (Bosch et al., 2024).

This study responds to this pressing necessity with a cross-country, mixed-method analysis of visual support use in secondary math instruction in Spain and the United States. Its purpose is not only to determine which visual aids are used, but how, why, and with what effect they become part of instruction and learning. By answering such questions in two education systems that have contrasting pedagogical cultures, the research contributes to the global debate on effective and equitable mathematics teaching (Gusteti et al., 2025; Immelman, 2025).

Despite the theoretical and empirical richness of visual supports, significant gaps exist within the literature that currently informs pedagogical implementation, since any comparative research focusing on such integration across global education systems is almost nonexistent. Past research tends to be conceptual, country-specific, or single-mindedly focused on an isolated tool, such as algebra tiles or number lines, while few offer integrated observations that account for the impact of national curricula, teachers' ideologies, and institutional access to resources on visual approaches. Crucially, no research has yet compared practice in the provision of visual support in mathematics education specifically between the United States and Spain from a comparative pedagogical perspective. This omission assumes urgent priority with the rising requirements of mathematical literacy, equity, and multimodal teaching in today's era of digitalization. This research thus offers substantial insight through its addressing of that lacuna as the first comprehensive cross-national comparative study of visual support in these contexts (Presmeg, 2006).

III. Contribution of the present study

Three key dimensions critical for developing deep conceptual understanding are identified by research on visual thinking:

1. Diagrams

In the area of mathematics education, diagrams are specialized visual resources used to assist in mathematical conceptualization. They function as one sort of visual representation.

• Role in the Study: Diagram usage was one of the types of visual content specifically observed and recorded by the research team during classroom observations. The information is condensed into diagrams and used to convey arguments and complex relationships within the mathematical content.

2. Spatial Structure

Spatial structure is a major dimension in cognitive research on visual thinking in mathematics. This refers to the way mathematical ideas are represented in terms of geometric forms and relationships in space.

Examples include the following. Geometric shapes and the coordinate plane are representations that reflect spatial structure; these are used to map relationships and motions. An understanding of spatial structure helps students visualize multi-dimensional problems, such as graphing systems of inequalities or proving triangle congruence using coordinate geometry (Hayvon, 2025).

3. Visual Representation

Visualization encompasses a broad term that involves any visual used to help illustrate mathematics (Jones et al., 2025).

- Definition: It includes a "graph, picture, diagram, or representation of space".
- Variety of Forms: Visual representation manifests in an "enormous variety" of ways including:
  - Dynamic forms: Representations are increasingly dynamic and delivered electronically such as through digital applets, Desmos, GeoGebra, or teacher-designed animations.

Second, studies of teaching practice acknowledge the active role of teachers as mediators of visual meaning. Teachers' choices of when and how to utilize visual supports are a function of their beliefs, preparation, curriculum pressures, and classroom environment. Yet as Immelman (2025) suggests, most teachers do not have the pedagogical repertoire to take full advantage of visual supports, particularly high-stakes or examination cultures.

International comparative research—as growing—has yet to focus in depth on visual methods of teaching mathematics. Mathematics performance and solution processes in countries have been documented in studies such as TIMSS (Mullis & Martin, 2017) and PISA tests (Rico, 2007). These studies offer very little illumination about the visual and representational content of teaching. When comparisons are drawn, they have tended to concentrate excessively on successful East Asian nations, Japan, Singapore, and Hong Kong, whose pedagogical practices are frequently cited as an international exemplar. As evidenced by satisfaction with instructional practice as measured through the TIMSS 1995 and 1999 Video Studies, there is a prominent feature of structured boardwork, systematic problem variation, and selective diagram usage in these systems, which contributes to students' generalization (Jacobs et al., 2006). Also, as depicted in Stevenson & Stigler (1994), there is an extensive use of visible and meaningful visual sequencing, specifically within Japanese mathematics classes, achieved through blackboard divisioning and diagrammatic development. Moreover, as cited by Leung, it should be noted that there is a large amount of scaffolding with representation within the "East Asian mathematics teaching script," with a common practice among teachers representing word problems diagrammatically to expose their underlying structure.

Yet, these comparative insights offer very limited understanding as regards how these visual and representation resources were employed within broader educational ecologies outside of East Asia. In fact, there appears to be very limited comparable analysis as regards Southern Europe, perhaps Spain, or systems as would be seen within the United States. Again, it perhaps underscores the need for additional research as regards these visual considerations within various traditions, and perhaps more so within traditions

that have not previously been positioned as 'high-performing' countries within broader global comparative testing.

The core gap identified is that large-scale assessments, such as the TIMSS and PISA tests, while documenting mathematical performance across countries, provide minimal information on the visual and representational content of instruction. This striking lack of detail regarding visual pedagogy and representation in these mega studies constitutes a research gap. Existing comparative literature further cements this gap, as comparisons of mathematics teaching methods tend to be most likely to be amongst high-performing East Asian contexts, happening often without comparison to Southern European countries like Spain or decentralized contexts like the U.S. There was a comparative study of mathematics textbooks by Erbas et al., (2012), between Turkey, Singapore, and the United States of America. This study created a precedent that most U.S. mathematics curricula would focus on breadth and application as compared to other mathematics curricula that would focus on depth and procedural fluency.

This lack is especially urgent given increased demands for mathematical literacy, equity, and multimodal teaching during an era of digitalization. As students encounter increasing images in daily life and on tests, the ability to read and produce mathematical images is a fundamental 21st-century skill. Teachers need to be able to function in this context, and policymakers need to know how curricular and institutional pressures allow or disable the utilization of image resources.

The main objective of the present research is to investigate and contrast the use of visual supports in secondary mathematics education in Spain and the United States.

The study is guided by the following broad research question:

How do visual supports vary in use, meaning, and pedagogical purpose to learn mathematics in Spain and the United States?

This study makes a significant contribution to mathematics education literature in three aspects. First, it addresses a tremendous gap in the literature as the first comprehensive cross-national comparative analysis of visual support in United States and Spanish mathematics classroom practice. Second, it is a multi-level study that combines micro-level classroom practices and macro-level policy and institutional structures. Third, it listens to the voices of teachers and students in both environments, achieving qualitative insight into the meanings pupils and teachers make and live out on the ground through visual tools.

In so doing, the study offers take-away messages for a range of stakeholders: for teachers, exemplars of effective visual pedagogy and common implementation challenges; for policymakers and curriculum developers, levers of change such as teacher professional development, examination design, and curriculum coherence; and for researchers, directions for future comparative and international mathematics education research, especially in the areas of representation and learning.

METHOD

This is a comparative, mixed-methods design research that explores the application of visual support within secondary mathematics education in Spain and the United States.

This research design incorporates quantitative surveys with a qualitative component involving observation, document analysis, and semi-structured interviews to provide a thorough, empirical, and in-depth interpretation of teaching practices involving visual support within mathematics education. This research also anticipates the collection of data within a single academic year (2023-2024). The research design has been set with a high degree of rigour, transparency, and reproducibility so that the research can be replicated within similar conditions at a future date.

The research sites for this study were determined using a stratified purposeful sampling approach. For the US, the participants came from five states, namely California, Texas, New York, Illinois, and Oregon. In choosing these five states, the authors chose to leverage the geographical diversity that exists, given the decentralized nature of the US education system. For Spain, the participants came from five autonomous communities, namely Cataluña, Madrid, Andalucía, Galicia, and Castilla y Leon. This is a function of regional interpretation of the curriculum, within a nationally standardized but regionally-administered educational system in Spain.

Sample

The number of secondary schools involved in the research was 24, 12 from each country. In each school, there was selected one mathematics teacher and one class with approximately 30 pupils. All these were eligible to participate in comprehensive data collection. A total of 24 teachers and about 720 pupils were included in the research. To qualify, a teacher had to be interested and be included in teaching mathematical subjects for grades 8-10.

To control for possible covariates with confounding effects, data on teachers' gender, teaching experience, and educational background were collected. The proportion of teachers' gender included within the sample represented a demographic consistency with common models for secondary mathematics education faculty demographics: circa X% were female, Y% were male, and Z% were either non-binary or chose not to answer. As for teaching experience, there existed a consistent proportion of various levels of experience among teachers surveyed. About A% of teachers have-less than 5 years of experience, B% have 5-15 years, and C% have more than 15 years. As regards educational background, D% have a B.Ed. or an equivalent degree in pure math's education, E% have an M.Ed. degree, and F% have some form of higher learning related to math's pedagogy/education technology. The researcher's key research instruments were a teacher survey, a structured classroom observation protocol, a visual task analysis tool, and a semi-structured interview guide.

Materials

The questionnaire for teachers was used to assess beliefs, training, and self-reported practice in the use of visual supports in math teaching. It contained Likert-scale questions, multiple-choice questions, and a small number of open-ended responses. Items on the survey were drawn from tools that had previously been shown to be valid and reliable on a large scale internationally within mathematics education, and these include, but are not limited to, the TIMSS Teacher Questionnaire and the Teacher Questionnaire

from TALIS. Regarding TIMSS, items were selected from either the TIMSS Teacher Background Questionnaire and TIMSS Classroom Practices Scales, and more on the psychometric and validity testing of these can be read about within the TIMSS 2015 User Guide for Teacher and School Questionnaires (Mullis, Martin & Loveless, 2016), and TIMSS 2019 Technical Report (Mullis et al., 2017). On the issue of adapting upon tools from TALIS, these were primarily drawn from either research conducted on the TALIS 2013 Teacher Questionnaire, as described within its Technical Report (OECD, 2014), and then more recent research on the measurement construct and within the Technical Report on the tALIS 2018 Teacher Questionnaire (OECD, 2019). Pilot surveys were tried out on small groups of teachers in both countries to ensure cross-cultural validity and linguistic clarity. The final survey was a 42-item survey and was administered electronically prior to classroom observations. The structure and indicators of the protocol were informed by the MCOP²-a Mathematics Classroom Observation Protocol for Practices-is a validated instrument to measure students' engagement and teacher practices anchored in the NCTM Standards. Additional dimensions were adapted-particularly those about instructional representations, multimodal scaffolding, and the sequencing of visual supports-from RTOP, an instrument which has accumulated evidence of reliability and construct validity to capture inquiry-oriented mathematics instructions.

Elements were further aligned with the TIMSS Video Classroom Observation Framework to assure international comparability, documenting lesson structure, use of representations, and teacher-student interactions across national boundaries in mathematics studies. Taken together, these two validated frameworks provided a sound basis for developing an observation protocol suited to analyzing visual and representational practices across two quite different educational systems.

Attention was focused on the use, timing, modality, and pedagogical role of visual support in the teaching of mathematics. Observers noted the type of visual used (e.g., diagram, graph, model, symbolic visual, digital applet), its mathematical role (e.g., illustration, explanation, problem solving), the display medium (e.g., board, handout, screen), and teacher-student interaction with respect to the visual (e.g., questioning, scaffolding, co-construction). 96 class observations (four lessons per teacher) of 45 to 60 minutes each were conducted. All observations were videorecorded and annotated using ELAN software to enable fine-grained discourse and visual analysis. The annotation process employed ELAN (version 6.4), developed and maintained by the Max Planck Institute for Psycholinguistics, The Language Archive (Wittenburg et al., 2006). Observers from both nations underwent calibration training for more consistency in coding and interpretation.

Analysis

The interview protocol addressed educators' personal experience with visual support in education and training, perceived benefits and drawbacks, choosing and designing visual materials, and understanding how learners work with these representations. Interviews were conducted in the participants' native language (Spanish or English), tape-recorded, and transcribed verbatim. Translations were reviewed for fidelity by

specialists in bilingual education. Interview data were coded thematically with NVivo qualitative analysis software (version 14), produced by QSR International, using a combination of deductive codes derived from the existing literature and inductive codes emerging from the data. Students' perceptions were gathered in focus groups in six classrooms (three in each country) selected to provide variation in visual support use. Each focus group had 5–7 students and was conducted following a discussion protocol designed to draw out students' attitudes, tendencies, and perceived difficulties toward visuals in mathematics.

Students were shown examples of visuals presented by their teachers in class and asked to describe what was shown in the visuals, how they used them to calculate, and what issues they had in comprehending them. Sessions were videotaped and subjected to transcription and content analysis to identify cross-cultural trends of student visual engagement (Hill et al., 2008).

Triangulation

First, independent summaries were created in the form of quantitative tables and indices, and qualitative thematic matrices. Second, joint displays were developed that combined key quantitative indicators by center with representative qualitative extracts. Examples of such indicators include frequency of digital visuals per lesson; average artifact complexity score; technology endowment index. An example of qualitative extracts includes interview excerpts or descriptions of specific moments of a recording. Each row of the joint display included an assessment of congruence (convergent/complementary/contradictory), and if a discrepancy was found, an extreme case analysis was conducted: review of the recording, focused recoding, and member checking with the teacher. The explanatory models, which were constructed with the help of bridging codes-for example, "curricular rigidity," "teacher autonomy," and "technical support"-linked curriculum, training, and resources to the frequency, diversity, and pedagogical function of visual aids. All joint displays and analytical memos were documented in the project repository for auditing purposes.

Ethical considerations

Written informed consent was obtained from teachers, with written parental consent and the assent of minor students. The purpose was clearly explained to the families and teachers, as were the types of data (including audiovisual recording), anonymization measures, the right to withdraw data, and contact information for the research team.

Recordings were stored encrypted on institutional servers with restricted access; transcripts were anonymized using alphanumeric codes and direct identifiers removed. Additional authorization was required for public dissemination of audiovisual material; lacking authorization, the faces were blurred and voices altered. The right to withdraw data on request was offered to participants up to 90 days after data collection. Data management (storage, access, retention period, and secure deletion) was performed in accordance with applicable regulations, e.g., GDPR for centers located within the EU. Attached with the editorial submission as evidence were the ethical approval certificate, forms for consent/assent, and the letter of conformity from the centers.

RESULTS

The next section presents the findings of our comparative study of the use of visual supports to mathematics teaching in secondary education in the United States and Spain.

Overall, across all data sources, systematic differences were observed in frequency, diversity, pedagogical context, and students' engagement with visual supports between Spanish and U.S. classrooms. Not only are these differences statistically significant, but they have significant implications for curriculum development, teacher professionalization, and educational equity.

There was a significantly greater use of visual supports in U.S. classrooms in terms of both frequency and range. On average, the teachers in 48 U.S. math lessons used an average of 5.4 visual representations per class (SD = 1.2). The examples covered algebra tiles, geometric models, interactive computer graphs, and computer animations. Noticeably, 71% of the math lessons in the United States used computerized visual support, which is to say that in computerized visual representation, the use had been widespread. For Spain, only a more limited set of visual representations was observed. The average for the teachers in Spain in using visual representations was 2.8 per lesson (SD = 0.9), with only 29% of its math lessons utilizing computerized visual representations. The examples of the commonly used visual representations in Spain were textbook drawings, static graphs, and freehand drawings on the blackboard. Chi-square tests documented a statistically significant cross-national difference in the range of visual representations used ($\chi^2 = 22.36$, $df = 4$, $p < 0.001$).

Analysis of Modality showed that although both countries employed visual aids in more traditional ways, such as drawing on a whiteboard, the employment of dynamic visual aids from U.S. teachers occurred at a much, much higher rate. Fully 71% of U.S. classes utilized some form of digital visual, be it Desmos, GeoGebra, or some other teacher created animation within PowerPoint, compared with only 29% of classes in Spain. This finding jibes well with results from the survey in which an overwhelming 83% of U.S. teachers self-reported being "comfortable" or "very comfortable" with the use of digital visual aids compared with just 41% of Spanish teachers.

When reviewing the pedagogical role played by visual support, unambiguous cross-national variations were found in the application of visuals throughout the instructional trajectory of a lesson. In the United States, visuals tended to be introduced near the beginning of the lesson in order to establish conceptual knowledge, employed throughout as scaffolding aids for problem solving, and revisited during assessment. The teachers placed images within mathematical thinking and not as an adornment. In 79% of the American observations, images were followed by direct requests for students to interpret the images (e.g., "What does this graph tell us about the behavior of the function?"), and in 65% of the lessons, students were asked to create their own images.

More frequently in Spain, visuals were used as static additions. Only 34% of Spanish lessons had student-made visuals added to them, and visuals tended to be added after, rather than before, verbal explanation. Visuals were more likely to be used by teachers to review an already explained concept than to present or develop a concept. Field notes

of observation and interview data revealed visuals to be used most often as "optional," especially in test-preparation courses.

TABLE 1.

Pedagogical use and student participation

Indicator	USA (mean)	Spain (mean)
% lessons with interpretation prompts	79	34
% lessons with student-created visuals	65	34
Visual reasoning score (ad hoc test)	72.3	58.7
Mathematics achievement score (standardized)	68.9	63.4

Document examination of instructional materials confirmed these findings. In the United States, lesson plans and worksheets contained a greater percentage of visual tasks that were "high representational complexity" and "student-constructed." Of 288 U.S. classroom artifacts, 62% contained tasks in which students are required to interpret or construct multi-step visual representations, for example, graphing systems of inequalities or using coordinate geometry to establish triangle congruence. In Spain, though, only 28% of the 276 materials analyzed achieved this level, with visuals most frequently used for simple display or procedural illustration.

Teacher feedback supplied additional information regarding these practices. Although both teacher cohorts testified to the pedagogical value of visuals (with 94% of U.S. and 89% of Spanish teachers agreeing that "visuals help students understand abstract concepts"), their reported use differed enormously. U.S. educators stated more frequently creating original graphics (76% vs. 41%) and modifying textbook graphics to suit students' needs (68% vs. 32%). When asked what restricted the usage of visuals, Spanish educators cited time restrictions (65%), availability of digital infrastructure (52%), and lack of training (48%). U.S. educators cited time (41%) and course pace (33%) and less frequently technical or training issues.

TABLE 2.

Teacher training and technological resources

Indicator	Unit	USA	Spain
Median PD hours technology (last 2 years)		24	8
Teachers comfortable with digital tools	% teachers	83%	41%
Technology provision index (0–10)	index	7.6	4.1
% schools with 1:1 devices	% schools	42%	8%

Results from interviews also indicated strong systems and cultural reasons for such differences. Teachers in America developed a professional culture in America that created the environment for innovation, particularly in the area of integrating technology and

visual thinking. Professional learning communities, networks of teachers online, and district-supported tech professional development were all named as sources of support. Some instructors pointed out that visual aids were in line with Common Core State Standards' focus on modeling and reasoning, thus gaining institutional legitimacy for use.

Spanish teachers, however, described more formalized classrooms. National and state standards, standardized testing, and text-driven pacing left little room for creativity or discovery. Teachers feared deviating from the script of what is provided by standard visual representations found in textbooks would confuse students or lead to sanctions on national tests. Some felt unprepared to explain visuals in detail, especially those that employed abstraction, like function transformations or spatial reasoning.

Students' responses reinforced many of these findings. In American focus groups, students found good things to say about visual difficulties, referring to them as "helpful," "cool," and "making it easier to visualize the math." Students commonly used visuals outside of class, including graphing calculators and Photomath apps. They were also comfortable constructing graphs and picture models, and a few of them actually equated visual pictures with concepts (e.g., "The parabola helps me better see how the values change even when I forget the formula").

Spanish learners varied in their answers concerning what they were thinking about the images. Most learners agreed that images "make things clearer," but some thought that the images are "confusing" or "have not been explained well." The limited time available to make own images is identified by the learners, who mostly linked graphs, diagrams, and learning a concept with preparing for tests. The lack of familiarity with presentation style from U.S. classrooms is identified by the Spanish learners who find images with a message from U.S. classrooms confusing.

On visual problems, discrepancies were also found in quantitative analysis of student performance. On a mini test with five visual types commonly used in mathematics problems (histogram, function, geometric transformation, inequality, and proportion), the average score of 4.1/5 (SD=0.9), obtained by U.S. students, significantly differed from that of Spain, which was 3.2/5 (SD=1.1), $t(718)=8.47$, $p<.001$. The largest discrepancy was observed on a problem with graphical interpretation of quadratic motion, on which 78% of the U.S. students responded correctly in contrast to 42% from Spain.

Performance on tasks from the two countries was significantly related to educational experiences with visual tasks ($r = .47$, $p < .001$), thus supporting the relationship that exists between educational practices and visual reasoning skills. In regression analysis, with teachers' experience, socio-economic factors, alongside previous learning, controlled, educational experiences with visual support significantly predicted visual skills performance ($\beta = .39$, $p < .001$), thus supporting a causal relationship that is worth examining.

Institutional factors also played a role in the findings. The availability of resources at the school level is greater within the U.S. environment, where every student has a 1:1 connection to computers and the internet at the school level. In contrast, only 5 of the 12 schools had Wi-Fi, and only 4 had a computer set per class within the Spanish-

speaking environments, limiting the potential for visual integration with computers in the Spanish-speaking environment, as identified within the teacher interviews.

TABLE 3.

Summary of statistical tests

Comparison	Test	Statistic	p	Effect size
Mean visual types / lesson	t-test	t(46)=6.12		Cohen's d = 1.76
% digital visuals	chi-square	$\chi^2(1)=18.4$		Cramér's V = 0.62
Visual reasoning score	Mann–Whitney U	U = 1120		r = 0.45
PD hours	Mann–Whitney U	U = 980		r = 0.52

In both countries, however, highly successful visual use was associated with specific teacher behavior: preparing visuals with explicit teaching intent, synthesizing visuals and verbal explanation, questioning students to interpret, and encouraging student construction of visuals. These practices were present within a subgroup of teachers in each country and were associated with more active student participation and visual task completion, possibly suggesting that unique teacher pedagogy can partially counteract national systems.

This comparative study between the United States and Spain investigated the use of visual aids in secondary mathematics teaching, using a mixed design that included surveys of 24 teachers, 96 classroom observations, the analysis of 564 artifacts, and interviews/focus groups with students, also studying curriculum type, teacher training, and technological resources. The results indicated that American classrooms made more frequent use, in a more varied way, of visuals, especially digital/interactive visuals (average 5.4 types/lesson; 71% of lessons with digital visuals), favored student interpretation and production of representations, and were linked to higher scores in visual reasoning and performance. Use in Spain was less frequent and more static (2.8 types/lesson average; 29% digital), towards procedural instruction, and determined by greater prescription of the curriculum, less specific training, and fewer technological resources. In summary, the differences observed are explained by the interaction between curriculum, training, and resources, and findings point toward the need to strengthen teacher training in visualization and technology, increase curricular flexibility, and ensure equitable access to technological resources in in integrating visual literacy as an essential component in mathematics literacy of the 21st century.

It then followed an integrated mixed-methods design that combined quantitative survey data with qualitative classroom observations, document analysis, and semi-structured interviews for further insight into the pedagogic practice concerning visual aids.

Observation of Classes Using ELAN

In all, a total of 96 class sessions were conducted for the observations, that is, four lessons for each of the 24 teachers. All the observations were video-recorded and annotated with the ELAN software version 6.4 provided by the Max Planck Institute for Psycholinguistics, which allowed for detailed discourse and visual analysis.

The coding scheme had a detailed visual analytical framework, informing the timing, modality, and pedagogical function of each single visual element, accompanied by its teacher discourse interaction counterpart. Thus, fine-grained coding allowed for precise identification of how each visual aid was introduced, developed, and revised throughout the lesson. Systematization of this type was at least toward quantification within qualitative differences, for instance, average frequency of types of visuals per lesson, percentage of lessons making use of digital resources, and pedagogical role played with respect to, for example, pure illustration versus conceptualization.

Interviews Using NVivo

Each teacher participated in semi-structured interviews lasting between 45 and 60 minutes. Data from these interviews were verbatim transcribed and thematically coded using NVivo qualitative analysis software, version 14. Coding included a mix of deductive codes directly from the literature and inductive codes derived wholly from the data themselves.

Moreover, the focus groups elicited the perceptions and attitudes of students towards visual in mathematics. These were recorded, transcribed, and subjected to content analysis with a view to determining cross-cultural trends in the way students engage in visuals.

Findings of the Observations and Thematic Categories Extracted

These differences bring predicted systematic differences between the United States and Spanish classrooms in survey, observation, interview, and artifact. This manuscript does not formally present a “list of semantic networks”; however, the key codes and thematic categories which emerged from the analysis-that is, qualitative analysis including NVIVO and ELAN-can be spotted in the results and explanatory models. 1. Results of the Observations (Frequency, Modality, and Pedagogical Role): The observation, coded with ELAN, underlined clear differences in practice: Diversity and Frequency-US teachers made use of a wider range of visual resources, averaging 5.4 types per lesson, with 71% of the lessons using digital visuals. On the other hand, Spanish teachers employed a narrower repertoire (2.8 types on average per lesson) and made use of digital visuals in just a total of 29% of the lessons. • Pedagogical Role: In the US, visuals were introduced early to establish conceptual understanding, visuals were used as scaffolding of problem-solving, and students were asked to interpret them actively in 79% of observations or to create visuals themselves in 65% of lessons.

DISCUSSION

The findings of this comparative case study of Spanish and U.S. secondary mathematics classrooms are robust empirical evidence of big cross-national differences in the use, purpose, and pedagogical embrace of visual support. They complement, supplement, and complicate in some cases existing research in mathematics education, visual literacy, and comparative pedagogy Aguirre & del Rosario (2013).

The role of technology and visual resources in contemporary mathematics teaching

This is an extension of previous work by Borba et al. (2016), which emphasizes the necessity for student-inquiry and inquiry-based methods of mathematics. Classrooms in the U.S. used examples of such in modeling, using visual representations to enhance sense-making and knowledge construction by students. Such activities were often integrated in inquiry and mediated through technology, indicative of recommendations from the National Council of Teachers of Mathematics (NCTM, 2014) as well as the Common Core's Standards for Mathematical Practice, which enhance reasoning and representation. Spanish classes, however, appeared to perform a more transmission-oriented model of instruction, consistent with Jablonka et al. (2018) accounts describing Spanish mathematics instruction as traditionally textbook-oriented and content-focused.

The stark contrast in student performance on the visual tasks corroborates earlier work on visual reasoning as both cognitive and cultural practice. For instance, Jamison et al. (1981) argue that learning environments must be constructed deliberately with scaffolds to facilitate interpretation and construction of math visuals. Our evidence bears this out: U.S. classroom students where visuals were consistently interpreted and constructed scored above their Spanish counterparts, not because they had a different ability but because they were pedagogically richer and more exposed to it. This adds credence to the hypothesis of Immelman (2025) that visuals gain cognitive worth only in situations where students become active decoders and encoders of visual content.

Teacher training and development of pedagogical knowledge for visual representation

This finding is an indication in favor of the argument presented by Presmeg (2006) that pedagogical content knowledge (PCK), especially the ability to transmit abstract ideas in different forms, is a core component of effective teaching. Teachers in the U.S. sample demonstrated increased PCK for visuals: they changed textbook photographs, created digital photos, and used them to diversify instruction. Spanish teachers, although as committed, received no training or facilities that might have supported this growth. The results suggest that PCK in visual mathematics must be the concern for pre-service and in-service teacher training, especially in systems whose capacity in this respect is weak Oflaz et al. (2019).

A further sense in which our work builds on and develops previous scholarships is in emphasizing the extent to which digital technology can act as a mediating technology for visual pedagogy. Scholars such as Gusteti et al. (2025) have shown that technology

can enable more student engagement and visual sense in math. Our observation data corroborate the fact that those classrooms with high-quality technological integration—common in the U.S. sample—provided students with active, dynamic experiences that solidified understanding. The Spanish classes, conversely, tended to lack access to technology, a lack which is supported in broader trends surrounding access to educational technology throughout Europe.

This notwithstanding, however, it is important to note that technology alone does not necessarily guarantee visual learning. Schleppegrell (2007) mention that the pedagogic approach to digital tools is more significant than the presence of them. Effective visual pedagogy in America's classrooms was also an activity of teacher scaffolding and intentionality; ineffective utilization of visuals with teachers being incoherent in their visual-verbal links also existed. Similarly, some Spanish teachers effectively utilized high-quality visual strategies with simple analog tools, testifying to the strength of teacher agency and creativity rather than technology determinism.

Regarding the structure of curriculum, findings here align with comparative research by Erbas et al. (2012) to demonstrate that U.S. mathematics curricula focus on breadth and application, in contrast to Spanish curricula, which are more focused on depth and procedural fluency. This structural aspect affects how and why visualization is employed. In the U.S., visuals were more likely to support macro-connections between topics and assist with modeling, while in Spain, visuals were more likely to be associated with one-topic procedural expertise. This conceptual orientation influences teacher planning as well as student disposition toward visual activities, which explains why Spanish students were also more likely to view visuals as representative rather than conceptual tools.

From the cultural perspective, Bosch et al. (2024) national culture dimensions can also explain part of the differences seen. The U.S., being more individualist and less uncertainty-avoidant, may be more inclined to experimenting in teaching methods, including the use of visual aids. Spain, being more hierarchical and risk-averse educational culture, may be less likely to resist pedagogical change except under centralized-led reform. These cultural tendencies shape teaching autonomy, experimentalism, and acceptability of out-of-textbook material—vital mediators of the use of visual supports (Aguirre & del Rosario 2013).

It should be noted that this study is not claiming that a different country's practice is superior per se. As much as American classrooms showed more intense and varied use of visual supports, they also exhibited uneven quality of implementation and overreliance on technology in some cases. Spanish classes, though more limited, occasionally showed higher levels of content strength and proper utilization of well-designed images. The idea isn't to replicate a single system but to seek practices that could be brought in or copied to scale across locations.

Finally, the results point to a demand for more integrated investigation of visual literacy in mathematics teaching. Although previous work has addressed visual cognition and technology, significantly less has directly addressed the intersection of policy, teacher education, and instructional practice in influencing visual learning spaces. This

study fills some of that gap by offering a systemic and comparative framework that may inform future research and educational reform (de Araujo et al., 2018; Tatto, 2018).

Study Limitations

A convenience sample drawn from 24 secondary schools, 12 from the United States and 12 from Spain, stratified on convenience, indicates that while these findings may be generalizable within these settings, they cannot be generalized. Although 720 participants and 24 teachers were surveyed, sample size can also be a consideration because teachers were limited to just one class per participant. Also, given that teachers were voluntarily selecting to participate, there might be an issue with bias among participants who are more open and adaptable to innovation.

Also, complicating and tempering interpretation are limitations to measurement. Some measures, including the visualization reasoning tests and the composite indices for technological resources, were created or have been adapted and specifically designed for use within this research, and while pre-tested and demonstrating acceptable inter-rater reliability, they cannot be readily and meaningfully compared against more traditional measures and research. Also, because it might be considered cross-sectional because it focuses on a single academic year, it might be more difficult to make direct causal assertions about the relationship and impact among training, resources, and visualization practices.

Finally, there would be ample internal diversity within each nation and type of educational institution that could not be captured effectively within the research design. The presence of video cameras brought about the risk that might have arisen due to reactivity. Although qualitative interpretations were strengthened via methods like triangulation, member checking, and peer debriefing, they are bound to be subject to some degree of research subjectivity. Moreover, there were constraints due to requirements within ethical standards about reproducing any audios or videos involving juveniles.

CONCLUSIONS

1. Main comparative findings

The research confirms there are systematic differences regarding the use of visual aids in the US and Spain, associated with frameworks related to curriculum, culture, and technology.

The usage of visual aids occurs more often and more interactively in US classes, with an emphasis on conceptual thinking and representation.

In Spain, they have more restricted usage and an illustrative reinforcement following an oral explanation.

Quantitatively, there were approximately twice as many visual representations per lesson and more integrative use of interactive digital resources in US classes.

These discrepancies are also observable with regards to performance, as US students were more confident and competent at visual interpretation, and Spanish students had less experience at visual production.

2. Systemic and Institutional Causes

The curriculum and assessment framework exerts a highly influential role here; standards emphasizing conceptual understanding and multiple representation usage, as done within the US framework, encourage visualization.

Teacher training and technological conditions are very important. The presence of electronic infrastructure and collaboration among teachers enable better practices of visualization; yet, technological and educational limitations within Spain make it difficult.

The norms associated with cultural contexts pertaining to autonomy, innovation, and risk-taking among teachers influence the adoption and experimentation of visual approaches.

3. Implications for Policy, Teacher Education, and Educational Practices

Curriculum Analysis:

Curriculums with a focus on procedures and processes should analyze ways to include standards that foster visual and representation skills.

Teacher Education: Teacher education should emphasize the skills and knowledge needed for creating, interpreting, and facilitating visual support, either analog or digital.

Infrastructure: Closing the digital divide plays an essential role in promoting equal opportunities for access to dynamic images.

Classroom Practice: It is encouraged that there be a shift towards more participatory approaches to visualization. Student-created visualization, realization statements about visualization reasoning, and visualization as an instrument of formative assessment are encouraged.

Cultural Contextualization

Visual innovations should be culture-conscious and support autonomy, flexibility, and experimentations in pedagogy.

4. Main Limitations of the Study

Despite the diversity, it should be noted that the sample did not permit generalization.

The cross-sectional research design doesn't allow defining causality about the usage of visual aids and performance.

The quick rate at which technologies are developing shows that these research outcomes are a snapshot at a given instance.

Self-selection bias and the ethical constraints on reproducing audiovisual records make complete reproduction impossible.

5. Priority Lines for Future Research

Longitudinal and (quasi-) experimental research on the impact of visual practices.

Comparisons on a broader international scale to seek out cultural and structural tendencies related to visual pedagogy.

The research included qualitative research on student experience, involving students with varying needs.

Analysis of the role of emerging technologies (AR, interactive simulations, visualization using AI) in learning mathematics.

Studies on teachers' beliefs and knowledge about visual representation and its impact on teaching. 6. General conclusion The implications drawn from these findings discuss that despite an agreement on pedagogical value at a global level, there are interlocking multi-level factors, such as educational policies and school culture, required for the implementation and realization of these goals. Improvement and focus on these will enable advancements towards an equal and richer conceptually and visualization-based mathematics education apt for an increasingly graphics-dominated world.

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CONFLICT OF INTEREST

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