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Reimagining Signature Pedagogies through Digital Prototypes: Inclusive Disciplinary learning in Geography and Mathematics

Ripensare le *Signature Pedagogies* Attraverso Prototipi Digitali: Apprendimento Disciplinare Inclusivo in Geografia e Matematica

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Abstract
The purpose of this article is to explore how digital innovation can improve subject teaching in Geography and Mathematics in the primary and lower secondary school through the development of inclusive and interactive prototypes. The study adopts the principle of *signature pedagogies* to analyse four digital learning units developed within the Erasmus+ DEM project (Digital Education Material). These prototypes, designed for primary and lower secondary education, incorporate multimodal resources, accessibility features and differentiated learning paths to address the diverse needs of learners. The analysis follows a qualitative approach and is guided by criteria focused on the authenticity of disciplinary practices, the usability of digital tools and equitable access to content. Findings suggest that technology, when thoughtfully integrated, can reinforce subject- specific learning while ensuring equitable access for all students.

Keywords: inclusive digital education, signature pedagogies, disciplinary didactics, Universal Design for Learning.

Riassunto
Lo scopo di questo articolo è esplorare come l'innovazione digitale possa migliorare l'insegnamento delle materie di geografia e matematica alla scuola primaria e secondaria di primo grado, sviluppando prototipi inclusivi e interattivi. Lo studio adotta il principio delle *signature pedagogies* per analizzare quattro unità di apprendimento digitale sviluppate nell'ambito del progetto Erasmus+ DEM (Digital Education Material). Questi prototipi, progettati per l'istruzione primaria e secondaria di primo grado, incorporano risorse multimodali, caratteristiche di accessibilità e percorsi di apprendimento differenziati per rispondere alle diverse esigenze degli studenti. L'analisi segue un approccio qualitativo e si basa su criteri incentrati sull'autenticità delle pratiche disciplinari, fruibilità degli strumenti digitali e accesso equo ai contenuti. I risultati suggeriscono che l'integrazione consapevole della tecnologia può rafforzare l'apprendimento specifico delle materie, garantendo al contempo un accesso equo a tutti gli studenti.

Parole chiave: educazione digitale inclusiva, *signature pedagogies*, didattica disciplinare, *Universal Design for Learning.*

Credit author statement
This contribution is the result of extensive work and was conceived jointly by the two authors. Vanessa Macchia wrote paragraphs 1 to 5.1, while Stefania Torri wrote paragraphs 5.2 to 6.4. The conclusion (paragraph 7) was written jointly.

1. Introduction

In the contemporary educational landscape, subject-specific teaching methods, understood as structured set of strategies tailored to the teaching of individual disciplines, are playing an increasingly central role in both student learning and teacher professional development. Mastery of disciplinary content and practices is not only essential for building deep, specialised knowledge, but also a key condition for fostering interdisciplinary and transdisciplinary connections. This need is especially pressing in today's complex and interconnected world, where students must develop both a solid grounding in core subjects and the ability to integrate knowledge across diverse domains.

The digital transformation of education has further emphasised the important role of subject-specific teaching. Accelerated by the ongoing social and technological changes and the impact of the pandemic, the adoption of digital technologies has profoundly altered the ways in which knowledge is accessed and how people participate in learning processes, as well as the very concept of teaching. When created with rigour and pedagogical consideration, textbooks and digital resources can promote greater accessibility, inclusivity, and personalisation of learning. These tools challenge the presumed superiority of traditional print media and offer new opportunities for educational innovation, particularly for students with special educational needs.

2. The DEM Project: Designing Prototypes for Inclusive Digital Learning

In this context, the DEM (Digital Education Material) project offers a valuable opportunity to reconsider and renew subject teaching from a digital perspective. Co-funded by the Erasmus+ programme and developed in collaboration with partners from Luxembourg, Italy, Germany and Austria, the project aims to design, develop and analyse accessible digital textbooks for mathematics and geography.[1] The project is divided into four phases, which evolve both in parallel and diachronically. These are: the analysis of digital textbooks in the participating countries; a systematic review of literature on the subject; the definition of criteria for creating inclusive digital textbooks, which will be incorporated into dedicated guidelines; and the creation of prototypes (for a comprehensive overview, see Macchia & Torri, 2024a, 2024b, 2025a, 2025b).

It should be noted that this contribution only describes the design and development phase of the DEM project. As outlined in the DEM project documentation, the project proceeds from initial analysis to prototyping before empirical evaluation (see dem-project.eu for details). Consequently, this paper does not yet present user validation data or in-depth data analysis; such empirical testing is planned for a future phase.

The article mainly focuses on the prototyping phase, currently underway for years three and four of primary school and year seven of secondary school.[2] Within the framework of the DEM project, a prototype is understood as a concrete and functional representation of a digital textbook or instructional resource. These prototypes translate the project's principles into practice, addressing pedagogical, design, technical and accessibility requirements. They are conceived to offer practical responses to authentic challenges in educational settings, thereby serving as a bridge between theoretical models and classroom application. This conceptualisation reflects long-established interpretations of prototypes in scientific literature, where they are viewed as early functional models used to explore, test, and refine ideas prior to full-scale deployment (Posner & Keele, 1968; Rosch, 1973; Hampton, 2006).

1 The preliminary findings presented are the outcome of close collaboration within the research team, which comprises the following academic institutions: *Centre pour le développement de compétences relatives à la vue* (Luxembourg, the coordinating institution), Free University of Bolzano-Bozen (Italy), University of Hamburg, University of Münster and University of Vechta (Germany), and Graz University of Technology (Austria).

2 For clarity, 'Years 3 and 4' refers to the third and fourth years of primary school, with students typically aged 8-9. This is equivalent to the third and fourth year of the Italian *Scuola primaria*. 'Year 7' refers to the second year of lower secondary school, with students typically aged 11–12. This is equivalent to the second year of the Italian *Scuola secondaria di primo grado*.

Building on this rationale, Mathematics and Geography were selected because they lend themselves particularly well to digital transformation strategies aimed at improving visual accessibility. Both subjects offer a high degree of representational flexibility; graphic and symbolic content can be reworked into three-dimensional models or enriched with sound modulations that convey variations in shape, altitude, and spatial organisation. Integrating oral narration is also a valuable cognitive aid, facilitating understanding of spatial constructs in geography and reducing the mental load associated with abstraction in mathematical reasoning (Macchia & Torri, 2025b). This aligns perfectly with the distinctive characteristics of these subjects, as identified by the theory of signature pedagogies (Shulman, 2005; Gurung et al., 2009; Chick et al., 2012): namely, their role in promoting critical thinking, spatial reasoning and problem-solving skills in primary and lower secondary education.

Through describing and critically analysing digital prototypes for Years 3, 4 and 7 of Mathematics and Geography, this article demonstrates how subject teaching and signature pedagogies can be rethought through digital innovation to improve teaching effectiveness and inclusivity.

Before examining how these prototypes exemplify disciplinary and inclusive teaching practices, it is important to outline the theoretical framework that underpins their design. The intersection between Signature Pedagogies and Universal Design for Learning (UDL) provides the conceptual foundation on which the DEM project's prototypes are developed, ensuring that both disciplinary authenticity and inclusivity are addressed from the outset.

3. Signature Pedagogies and Universal Design for learning: a framework for Inclusive Disciplinary Teaching

A relevant aspect for an inclusive and equitable approach to digital education is the close theoretical and practical alignment between Signature Pedagogies and the principles of Universal Design for Learning (UDL). Both frameworks place learner diversity at the centre of the teaching–learning process and promote accessibility, flexibility, and engagement through multiple means of representation, expression, and participation. While Signature Pedagogies (Shulman, 2005; Chick et al., 2012) identify the distinctive epistemic and ethical practices that characterise each discipline, UDL (CAST, 2024) provides a design framework that ensures these disciplinary practices are accessible to all learners. Integrating the two therefore enables the preservation of disciplinary integrity while extending equitable participation to students with different abilities, backgrounds, and learning preferences.

Recent studies have begun to explore these convergences more explicitly. In professional and higher education, for instance, the American Occupational Therapy Association (AOTA, 2018) has recognised UDL as a *signature pedagogy* guiding how future practitioners are educated within occupational therapy programmes. Similarly, reviews of research on UDL in higher education have shown that it promotes proactive course design and reflective practice, encouraging educators to anticipate learner variability and to reframe inclusion beyond mere accommodation (Fornauf & Erickson, 2020).

Extending this reasoning to primary and lower-secondary education, research has focused on the operationalisation of UDL principles within everyday classroom practice, showing how inclusive design can sustain disciplinary teaching. In the Italian educational context, studies highlight that UDL-oriented design enables teachers to plan flexible and multimodal learning pathways that accommodate cognitive, linguistic, and sensory diversity (Cottini, 2019; Murawski & Scott, 2021; ASNOR, 2023). These contributions underline that the integration of UDL principles into subject teaching not only removes barriers but also reinforces students' engagement with the epistemological structures of each discipline. UDL supports both inclusion and the development of deep subject understanding.

Within the DEM project, this dual perspective is operationalised by combining the epistemological specificities of Mathematics and Geography with the principles of accessibility and multimodality derived from UDL. Through this lens, the digital prototypes are conceived not merely as barrier-free resources, but as learning environments that re-enact the disciplinary ways of thinking and doing described by Shulman as Signature Pedagogies—now rendered accessible to a broader range of learners.

4. Signature Pedagogies in Geography and Mathematics: Specifities and Challenges

The concept of 'signature pedagogies', developed by Shulman (2005), is key to understanding how disciplinary knowledge is transmitted and absorbed. These distinctive teaching methods are expressed through characteristic teaching practices and represent the unique features of each discipline. They influence the way students think, act and behave within a given field of study, thereby contributing to the development of their professional and disciplinary identity. Signature pedagogies are not just teaching strategies; they are deeply rooted in the epistemological and ethical principles that define each field of knowledge.

Building on the theoretical rationale outlined above, Mathematics and Geography offer fertile ground for exploring how digital innovation can enhance signature pedagogies. Both disciplines possess distinctive epistemological and methodological traits that make them exemplary cases for analysing disciplinary teaching within the DEM project.

In mathematics, these traits are evident in problem solving, guided discovery learning, the use of multiple representations and collaborative reasoning. Problem solving encourages students to tackle mathematical problems using different strategies, thereby promoting both procedural mastery and conceptual understanding. Exploring mathematical concepts through symbolic, visual, and concrete languages fosters a deep and flexible grasps of ideas (Ball & Bass, 2003; Ball et al., 2005). Collaborative reasoning is achieved through classroom dialogue and collective problem-solving, giving students the opportunity to articulate, discuss and refine their mathematical thinking.

In geography, signature pedagogies focus on spatial analysis, cartographic interpretation, inquiry-based exploration and the integration of heterogeneous data sources. Map interpretation involves reading, constructing, and analysing cartographic representations, thereby developing the spatial reasoning skills essential for geographical thinking (Lambert & Morgan, 2010). Exploratory investigation involves studying real phenomena through fieldwork, collecting data, and critically analysing environmental, social, and economic factors (Mönter, 2018; Lathan, 2024; Wittlich, et al., 2024). Integrating multiple sources involves combining geospatial data, images, and statistics to promote an articulated and systemic understanding of territorial complexity.

Both disciplines face significant challenges in the current digital context. Textbook analysis conducted as part of the DEM project has highlighted the lack of authentic interactivity and accessibility in many of the resources currently available. The integration of digital technologies should therefore not merely entail the transposition of content but instead aim to translate these disciplinary practices into digital formats that maintain their epistemic rigour while expanding accessibility and interactivity.

4.1 The value of digital innovation in subject-specific and interdisciplinary teaching

Digital innovation is a key driver of teaching renewal in both subject-specific and interdisciplinary contexts. When designed effectively, digital resources can increase accessibility, encourage interaction and facilitate personalised teaching. They also play a vital role in fostering connections between different subject areas. By adhering to principles such as the Web Content Accessibility Guidelines (WCAG) (W3C Recommendations, 2024) and Universal Design for Learning (UDL), (CAST, 2024), digital materials can be structured to be accessible to all students, including those with visual impairments or other specific requirements. On this topic, particularly relevant are the contributions by Degenhardt (Degenhardt et al., 2006, Degenhardt, 2014 and 2025).

Tools such as dynamic simulations, interactive maps and adaptive exercises based on artificial intelligence make interactivity and personalisation of learning possible. These tools can provide real-time feedback, differentiated learning paths and opportunities for active participation. Interdisciplinary connections can be facilitated by digital platforms that integrate data and representations from different fields of knowledge. Such platforms support teaching approaches grounded in inquiry and aimed at solving complex problems that transcend traditional subject boundaries. In light of these possibilities, the COVID-19 pandemic has prompted many countries to commit to digitalisation as a means of transforming education. Austria serves as one such example, as discussed by Edelsbrunner et al. (2021).

However, the literature review conducted as part of the DEM project highlights that the current landscape of digital textbooks for mathematics and geography is still unsatisfactory. In many cases, these resources are merely digital versions of paper-based materials and lack innovative features and effective accessibility. A recent study by Brnic et al. (2024) revealed that digital books offer significant advantages over paper materials in the field of mathematics, demonstrating that students can greatly benefit from the features of this kind of material (Brnic et al. 2024 and 2021). Therefore, the challenge is to design digital prototypes that are consistent with the epistemological core of the relevant disciplines and capable of harnessing the potential of digital technologies to enhance learning.

In the following section examples of digital prototypes developed for Grades 3/4 and 7 — one for each school level in the two considered disciplines will be illustrated and analysed. The prototyping process follows an iterative design-based research approach. Each prototype is developed and evaluated in cycles: the research team conducts initial design iterations, applies evaluation criteria and feedback options, and refines the design. This cycle of design, evaluation and revision is repeated until the prototype meets the required pedagogical and accessibility criteria.

5. Prototype 'Geld zum Einkaufen nutzen' (Using money to go shopping) Mathematics – Year 3 and 4 primary school

This prototype is a digitally enhanced mathematics teaching unit that focuses on the concept of money within the broader contexts of measurement and problem solving. Designed as a modular, interactive resource, it uses a variety of multimedia elements to stimulate mathematical reasoning, encourage the practical application of knowledge, and provide an inclusive learning experience.

5.1 Main features and structure

The prototype stands out due to its high level of accessibility, thanks to features such as dynamic visualisations, interactive tasks, multiple access modes, opportunities for differentiation and a section dedicated to teacher support. In terms of visualisation, the resource includes videos with transcripts and subtitles, drag-and-drop exercises, audio recordings, drawing tools, closed questions, tables, and fill-in-the-blank activities. Visual and audio information is carefully coordinated to cater for different learning styles.

Interactive activities involve students in tasks anchored in real-life situations, such as planning shopping trips, calculating totals and managing change. The box below provides an overview of the activities included in the unit.

Recording or writing responses to open-ended questions about shopping experiences
Watching a video showing a shopping situation where the students check that they have enough money
Drag-and-drop exercises with product selection, cost calculation, and matching coins to their amounts
Problem solving: Maximizing purchases while staying within a set budget
Problem solving: comparing prices and offers from different sellers before buying
Opportunities for peer sharing and collaborative comparison of solutions

Tab.1: Interactive tasks

With regard to accessibility and educational customisation, the prototype offers a variety of access methods for activities, including text and audio input options, adjustable difficulty levels, and the ability to enable or disable non-essential visual elements. The programme also incorporates support tools for educators, encompassing both educational methodology and practical guidelines for utilising real currency or tactile materials with students who are visually impaired. It is important to note that all interactive elements are accompanied by accessible alternatives. As the prototype design remains in a state of development, the research team reserves the right to determine which of the suggestions in this, and other prototypes are to be integrated directly into the prototype and which are to be incorporated into the official *Guidelines*.

5.2 Prototype "Gefäße füllen" (Filling vessels) Mathematics – Year 7 lower secondary school

The mathematics prototype, designed for Year 7 secondary school students, uses practical examples to help them better understand the relationships between variables. It involves them in activities where they measure the volume and height of liquids in differently shaped vessels to explore how these values change and influence each other.

5.2.1 Main features and structure

The prototype is structured into several interconnected stages. First comes an exploratory phase, dedicated to investigation *(Erforschen)*. This is followed by an experimental or simulation component, which includes data collection. Next is a visualisation step, where results are graphically represented. Then comes a segment devoted to discussion and reasoning. Finally, there is a deepening activity *(Vertiefung)*, designed to consolidate and expand understanding through a targeted task.

During the investigation phase, students formulate hypotheses about the relationship between the volume of water and the fill level height in two differently shaped containers. In the prototype, an input field called 'Collaborative Text' encourages them to share their hypotheses with their classmates. The next step is the experiment/simulation, for which there are three options. In option 1, learners conduct a physical experiment, measuring the filling height in 40 ml increments using a real glass, a ruler, and a graduated cylinder. In option 2, they use a GeoGebra simulation in which two GeoGebra applets reproduce the containers, allowing them to control the volume virtually and measure the height interactively. Option 3 involves watching a video demonstration: a video with real-time commentary showing the experiment, with a strong focus on the water level and measuring scale. This is accompanied by an accessible transcript and optional captions. The video is also planned to be preceded by explanatory pictures, which will contain keywords in German to facilitate comprehension for all viewers. As demonstrated in Figure 1, the research team is developing a possible image to be incorporated into the prototype.

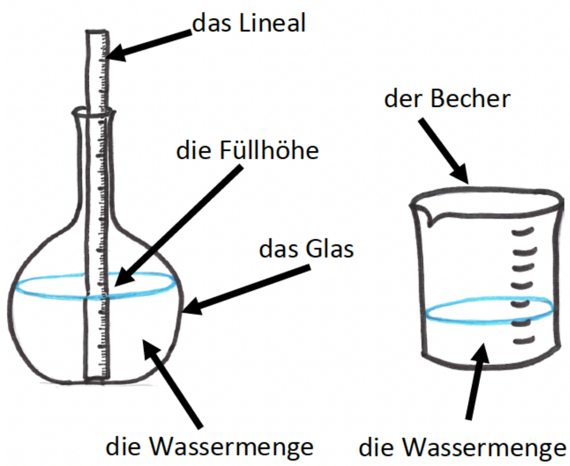

Fig. 1: Example of an explanatory picture

When representing data graphically, students can either draw a graph showing the relationship between volume and height or use a GeoGebra-based design tool. They can create this digitally or manually using a printable coordinate grid. This exercise helps them develop a better understanding of the relationship by exploring different modes of representation. In the discussion and reasoning section, students use guided suggestions to compare graphs, justify whether and how to connect various discrete data points and explain how to do so. They also consider how the shape of the container affects the graph's slope and curvature, relating the container's geometry to the function's behaviour. The in-depth task requires students to apply the concepts they have learnt. They are asked to evaluate the effectiveness of pencil sharpeners, enabling them to apply functional thinking to a new situation. The prototype incorporates a variety of task formats, including drag-and-drop, fill-in-the-blank, digital tables and flip-open hints. In addition, it provides a simple feedback mechanism (e.g. correct/incorrect indicators) to facilitate self-assessment.

5.3 Prototype: "Welcher Weg zum Gipfel?" (Which Path to the Summit?) – Geography, Year 3 and 4 primary school

This geography prototype is a digitally enhanced learning module focused on analysing and using altimetric representations in topographic maps. Designed for third- and fourth-year students, it uses interactive technologies and multimodal resources to develop spatial thinking and map-reading skills, as well as greater awareness of different users' needs.

5.3.1 Main features and structure

The prototype shares similar features with the one developed for mathematics targeting the same year groups. It includes an interactive digital map, multimodal input and output systems, built-in accessibility and differentiation strategies, open-ended and collaborative tasks, as well as dedicated support for educators.

The core resource of the prototype is a digital, interactive topographic map. It features elevation lines, customisable colour levels, legends and selectable routes. Students can explore the map and activate or deactivate information levels, as well as interact with various map elements. Multimodal inputs and outputs consist of images and descriptions of characters. These tools motivate students and create context by introducing three hikers with different needs: a wheelchair user, a mountain biker, and a hiker with a fear of heights. Audio tracks play the hikers' statements and instructions to promote auditory learning and accessibility. Tasks are presented in text and audio formats, and students can respond in writing, orally or tactilely. Accessibility and differentiation are achieved using tactile graphics (swell paper) and 3D-printed models based on the base map. This enables visually impaired students to perceive differences in height and routes. Texts written in simple language and step-by-step instructions support students with language or learning difficulties. Further differentiation is achieved through optional in-depth tasks (e.g. integrating weather variables) and open-ended tasks. The latter are distinctly cooperative in nature: students are asked to assign the most suitable route for each hiker, justifying their choices using the map information and the hikers' needs. As in previous cases, methodological notes guide teachers in adapting materials for different types of students, integrating tactile and digital tools, and encouraging collaborative learning.

5.4 Prototype: Die Erdoberfläche im Wandel (Transformations of the Earth's Surface) – Geography, Year 7 and 8 lower secondary school

This prototype focuses on the formation of stratovolcanoes and demonstrates the perfect integration of multimodal, differentiated, and inclusive learning approaches. Compared to the version designed for primary school students, this prototype expands both the pedagogical and technological dimensions to better address the cognitive, linguistic, and sensory needs of learners at the secondary level.

5.4.1 Main feature and structure

The instructional sequence is structured around the central guiding question – Wie ist der Berg entstanden? (How did the mountain form?) – and unfolds through a carefully designed learning pathway incorporating *visual stimuli*, collaborative hypothesis generation, and a differentiated exploration of volcanic processes.

At the core of the didactic design lies the explanation of how a stratovolcano forms. This is delivered through three adaptive learning pathways, each of which is tailored to specific learner profiles.

1. Learning Pathway 1 is designed for students who are visually oriented, as well as those with special educational needs in the language domain *(Förderschwerpunkt Sprache)*. This pathway emphasises image-based interpretation and guided written expression.
2. Learning Pathway 2 is designed for audiovisual learners and students with general cognitive learning difficulties *(Förderschwerpunkt Lernen),* employing interactive simulations, audio narration and scaffolded completion tasks.
3. Learning Pathway 3 is specifically developed for students with visual impairments *(Förderschwerpunkt Sehen*), offering tactile graphics, 3D-printed models and audio-based explanations.

Each pathway culminates in a personalised learning output (a written text, a completed cloze activity or an audio commentary), supported by intelligent feedback mechanisms. These mechanisms include AI-powered recognition of key disciplinary terminology and the use of structured sentence starters to guide learners in the independent formulation of subject-specific knowledge.

6. The impact of technology on the evolution of signature pedagogies and accessibility

In this section it is discussed how technology exemplifies, highlights and enhances the distinctive features of mathematics and geography, as well as accessibility.

6.1 Mathematics – primary school

The example applied to primary school clearly demonstrates the concept of authentic contextualisation: mathematical reasoning is placed in a familiar, everyday context, such as shopping. This allows abstract concepts, such as number sense, addition, subtraction and value comparison, to be anchored to meaningful and relevant experiences. This approach aligns with the signature pedagogy that links mathematics to real-life situations. Contextualisation is a key element in promoting mathematics learning and problem solving. Real-life contexts, in particular, allow students to apply their mathematical knowledge to analyse concrete situations. Proposed activities such as checking whether there is enough money for a purchase, comparing prices, and making the most of a set budget show how mathematics can be integrated into everyday life. These tasks stimulate the practical application of mathematical skills as well as critical reflection on and communication of the reasoning behind solutions. These elements lie at the heart of signature pedagogies in the mathematical field and are fundamental to developing students' skills in this domain. Another distinctive feature, highlighted by the prototypes, is the use of multiple representations and modalities: integrating video, audio, text and interactive graphic elements enables students to engage with mathematical content via various sensory channels. Drag-and-drop features for coins and products, combined with calculation fields and drawing tools, promote flexible mathematical thinking and cater for different learning preferences. Additionally, collaborative and reflective practices are emphasised, such as audio and text sharing features and peer comparison suggestions, which foster a culture of discussion, explanation, and collective validation of strategies in the classroom. These elements are fundamental to distinctive mathematical pedagogies. Problem solving with gradual support through differentiated tasks or optional in-depth activities (such as price validation or real-world price research) and guided teacher comments provides valuable support for struggling and advanced students alike. Furthermore, metacognitive awareness is promoted by encouraging students to explain their strategies and compare their answers with their peers'. The prototype encourages students to find multiple solutions, explore different strategies, and consider efficiency and accuracy. This promotes flexible problem solving and supports the development of creativity and mathematical adaptability.

The prototype demonstrates a strong commitment to accessibility, particularly for students with visual impairments or other learning needs. Alternative input and output modes are available, with each activity offering both audio and text input. This allows students with different strengths or disabilities to participate fully. The accessible visual design offers the option to enable or disable decorative images and use simple, high-contrast graphics. It also includes transcripts and subtitles for all videos, making content accessible to students with low vision or cognitive processing difficulties. Tactile and real-world adaptations are also included; for example, notes for teachers recommend using real coins and banknotes marked in Braille or with tactile indicators for blind or visually impaired students. This bridges the gap between digital and physical learning environments, ensuring authentic access to mathematical concepts. It is also worth mentioning the prototype's adherence to Universal Design for Learning (UDL): it offers multiple modes of engagement, representation, and expression, making the learning of mathematics accessible and meaningful for all students.

6.2 Mathematics – lower secondary school

The prototype for lower secondary school demonstrates how digital tools can enhance distinctive teaching methods in mathematics at this level. In this case, these methods are guided discovery, multiple representations and experimental investigation. The prototype also ensures accessibility for students with different needs. Guided discovery is achieved through dynamic visualisations and simulations. GeoGebra applets enable the real-time manipulation of water volume and provide instant visual feedback on fill height. Thus, interactive graphs are used to explore functional dependencies rather than static diagrams. This interactivity promotes guided discovery, as students refine their understanding iteratively based on visual evidence. Multiple representations can be seen in the multimodal input of data. For instance, offering both physical and virtual investigation paths — such as a video with synchronised captions and a complete transcript containing height measurements — enables students with hearing or visual impairments to select the most suitable mode. The adjustable representation formats further refine the accessibility of the proposed tools: the digital coordinate tracking tool and downloadable high-contrast PDF grids enable students with motor or visual impairments to interact with tables that are compatible with screen readers or tactile overlays. Additionally, the inclusion of pop-up text prompts ensures that students who need additional support can sustain their cognitive load. Furthermore, the structure of the prototype itself (formulation of hypotheses, data collection, graphical analysis and reflection questions) reflects the mathematical disciplinary habit of experimental investigation and metacognition. Students then design, perform and interpret experiments to demonstrate function concepts.

The two mathematical prototypes clearly show how technology can effectively support and enhance typical teaching methodologies of the subject, ranging from basic problem solving and real-world contextualisation to complex experimental investigation.

6.3 Geography – primary school

The distinctive characteristics of geography are clearly evident in the primary school prototype. The decision to interpret elevation lines, legends and symbols is indicative of spatial thinking and map interpretation, thereby promoting the development of essential spatial reasoning abilities.

The selection of routes for hikers with various requirements situates map reading within a practical, problem-solving context, establishing the basis for inquiry-based and contextualised learning. As in mathematics, multiple representations and modes play a central role in geography: the prototype combines digital, tactile and auditory resources, enabling students to access and represent spatial information in various ways. Students must manipulate and explore digital maps, justifying their decisions based on the characteristics of each map. Additionally, empathy and the ability to take on different perspectives are fostered: by considering the needs of different hikers, students' mental horizons are broadened, and the discipline of geography itself is positioned between accessibility and personal experience. Open reasoning, discussion and collaborative problem solving are also encouraged. From a technical accessibility perspective, the prototype demonstrates a strong commitment to universal design: tactile and 3D materials are available for visually impaired students, enabling them to explore altitude and routes through touch and ensuring their full participation in typical spatial reasoning activities. All instructions, map features and character statements are also available in audio format to support students with visual or reading difficulties. Plain language texts and clear, detailed instructions reduce barriers for students with language or learning difficulties. Students can also respond in a variety of ways: orally, in writing or via audio recordings, allowing for differentiated expression and assessment.

6.4 Geography for lower secondary school

The prototype exemplifies signature geography pedagogies through its emphasis on process thinking, model-based reasoning, and multimodal literacy. Process thinking is demonstrated through the focus on volcanic genesis, promoting an understanding of the Earth's dynamic systems and, consequently, spatiotemporal processes. Interacting with schematic representations, simulations and physical models to visualise underground structures and eruptive sequences promotes model-based reasoning, encouraging abstraction and conceptual transfer. Multimodal literacy is achieved by integrating visual, textual, auditory and tactile modalities, promoting a deeper understanding of geographical concepts and enhancing the ability to interpret complex representations through different sensory channels.

The prototype also demonstrates a high degree of accessibility thanks to its multimodal design, which can be adapted to different user needs. Its main technological features consist of highly specific tactile aids, such as swell paper and 3D-printed models, which make spatial and structural information accessible to blind and visually impaired students while preserving the integrity of the subject content. Audio narratives and other inputs support students with reading difficulties, auditory processing or motor disabilities. Image sequences can be interrupted at any point to activate specific terminology, enabling students to manage their own pace and cognitive load. A specific feature of this prototype is AI-supported feedback: intelligent systems provide personalised feedback based on the presence and contextual use of key terms, thereby improving metacognitive awareness and subject accuracy. Together, all these features make the principle of Universal Design for Learning (UDL) operational, ensuring access to the discipline is not dependent on a single mode of representation or expression.

This concise critical discussion of geographical prototypes demonstrates how technology can amplify and make key features of the discipline, such as spatial learning, inclusive design, and the development of affective skills like empathy, more accessible.

The subsequent table provides a comparative overview of the features identified in the prototypes.

Prototype	Grade Level	Discipline	Signature Pedagogies	Accessibility Features
Using money for shopping	Grade 3	Mathematics	Problem-based learning, multiple representations, real-world application	Audio/text input, tactile money, toggle images
Volume and functional relationships	Grade 7	Mathematics	Experimental inquiry, graphing, guided discovery	GeoGebra simulation, captions, tactile graphs
Which path to the summit?	Grades 3/4	Geography	Map interpretation and special reasoning, empathy	Tactile maps, audio support, simplified language
Stratovolcano formation	Grades 7/8	Geography	Processual thinking, model-based reasoning	3D models, audio narration, AI feedback

Tab. 2: Comparative Summary of Prototypes

7. Conclusion

The analysis of the four prototypes (two from mathematics and two from geography) reveals cross-cutting themes that demonstrate digital technologies' potential to promote subject-specific learning and inclusion. Firstly, all prototypes embody the principles of Universal Design for Learning (CAST, 2024), providing various modes of engagement, representation and expression to accommodate diverse student profiles. Secondly, each prototype aligns with the epistemological practices of its respective discipline according to Shelman (2005) and further studies (Gurung et al., 2019, Chick et al., 2012), emphasising approaches such as inquiry, model-based reasoning, and problem-solving in authentic contexts. It is worth emphasizing that the integration of technological tools in the promotion of signature pedagogies contributes to enhancing accessibility. The two elements are closely interconnected: many signature pedagogies already inherently contain the foundations for promoting accessibility, which in turn can serve as a means to strengthen their effectiveness. Furthermore, the use of multimodal resources, including text, audio, video, tactile graphics and simulations, ensures differentiated access to and inclusive use of subject content. Finally, the prototypes demonstrate how digital technologies can promote metacognitive reflection processes, collaborative dynamics, and personalised feedback, significantly contributing to the accessibility and conceptual soundness of learning pathways. This shows that content digitalisation is not a static process. It has the potential to transform teaching practices in experiences that are both epistemologically sound and socially inclusive.

In general, the analysis reveals that technological tool, represented by the prototypes, functions as a "litmus test" for bringing to light the distinctive features of the disciplines under examination. These specific features guide the teacher's educational approach in fostering the development of a broad range of competences, from strictly cognitive skills to more transversal ones.

While this paper has focused on the design and development stages of the DEM project, the forthcoming phase will address the empirical validation of the prototypes in real classroom contexts. These trials, planned across partner countries, will explore teachers' and students' interactions with the digital materials through classroom observations, interviews, and learning outcomes analysis. The resulting evidence will allow for a more systematic assessment of the educational impact and scalability of the DEM approach.

In considering the evolution of educational systems in the digital age, these teaching solutions can be regarded as a potential model for the development of future curricula, teacher training and educational research.

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