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Designing augmented reality concept maps applying a UDL-based chatbot: an integrated approach based on UDL guidelines

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Abstract: Augmented reality (AR) and generative artificial intelligence are increasingly present in education, yet their classroom use often overlooks learner variability, the reliability of data sources and privacy. This theoretical contribution proposes an integrated approach for designing AR concept maps that are inclusive by design. Drawing on the literature on AR, concept mapping and cognitive load, and on the Universal Design for Learning (UDL) Guidelines 3.0, the paper combines SMapp, an authoring tool that overlays multimedia content on paper-based concept maps through Near Field Communication technology, with a chatbot grounded in the UDL Guidelines and built on a Model Context Protocol server architecture. The result is a nine-step methodological model organized into three blocks: teacher-led conceptualization of the map, UDL review supported by the chatbot, and implementation of the AR map with SMapp, in which students can also produce the multimedia content. The paper also introduces inclusive node density, a criterion that links each resource attached to a node to an anticipated learning barrier, in order to prevent design by accumulation and the cognitive overload it may cause. Consistent with a human-in-the-loop perspective, the teacher retains final responsibility for design choices. A pilot study with teachers is planned as the next step.

Keywords: Augmented reality; Concept maps; Universal Design for Learning; Artificial Intelligence in Education; Human-in-the-loop

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1. Introduction

The early 2020s have seen a significant increase in educational research on the application of generative AI tools in teaching and learning (Garzón et al., 2025). In this context, a label has gained relevance: Artificial Intelligence in Education (AIEd) (Chen et al., 2022). AI is useful to optimize processes that require repetitive actions or when the teacher must create multiple variations of the same scheme, e.g., when designing assessment tools for students. AI represents a valid support for these activities, but many studies in different scientific disciplines stress the need for human experts to take part in the creation process as active participants in the system (Alkam et al., 2025; Nikitenko et al., 2024; Zajko, 2022). Theoretical approaches such as the human-in-the-loop (HIL) framework have formalized this scheme in a structured way (Natarajan et al., 2025).

Commercial tools for generative AI (genAI) are widespread and intensively used by an increasing number of users in every part of the world. AI systems are often applied in educational contexts without real knowledge of the system behind them and of its potential risks. The application of these commercial tools does not consider privacy risks or where students' sensitive data could be stored. In addition, hallucinations are not exceptional in these systems, because the knowledge bases from which they extract data are not validated by educational experts who could check the results and guide the selection of trusted information from correct data sources. Additionally, these systems are general-purpose and rarely consider the different needs in a class, including special educational needs. Starting from this background, the authors intend to provide a proposal that faces these challenges.

2. Materials and Methods

Augmented reality (AR) offers the opportunity to use digital tools that superimpose digital assets on the real world, as captured by a camera. Milgram and Kishino (1994) classified AR as a part of the Reality-Virtuality Continuum, where mixed reality (MR) embraces all the components between the real and virtual environments and AR is closer to the real side, because it represents only a digital support to the tangible world and the level of virtuality is low. AR is gaining a significant impact in education; nevertheless, research has yet to consider the whole potential of the AR application for learning, exploring pedagogical approaches that leverage the unique affordances of augmented reality, especially in active learning, problem-solving, collaboration and the development of critical thinking skills (Koumpouros, 2024). The capacity of augmented reality to improve learning outcomes in educational environments is well known and, in particular, educational AR-based approaches enhance comprehension and long-term memory of the subject matter (Tian & Ironsi, 2025). As with all methodologies, the application of AR also presents conflicting results in terms of cognitive load. In many cases, it appears to have a potentially negative effect on cognitive load (Buchner et al., 2021, 2022), possibly due to the intricate nature of AR tools, which require an initial full understanding of how they work (Tian & Ironsi, 2025).

One way to reduce cognitive load is the use of concept maps (Bolatli & Bolatli, 2024; Costley et al., 2025; Krieglstein et al., 2022), which have the potential to compensate for the difficulty of a topic by producing a visual and clear representation of the main concepts. In this way, teachers, acting as learning designers, are the crucial actors who can develop an understandable concept map that supports the learning process. The connection between concept maps and augmented reality is at an initial stage (Kefalis et al., 2025) but shows a good impact on learning outcomes (Liang et al., 2021), in particular for students with low prior knowledge of the subject, and helps to reduce the cognitive load and support the information retention (Ma et al., 2025).

In this context, it is essential to select solutions that combine the potential of concept maps with the advantages of AR and that, at the same time, have shown good usability in previous studies. An interesting tool in this sense is SMapp, a learning tool based on interactive AR maps developed by Smarted Srl (https://smarted.it/smapp-it/). SMapp is a mobile AR application based on Near Field Communication (NFC) technology, where digital multimedia content is overlaid onto a paper-based concept map via smartphone. Using SMapp, the

physical support remains central to learning, allowing a gamified and learning-by-doing experience. The software is designed as an authoring tool allowing the teachers to create their own AR concept maps without any specific prior knowledge in programming. Teachers can design physical concept maps, enabling interaction with the digital component that emerges when browsing the paper-based concept maps with a traditional smartphone equipped with the SMapp application (https://play.google.com/store/apps/details?id=it.smarted.smappreader&hl=it). This application allows teachers to empower the physical maps with digital information, including different multimedia. This multimedia content can include audio and video recordings made at school by the students or by the teacher, creating a strong emotional connection during the learning experience and supporting a constructivist approach. Initial studies indicate good usability of the system (Lella et al., 2025), an aspect that has the potential to mitigate the known cognitive overload associated with AR tools.

Nevertheless, this approach does not include any inclusive orientation. Although concept maps are known for their impact in special education (Ciullo et al., 2015), using SMapp the teacher has an open sandbox in which any type of content can be included, but no scaffolding for the inclusion of special educational needs. In this sense, an opportunity is offered by the Universal Design for Learning (UDL) principles, which consider learner variability a crucial aspect of human diversity and focus on it without treating it as an obstacle (Hitchcock et al., 2002; Kennette & Wilson, 2019; Meyer et al., 2014). The UDL framework was conceived to overcome barriers, at cognitive and physical level, ensuring flexibility in the presentation of the information. The latest version of the guidelines, 3.0, was published by CAST (2024) and provides a clear scheme to design innovative and inclusive learning tools.

The inclusion of the UDL approach in designing significant learning experiences that apply AR concept maps is not straightforward, because teachers must have a deep knowledge and understanding of the UDL framework and be able to apply it without any supervision.

In this sense, artificial intelligence can support teachers by guiding them, on the basis of the UDL guidelines, in the design of concept maps to be implemented with a usable tool such as SMapp. For this purpose, a chatbot (Sasanelli et al., 2025) adhering to the UDL 3.0 guidelines was developed on a Model Context Protocol (MCP) server architecture that incorporates the guidelines and facilitates the multimodal transposition of instructional materials (https://udl-mcp.pages.dev/). Each document or prompt undergoes a UDL evaluation, which leads to the adaptation of the file and the subsequent generation of a task. Within the conversation loops, the orchestrator provides the outcome in terms of a new file or a proposal of action on the initial prompt.

Among the technologies explored by educational research in recent years, augmented reality (AR) has a feature of particular interest for inclusive teaching: it leaves intact the physical environment in which learning takes place and enriches it with information that each student can activate and explore according to their own needs. Applied to the concept map, this feature acquires specific relevance. On paper, the map conveys the architecture of a knowledge domain through nodes, propositional relations and hierarchical levels (Novak & Cañas, 2008), while leaving implicit much of the meaning condensed in each concept, much as a city plan

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describes the layout of spaces without saying anything about what happens inside them. AR makes it possible to associate verbal, iconic or audiovisual resources with each node, while the paper base continues to ensure the stability of the structure. This hybrid nature is reflected in two passages of the UDL Guidelines 3.0. Consideration 1.1 observes that in print materials information is presented in a "fixed and permanent" way, unlike digital formats, which allow it to be customized; consideration 1.2 recognizes the advantage of permanence offered by text and suggests making it available in auditory form as well, so as to combine this stability with the benefits of listening (CAST, 2024). The augmented map reconciles both requirements.

The Guidelines, moreover, explicitly refer to the concept map at several points, spread across the principles "Design Multiple Means of Representation" and "Design Multiple Means of Action & Expression": as a tool for making the relationships between ideas visible (consideration 2.1), among the advance organizers that help activate prior knowledge (3.1), as an aid to note-taking and to connecting new information with existing knowledge (3.4), and among the tools for construction and composition (5.2) (CAST, 2024). These are complemented by more general references to graphic organizers, the category to which the concept map belongs, used to highlight big ideas and relationships (3.2) and to organize information when the load exceeds working memory capacity (6.3). This invites a reading of the map as a device that cuts across several levels of the framework, rather than as one of its many possible applications. On the empirical side, the effectiveness of concept maps is supported by meta-analytic evidence (Nesbit & Adesope, 2006), and positive effects on learning outcomes have also been reported for AR (Garzón et al., 2019; Tian & Ironsi, 2025). The picture regarding cognitive load is less clear-cut: according to the systematic review by Buchner et al. (2022), the novelty of the medium and the need to integrate information from the physical and the digital world can increase extraneous load, at the expense of the attentional resources available for processing. Ma et al. (2025) investigated the introduction of a concept map strategy in an AR learning environment and found a positive effect on the development of mental models among students who started from low- or intermediate-level models, together with a reduction in perceived mental effort, whereas no significant differences emerged in mental load. This suggests the hypothesis that, in these contexts, the map performs a compensatory function, which is more marked for learners with fragile prior knowledge.

The design question remains open. Authoring applications such as SMapp give teachers considerable freedom in associating materials with nodes and, in the absence of explicit criteria, may lead them to proceed by accumulation, in the belief that multiplying channels and resources in itself makes the activity more accessible. The Guidelines provide arguments for questioning this assumption. Consideration 3.3 recommends chunking information so as to avoid cognitive overload and removing unnecessary distractions; consideration 7.4 suggests varying the number of items presented at the same time; consideration 4.2 warns that accessibility should not inadvertently reduce the level of challenge (CAST, 2024). The considerations should therefore be understood as indications to be selected and combined in relation to goals and context, rather than as requirements to be met all at once. Read in this way, they make the principle "Design Multiple Means of Representation" compatible with the redundancy principle of the cognitive theory of multimedia

learning (Mayer, 2020), since what the framework calls for is variability intentionally planned in relation to anticipated barriers (Meyer et al., 2014). An option lacking these anchoring risks adding complexity without widening access.

To translate these indications into the construction of the augmented map, it seems useful to complement the vertical organization by principles with the horizontal one, which distinguishes the Access, Support and Executive Function rows. The paper base, with its activation points, mainly concerns the Access row: here the teacher's choices relate to perception, for example the availability of auditory and textual equivalents or the adjustment of volume and playback speed (considerations 1.1 and 1.2), the ways in which students can move through the map and activate its nodes (4.1 and 4.2), and the exploratory and playful component of the experience (7.3). The multimedia content associated with the nodes, by contrast, falls mainly within the Support row, where it can serve to clarify disciplinary vocabulary and to illustrate concepts through different languages (2.1 and 2.5). Its production can be entrusted to the students themselves, who are asked to create explanations, examples and short narratives to be linked to the nodes (5.1 and 5.2); in this case, the map welcomes the voices and perspectives of the class, also responding to a need that the Guidelines place in the Access row (1.3), and fosters interdependence and a sense of belonging to the learning community (8.3 and 8.4). Finally, the hierarchical structure of the map involves executive functions, as it highlights the main ideas and their connections (3.2), relieves working memory (6.3) and provides a reference point to return to in order to monitor progress and reflect, individually and in groups, on one's own learning path (6.4 and 9.3). It is also plausible that placing digital content at the node to which it refers mitigates split-attention effects, in line with the spatial contiguity principle (Mayer, 2020), although on-screen display maintains a partial separation between the two sources.

Taken together, these choices are consistent with the goal that the Guidelines place at the top of their graphic organizer, namely the development of learner agency that is "purposeful & reflective, resourceful & authentic, strategic & action-oriented" (CAST, 2024). Within this framework, the UDL-based chatbot is assigned a review task: it provides the teacher with an analysis of the consistency between the decisions taken and the UDL considerations, while leaving final responsibility with the teacher, according to a human-in-the-loop approach already discussed in relation to initial teacher education (Sasanelli et al., 2025).

Returning to the risk of design by accumulation, we propose a criterion, provisionally termed *inclusive node density*, intended to support the teacher during the ideation phase and the chatbot during the review phase. It takes the form of a question that teachers can ask themselves whenever they intend to link a resource to a node: which barrier to learning do I intend to overcome with this resource, and for which students? When the answer is clear, the resource has a reason to be in the map, since it corresponds to a barrier identified in advance and to a specific UDL consideration; when the answer is missing, the resource is likely to be superfluous and to end up weighing the node down. Consider a map on the states of matter. To the node "gaseous state", the teacher can attach a short animation showing particles moving freely in a gas, compared with their ordered arrangement in a solid, aimed at students who struggle to represent a model that cannot be directly observed (considerations 2.5 and 3.3), and a read-aloud of the definition, intended for students with difficulties in decoding written text (1.2 and 2.2); each of the two

resources addresses a specific barrier. If a second video, an interactive game, a quiz and a table of boiling points were added to the same node without a comparable rationale, students would face an number of stimuli that is difficult to manage, and the map, designed to orient them, would end up disorienting them. Inclusive node density thus refers to the ratio between the amount of material associated with a node and its actual instructional rationale. This hypothesis lends itself to empirical testing that compares three types of data: the number and type of elements prepared by the teacher for each node; those actually accessed by students, which can be traced through the application's usage logs; and perceived cognitive load, measurable through self-report scales. Cross-referencing this information would make it possible to establish whether the range of options made available translates into actual understanding or remains underused or even becomes a source of fatigue.

3. Results

The AI chatbot is grounded in the UDL guidelines: the chatbot does not rely on untrusted or unvalidated data, the goal being to build an infrastructure that hides technical complexity, so that teachers can focus only on their teaching, with a system able to supervise it from an inclusive perspective.

The proposal of this paper is to present a methodologically integrated approach for a coherent development of concept maps based on UDL 3.0 guidelines aimed at designing a truly inclusive learning experience empowered by the potential of augmented reality.

3.1. The nine-step methodological approach

The methodological approach consists of nine steps aimed at guiding the teacher in the development of AR concept maps:

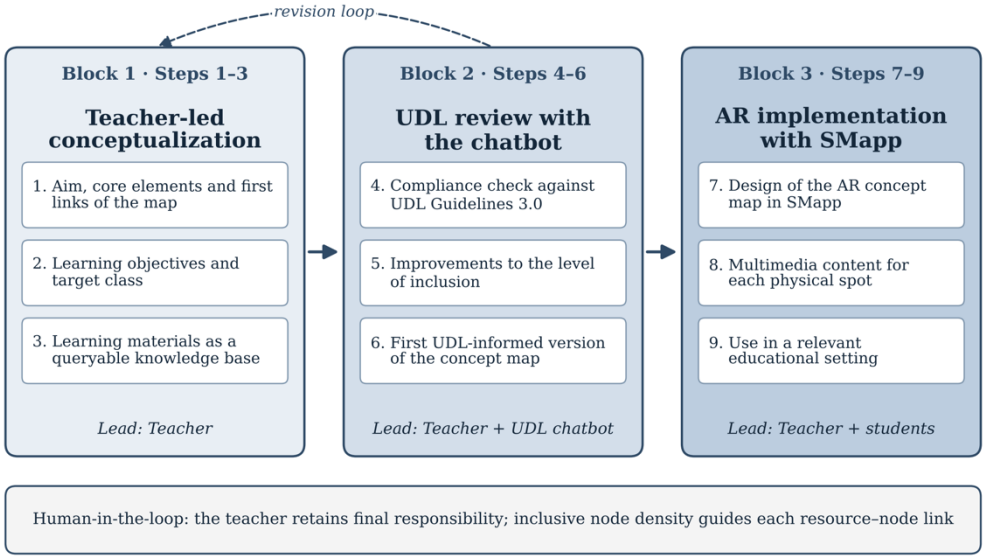
Numbered lists can be added as follows:

1. Define and report, in a template shared in the conversation with the AI, the aim of the concept map, its crucial elements and the first interconnections between its components.
2. Define the learning objectives and the class or the students the concept map refers to.
3. Include all the learning materials that could be used as resources for the chatbot, transformed into a queryable ontology.
4. Evaluate the compliance with the UDL guidelines using the feedback provided by the UDL chatbot.
5. Improve the level of inclusion of all students, if needed or proposed by the UDL chatbot.
6. Deliver the first version of the concept map derived from the UDL chatbot.
7. Design the AR concept map by using the SMapp authoring tool based on the results of the interaction with the UDL-inspired AI chatbot.
8. Include the digital multimedia in each physical spot, with the support of the UDL chatbot.
9. Apply in a relevant educational setting.

3.2. Organization of the steps into three blocks

As further discussed in Section 4, the nine steps can be grouped into three blocks of three actions each, which differ in the actor leading the process, the role played by the UDL chatbot and the output produced (Figure 1 and Table 1). The first block (steps 1–3) concerns the teacher's conceptualization of the map: the teacher defines its aim, core elements and first interconnections, specifies the learning objectives and the target class, and provides the materials that the chatbot transforms into a queryable knowledge base. The second block (steps 4–6) is the UDL review phase, in which the chatbot assesses the draft against the UDL Guidelines 3.0, proposes adjustments to increase the level of inclusion and returns a first version of the concept map; when its feedback calls for substantial changes, the teacher can go back to the first block. At this stage, the inclusive node density criterion is applied to verify that each resource planned for a node responds to an anticipated barrier.

Figure 1. The three blocks of the nine-step model for designing UDL-informed AR concept maps. The dashed arrow indicates that the UDL review may send the design back to the conceptualization phase.



The third block (steps 7–9) covers the implementation of the AR map with the SMapp authoring tool, the association of multimedia content with each physical spot and the use of the map in an educational setting; in this block, students can take part in producing the content. Across the three blocks, the teacher retains decision-making responsibility, while the chatbot acts as a reviewer, consistent with the human-in-the-loop approach (Natarajan et al., 2025).

Table 1. Organization of the nine-step model into three blocks.

Block	Steps	Lead actor	Role of the UDL chatbot	Main output
Conceptualization	1–3	Teacher	Receives the template, objectives and materials; builds a queryable knowledge base	Draft structure of the map, learning objectives, resource base
UDL review	4–6	Teacher with the UDL chatbot	Checks compliance with the UDL Guidelines 3.0, suggests improvements, supports the inclusive node density check	First UDL-informed version of the concept map
AR implementation	7–9	Teacher and students	Supports, on request, the creation of multimedia content for each spot	AR concept map in SMapp used in an educational setting

Note. AR = augmented reality; UDL = Universal Design for Learning. Step numbers refer to the list in Section 3.1.

4. Discussion

The debate on the role of the AI in the educational field is still open, with a big question in the background: is AI better than my professor? (Chan & Tsi, 2024; Fitria, 2023; Triberti et al., 2024). In this proposal, the teacher is supported by AI only for compliance with the UDL guidelines and for exploiting the potential of AR tools. The teacher is called to trigger the system, not with the usual prompt of a couple of lines, but by also providing the first intellectual effort in defining the first sketch of the concept map, which will then be optimized on the UDL principles.

The nine-step model is divided into three blocks of three steps each (see Section 3.2, Figure 1 and Table 1):

i) the first three actions relate to the teacher's conceptualization of the concept map, which is carried out in a structured manner but may include any type of document that the teacher considers coherent and useful;

ii) from the fourth to the sixth actions, the chatbot checks compliance with the UDL guidelines and provides its feedback and assessment;

iii) the last three steps implement the results of the interaction with the chatbot, using the SMapp authoring tool for the final creation of the AR concept map.

In particular, the last block is where the teacher creates – potentially with the support of the chatbot – the audio and video content that will be crucial in the interaction. This part could be performed also in class by the students: the teacher defines the learning objectives, and the initial scheme of the AR concept map, and the students develop the multimedia content. In this way, students acquire new knowledge of a given topic by developing materials, in a constructivist approach: they could also use AI, but with the primary aim of conceptualizing the content and realizing it in a well-crafted, aesthetically pleasing form, applying an inclusive approach. This proposal is in line with the Human-in-the-Loop approach, where teachers and students are fully supported by AI but remain a crucial part of the process, leading to an inclusive result based on UDL guidelines.

The formalization of the methodological approach for an integrated inclusive model represents the initial stage of the research; the next step, not included in this

proposal, is an empirical pilot study involving teachers in the creation of AR concept maps and evaluating its impact in specific fields.

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