MULTIMODAL STRATEGIES FOR STEM/STEAM EDUCATION: ANALYSIS OF AN INCLUSIVE WORDPRESS-BASED PROGRESSIVE WEB APPLICATION

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МУЛТИМОДАЛНИ СТРАТЕГИИ ЗА STEM/STEAM ОБУЧЕНИЕ: АНАЛИЗ НА ПРИОБЩАВАЩО ПРОГРЕСИВНО УЕБ ПРИЛОЖЕНИЕ, БАЗИРАНО НА WORDPRESS

Abstract

This paper investigates the foundations and practical implementation of multimodal learning strategies in digitally inclusive STEM/STEAM education. The realization of a blended learning environment through a progressive web application, linked to a decoupled WordPress instance, is presented. By following a mixed-methods methodology, anchored in multimodality principles, the educational platform provides support for real-time content management and optimized cross-platform performance. Its conceptual structure relies on an ontological model which features WordPress content objects as learning artifacts for the encouragement of reflective and accessible knowledge construction. The paper further examines the pedagogical affordances of enabling students, enrolled in software engineering and digital media focused bachelor programs, to engage in content publishing and visualization as a learning approach, while assessing the effects of technological separation on user experience. Findings contribute to the discourse on educational multimodality by demonstrating the potentials of the integrated solution in fostering STEM/STEAM competencies.

Keywords: *STEM/STEAM Education; Multimodal Learning Strategies; Inclusive Digital Learning Platforms; Blended Learning Environments; WordPress; Progressive Web Applications (PWA); Ontological Model.*

1. INTRODUCTION

Even before the Common Era, early philosophy wrestled with the idea that an object is viewed as a collection of its appearances. As it is described in the Diamond Sutra [1], Buddha separated the essence of the universe from various modalities such as sight, sound, smell, taste, and touch. In the 18th century the philosopher Immanuel Kant took this concept a step further by positing that humans perceive not the “thing-in-itself”, which he called noumenon, but only its representations, or phenomena, from the empirical world, stating in his work Prolegomena: “And we indeed, rightly considering objects of sense as mere appearances, confess thereby that they are based upon a thing in itself, though we know not this thing in its internal constitution, but only know its appearances, viz., the way in which our senses are affected by this unknown something” [2]. A phenomenon, for Kant, denotes that which appears within the restricted sphere of understanding in relation to the conditions of sensible intuition, and is scientifically treatable. Conversely, the noumenon refers to the purely thinkable, that which could not be the object of scientific consideration, but can, in principle, be an object of rational thought [3]. From this perspective, human cognition of the world, may therefore be seen as the sum of multiple modalities of underlying, yet fundamentally unobservable objects [4].

The importance of multimodality extends beyond metaphysics to learning practices. In this connection, multimodal learning is a domain that develops at a rapid pace by featuring distinct methods for the synthesis and utilization of a range of informational media, comprising text, images, audio, video, and sensor data for different purposes, for instance, natural language processing, speech recognition and education [5]. Multimodal learning can also be perceived as an educational approach that takes into account the many ways in which individuals absorb, process, and integrate information [6], [7].

The significance of current multimodal pedagogy rests in its transformative capacity to nurture problem-solving abilities and a lifelong dedication to learning. This engagement with learning is encouraging for students to actively investigate, inquire about, and put knowledge into practice as well as create bonds with the subjects they are studying in the contemporary reality, where the information is in a constant state of flux [8], [9], [10]. Multiple academic areas, including sciences and arts, use multimodal learning strategies, which demonstrates the adaptability and wide application of those strategies for diverse educational needs [11].

There are two main approaches that focus on teaching science effectively - STEM (Science, Technology, Engineering and Mathematics) and STEAM (Science, Technology, Engineering, Arts and Mathematics). The STEM approach to education aims at motivating learners through practices, contexts and processes that enable them to participate in activities that lead to STEM-career pathways [12]. It employs an interdisciplinary method that fosters inquiry, imagination, questioning, creativity, invention, and collaboration [13], stressing the crucial role of equipping 21st century skills like critical thinking, agility, initiative, effective communication, and morals [14]. In STEM the access and analysis of information are also supported, as well as opportunities to apply the acquired understandings and insights in the field of science [15], [16].

The distinction between STEM and STEAM lies in the inclusion of 'Arts' in STEAM. The framework for the STEAM educational approach incorporates the arts to enhance education by exposing the learners to the objective view offered by science complementary to the subjective view of the world espoused by the arts [17]. The common processes of science and arts encompass discovery, observation, experimentation, description, interpretation, analysis, evaluation, visualization, exploration, and communication [18], although the differences in their manifestation can be linked to the emphasis that art places on combining knowledge and personal experience, while science mainly concentrates on the search for objective evidence to generate knowledge [19].

The paper is organized as follows: after the introduction, the foundations, theories and commonly adopted frameworks of multimodality in learning are outlined. Next, an ontological model is formulated along with an analysis of the implemented multimodal strategies in a progressive web application (PWA), geared towards providing a blended inclusive learning environment. The application is based on the content management system (CMS) WordPress and functions as a learning platform for university STEM/STEAM disciplines, where the topics of CMS and software and media ergonomics are studied. Further, the chosen research methodology is justified and the results from a contextual questionnaire, involving student participants in the aforementioned disciplines, are systematized and evaluated. Finally, a discussion explores questions concerning the accessibility and multimodal credibility of learning management systems (LMS) solutions and their effect on user and learning experience and the cultivation of STEM/STEAM competencies. A brief conclusion then summarizes the key findings of the research.

2. Foundations, Theories and Frameworks of Multimodality in Learning

Concept and Historical Roots of Multimodality

The channels for learning and information processing in the human mind have a profound impact across various educational activities with one of the most significant manifestations being the fusion and synergy of multimodality in education [20]. In this regard, humans interpret a construct through an array of such channels in the forms of text, image, sound, gaze, and other sensory inputs. These distinct types of informational media are referred to as "modalities" and each one of them partially contributes to making sense, while being instrumental to the whole process of learning [20], [21].

In fact, researchers have investigated the multimodality quality of learning for centuries. The early history of multimodal learning can be traced to the milestone work of John Amos Comenius, entitled Orbis Pictus (1658) [22], which is the very first textbook with pictures in the history of education. It was used for studying by European children for over two centuries and its content was presented in the majority of its editions in the Latin language, whereas the images and the embedded objects were explained in two separate languages concurrently. This picture textbook had a long-term influence on children's education, since it acted as an early model for both visual and textual educational approaches [23].

In the 19th century Laterna Magica (Magic Lantern) arose as a medium for conveying learning information, also serving as a pioneering version of the device, known as the projector. Through this invention concrete learning content can be structured and visualized, deeming it a major achievement for visual aids in education [23]. Later in the first half of the 20th century motion pictures, represented by film and television could relay messages and transmit knowledge, thereby increasing the amount of the disseminated information in the educational resources [24]. As audio-visual media was being adopted at an accelerated rate in public institutions, a practical need emerged for uncovering the extent of multimedia's impact in the processes, connected to the perception of learning material [25].

Dual Coding and Multimedia Learning Theories

The authors of [26] put forward the idea that humans are in possession of two cognitive subsystems: a verbal system that interprets linguistic information through media like text and an imaginal system that assigns meaning to non-verbal information like image sensory input. While the former excels at sequential and symbolic information processing, the latter specializes in holistic and spatial information processing. Even though the two systems can be distinguished, they work in collaboration for interactions which improve memory and comprehension [23]. For example, if students read written down words, this may lead to a simultaneous generation of a parallel visual imagery. However, due to the difference in their knowledge and educational experience, such visualization could be less accurate. In [26] a hypothesis is proposed that when students learn from multimedia with both verbal and visual explanations of a natural phenomenon, they first build respective mental representations of verbal and visual systems, followed by the construction of referential connections between those two representations. This theory was termed Dual Coding Theory (Fig. 1).

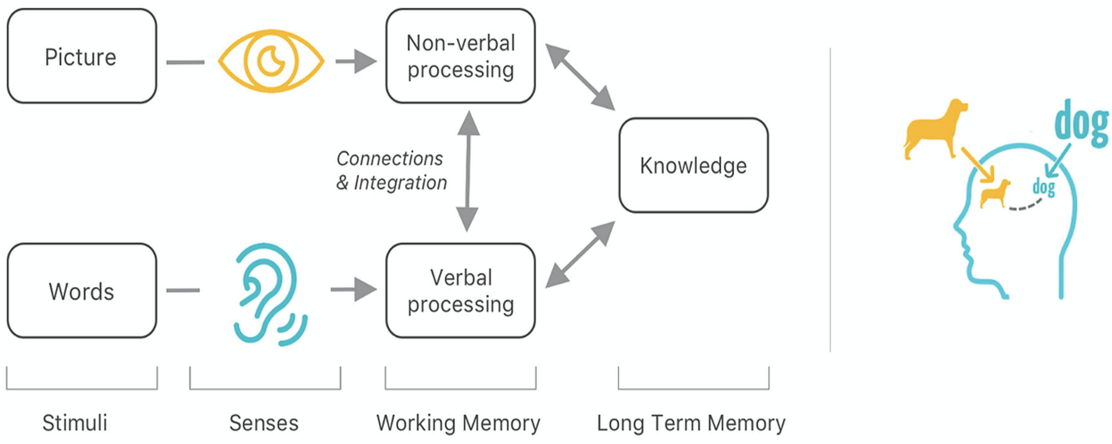

Fig. 1. Dual Coding Theory

In alignment with the dual coding theory, [27] introduced the Multimedia Learning Theory (Fig. 2), which posits that students' working memory enables the generation of mental representations of external sensory stimuli and the establishment of referential connections between the visual and verbal representations. Because of the constraints of the working memory, the capacity for processing information of each channel is limited. Therefore, experiencing overload on any channel can result in impeded learning and information retention, which is why the depth of content provided to learners should be carefully considered [23]. In [27] these cognitive limitations are addressed by listing the following principles: 1) multimedia - effective learning requires combined text, images and audio, 2) contiguity - text and images should be presented closely rather than separately, 3) modality - the explanation of visual material via narration is of great efficiency, 4) redundancy - excessive on-screen text can strain the visual channel, 5) coherence – the addition of extraneous material should be avoided, if it does not directly support the learning objectives, 6) personalization – word presentation should refrain from entirely formal, machine style of writing, 7) segmentation – breaking a lesson into user-paced segments simplifies its interpretation, 8) pre-training – preliminary familiarization with concepts can enhance the understanding of the material.

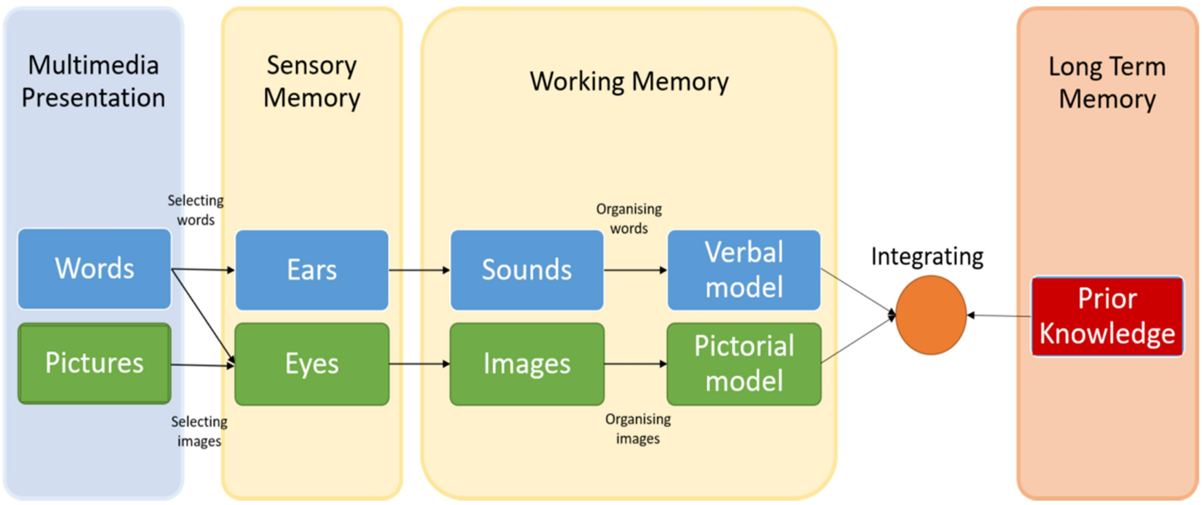

Fig. 2. Multimedia Learning Theory

VARK (Visual, Aural, Read/Write, and Kinesthetic) Multimodality Framework

While the channels for information processing are well articulated in the Dual Coding and Multimedia Learning theories, researchers determined that learning extends beyond media types to include communication modes. In [21] the proposition of a more sophisticated framework for multimodal learning is foregrounded, called VARK, where the acronym VARK stands for Visual, Aural, Reading/Writing and Kinesthetic modes, shown on Fig. 3. Visual (V) learners opt for acquiring knowledge through seen data like images and flow charts. Aural (A) learners lean towards hearing the information that needs to be interpreted. Read/Write (R) learners find the written words more suitable for studying, for instance a common practice for them is to take notes, reread them multiple times and repeat them verbatim. Finally, kinesthetic (K) learners grasp new ideas better through experience and practice and consider real-life examples helpful [28]. The assertions of VARK are founded on cognitive science such as neuro-linguistic programming, split-brain research, and left/right brain modalities. Furthermore, it merits attention that the authors of [21]: 1) differentiate preferences for graphical and symbolic representation – the 'visual' mode from printed representation - the 'Read/Write' mode 2) express deep concerns about the students' metacognition on their learning styles, 3) offer strategies for learning that correspond to individually preferred combinations of learning modalities. Posterior studies have revised and validated the VARK framework by demonstrating the effectiveness of multimodal teaching [29] and by examining the distribution of favored learning modalities among students [30].

Fig. 3. The VARK framework for multimodal learning

3. METHODOLOGY

Objectives of the Current Study

Many contemporary traditional learning platforms face the issue of fragmented learning and user experience by offering static and uniform content that cannot adapt to the diverse learning styles of students, often lacking a cohesive, theoretical framework to guide their design. To address these limitations the current study evaluates the pedagogical affordances and the technical implementation of an inclusive WordPress-based progressive web application. The aim of this work is to create and validate the resulting dynamic blended learning environment that is continuously adaptable to the needs of learners by employing a preliminary theoretical foundation realized through an ontological model, a hybrid architecture for the development of the target application, questionnaire data collection and a qualitative and quantitative analysis that assesses its impact on student skills acquisition. This approach can provide evidence for the efficacy of multimodal learning strategies in cultivating STEM/STEAM competencies.

The methodology includes the following stages:

- Platform Design and Development: The progressive web application is constructed in line with the entities of a predefined ontological model
- Data Collection: A structured questionnaire is administered for gathering student perceptions on the features of the platform and its overall influence on their learning styles and practices
- Data Analysis: Machine learning algorithms such as k-means and linear regression are used to analyze the collected data from the survey and to identify patterns in the feedback from the students
- Validation and Interpretation: The questionnaire results are evaluated so that the design principles of the platform can be validated and their implications discussed in terms of the integration of multimodal techniques in learning management systems

Theoretical and Pedagogical Framework

The design of the progressive web application is rooted in the pedagogical postulates of multimodal learning and the VARK framework whose model serves as a lens through which the learning preferences of the students can be categorized, thereby directing the engineering process of the platform's functionalities. Such design gives precedence to accessible and engaging educational materials for all students, which is critical for sustaining the inclusive learning environment, for nurturing STEM/STEAM skills and competencies such as digital literacy, problem solving and creativity, as a deeper understanding of technical concepts can be gained by addressing multiple learning styles concurrently.

Research Design

The study adopts a mixed-methods research design, which blends data collection with qualitative and quantitative analysis via a completed questionnaire. The qualitative aspect yields detailed insights into the learning and user experience of the students and subsequently the collected data undergoes quantitative analysis to move beyond subjective accounts, so that statistically significant relationships and patterns can be identified. Ultimately, by merging individual student feedback with broader, data-driven observations a thorough evaluation of the learning outcomes from using the platform is achieved.

Data Collection and Preparation

The research material for this study is the target progressive web application, which is an educational tool for two semester-long undergraduate courses Content Management Systems and Software and Media Ergonomics. Data were collected through a conducted Google Forms questionnaire with restricted access for the students enrolled in the bachelor degree programs Software Engineering and Information Brokerage and Digital Media in the 2nd and 3rd year of their higher education, respectively. The questions of the survey adhere to the ontological model and the learning components of the platform and are designed to assess the level of usability of the user interface and the multimodal engagement with Likert-scale responses on the quality of the visual, aural, textual, and kinesthetic features as well as the improvement of digital competencies in the concrete areas of the disciplines. The data were gathered at the end of the semester given the fact that students had extensive experience with the platform. The questionnaire data, consisting of both numerical ratings and textual responses were converted to a CSV file in order to be preprocessed with helper Machine Learning libraries for the programming language Python within the Jupyter Lab environment. Textual responses were arranged into categories and all the data were prepared for algorithmic analysis which involved the normalization of numerical scales and initial visualization.

Data Analysis Algorithms

The preprocessed data were analyzed using two key machine learning algorithms to uncover patterns and interconnections:

- K-Means Clustering: The k-means clustering algorithm is a commonly adopted algorithm in cluster analysis due to its simplicity and scalability [31]. It is capable of automatic clustering when handling unlabeled datasets and can be applied to different dataset types, categorizing it as unsupervised learning. In addition, K-means clustering is also very interpretable and can clearly show the clustering results [32]. Hence, this unsupervised algorithm was used for the identification of distinct learning preference groups derived from the answers to the questionnaire by the undergraduate students. By forming clusters of students who share similar learning preferences or have left similar feedback in the survey, it was possible to segment the user base and discern the different learning profiles (visual, aural, read/write and kinesthetic) which belong to the VARK framework and how their representatives interact with the platform.
- Linear Regression: Regression analysis estimates dependent 'y' variable value as a function of the range of independent variable values 'x' [33]. Linear Regression is a case model which distinguishes the influence of independent variables from the interaction of dependent variables [34]. This supervised algorithm was implemented to make models and predictions of the relationship between given variables. It was used for the testing of specific hypotheses, for instance whether a student's engagement with a particular set of multimodal elements (e.g., visual heuristics) directly correlated with their self-reported improvement in a specific competency (e.g., creative skills). Other hypotheses investigated the correlations between learning engagement with textual or aural features and stated improvements in data literacy skills, or how kinesthetic features affect problem solving abilities.

4. Ontological Model of the Inclusive WordPress-based Progressive Web Application

Ontologies are a formal and explicit means of describing taxonomies and enabling a classification within conceptual networks, essentially defining a vocabulary and a conceptual structure for a domain of interest, where the nouns represent classes of objects and the verbs relations between those entities [35]. While ontologies resemble class hierarchies in object-oriented programming, there exist several critical differences that should be noted. Class hierarchies are primarily designed for representing programmatic structures and type systems used in source code that evolves fairly slowly, whereas ontologies are expected to be almost constantly refined. Moreover, class hierarchies tend to be mostly static, relying on far less diverse data sources. On the other hand, ontologies are engineered for formal knowledge representation and semantic interoperability and provide rich axioms which capture intricate domain relationships and constraints. This inherent flexibility to integrate and interpret information that stems from heterogeneous data sources is what fundamentally distinguishes them from class hierarchies [36].

The conceptual framework of the inclusive WordPress-based progressive web application is delineated by an ontology that leverages the Web Ontology Language (OWL 2) to develop a machine-interpretable, declarative model of the learning platform domain's core entities and their interrelationships using the specialized software Protégé in a desktop environment. In Fig. 4 the ontology is displayed as a class hierarchy.

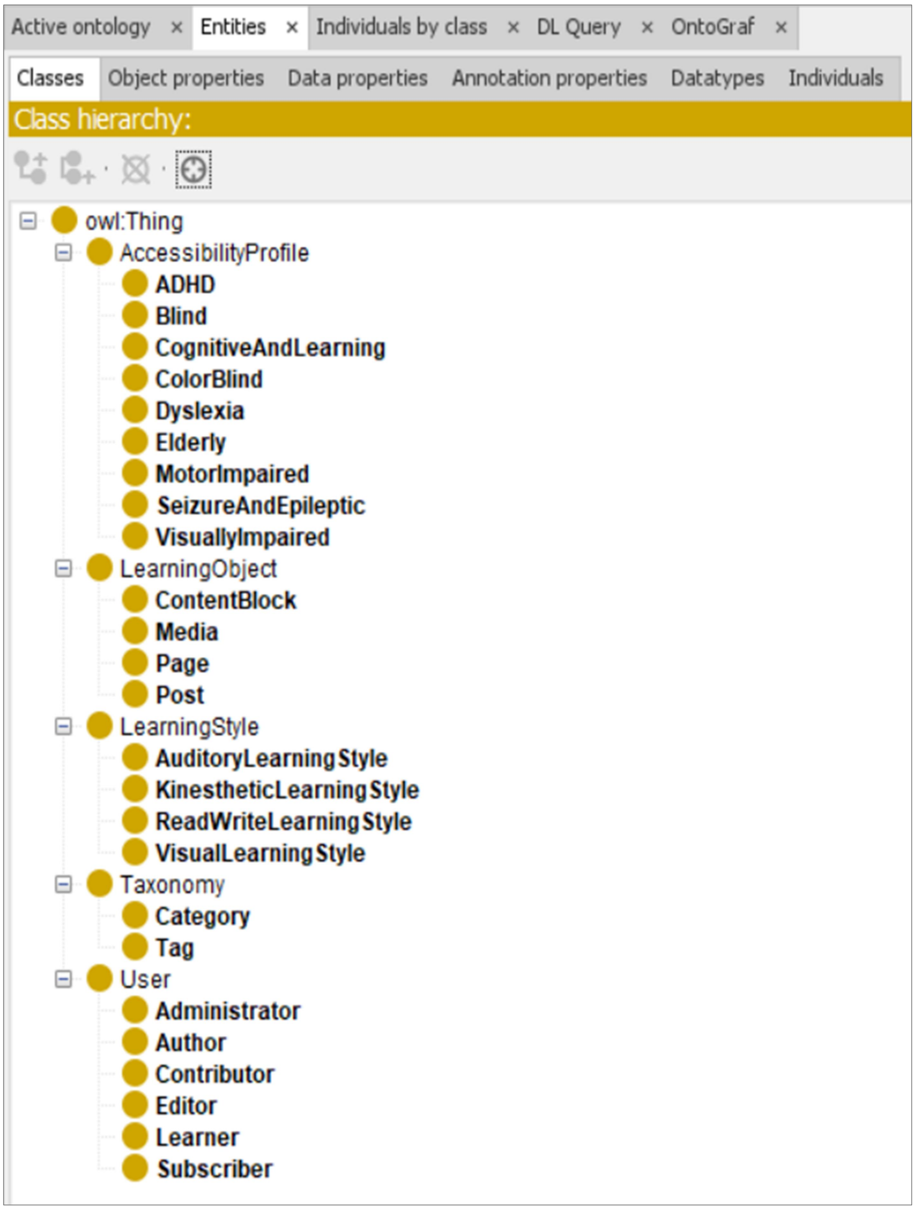

Fig. 4. Class hierarchy of the WordPress-based progressive web application in the editor interface of the software Protégé

The first step in the construction of the ontological model involved the establishment of a foundational terminological box by creating a set of highly abstract, top-level classes, namely:

- LearningObject – serves as the main conceptual anchor for all educational content within the progressive web application and as an abstraction for common characteristics of the learning artifacts of the system
- Taxonomy – an abstraction for organization and classification of educational resources
- User – an abstraction of agents that engage in learning or administrative activities within the system and that have distributed roles and privileges
- LearningStyle – corresponds to an abstraction of a diversity of learning preferences and the personalization of the content delivery
- AccessibilityProfile – a specially introduced abstraction, critical for model characteristics, which are pertinent to the accessibility needs of students with disabilities and require intuitive content adaptation

This phase aligns with a top-down methodology for ontological modelling by transitioning from general conceptual categories to more granular definitions, reflected in more concrete, domain-specific concepts that incorporate the underlying data structures of the WordPress content management system, retrieved from the public documentation of its application programming interface (API) [37]. This hierarchical structuring is realized through subclass axioms for inheritance and semantic subsumption, where the following subclasses are added to the abstract ones:

- Under LearningObject concrete types such as Post, Page, Media and ContentBlock were specified, which are representatives of the editor entities/blocks of WordPress. This way a variety of educational resources are formalized, which can be distinct, but maintain a strong correlation between them in the context of the content management philosophy of WordPress.
- The User class is separated into the subclasses:
  - Administrator – users with the most privileged role in the scope of WordPress who are the lecturers of the related university disciplines that configure the students' profiles, observe their activity, and edit content as necessary
  - Author - content creators from WordPress, the role of which is assigned to students who work with the system for drafting and publishing their thematic coursework for the target university courses
  - Editor – users with a high-level of privileges in terms of content management in WordPress that can author and edit their own content as well as make modifications to the content of other users except for the administrators, but do not have sufficient rights to change the design and settings of the administrative dashboard
  - Contributor – users with lesser privileges than the authors in WordPress that can comment foreign content, but cannot create/publish their own content
  - Subscriber – users with a viewer-only profile in WordPress
  - Learner – users that do not have access to the dashboard interface of the WordPress instance yet, but view the learning content from the progressive web application, until the author role is assigned to them, when the deadline for starting with the writing of the documentation part of their coursework approaches

- The Taxonomy class is specialized into the subclasses Category and Tag which mirrors the native content classification mechanisms of WordPress. Categories and tags can be attached to posts, but they are not supported for the other learning objects.
- The LearningStyle class is divided into a fine-grained categorization of subclasses according to the modes of the VARK framework, to which the interface of the learning platform can be accommodated: AuditoryLearningStyle – for the aural type of learners, KinestheticLearningStyle – for the kinesthetic type of learners, ReadWriteLearningStyle – for the read/write type of learners and VisualLearningStyle – for the visual type of learners.
- The AccessibilityProfile class features subclasses for profiles of partially or entirely disabled individuals that embody a generalization of their condition, that is, Blind, CognitiveAndLearning, ColorBlind, Dyslexia, ADHD, Elderly, MotorImpaired, SeizureAndEpileptic and VisuallyImpaired.

The next step in constructing the ontological model is the definition of Object Properties, illustrated in Fig. 5, which represent binary, directed relationships between instances of classes. Each property is assigned Domain and Range, where the Domain specifies the class or classes whose instances can be the property's subjects, whereas the Range indicates the class or classes whose instances can be the property's object.

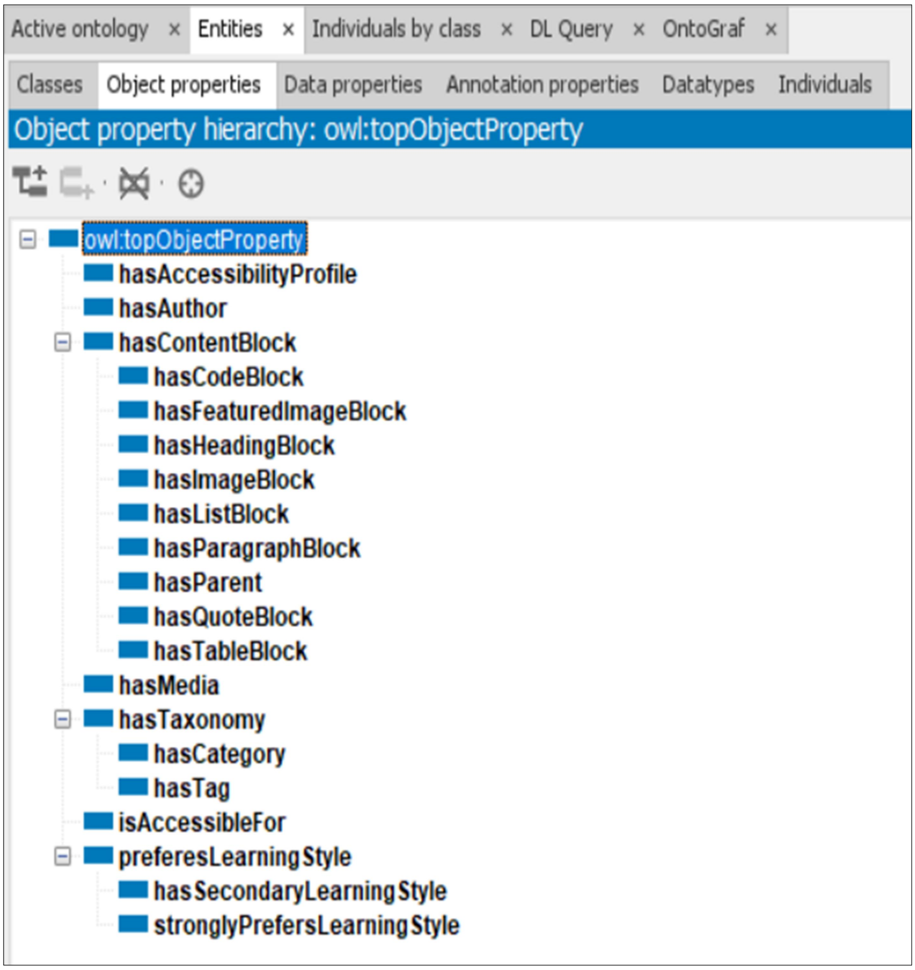

Fig. 5. Axiomatization of relationships (Object Properties)

Within this ontology, several object properties formalize the relationships between the classes in the hierarchy:

- hasAuthor – its domain is LearningObject, ensuring that only learning content can be associated with an author and Author as its range, which logically constrains which user can become an author of learning material
- hasMedia – links content elements (ContentBlock, Post and Page as its domains) to embedded media (Media as its range)
- hasTaxonomy – assigns categories and tags (Taxonomy as its range) to posts, which are regarded as learning resources (Post as its domain). Its sub-properties are hasCategory and hasTag.
- isAccessibleFor – links learning artifacts (LearningObject as its domain) to accessibility profiles (AccessibilityProfile as its range), contributing to the inclusivity dimension of the progressive web application
- hasAccessibilityProfile – associates users (User as its domain) with accessibility profiles (AccessibilityProfile as its range)
- hasContentBlock – links subjects of the domains Pages and Posts to objects of the range ContentBlock. The core property is enriched with sub-properties to categorize the type of ContentBlock. The sub-properties include:
    - hasHeadingBlock - identifies hierarchical document elements explicitly and is aimed at headings in text content
    - hasParagraphBlock - for general content textual blocks
    - hasImageBlock – for visual media which is embedded as blocks
    - hasListBlock – for structured enumerated content
    - hasQuoteBlock – for attributed textual excerpts
    - hasCodeBlock – for embedded code snippets
    - hasTableBlock – for structured tabular data
    - hasParent – identifies the parent container of a concrete content block
- prefersLearningStyle: its domain is Learner and its range LearningStyle, allowing for personalization that conforms to the modes of the VARK framework. It consists of two sub-properties: stronglyPrefersLearningStyle and hasSecondaryLearningStyle.

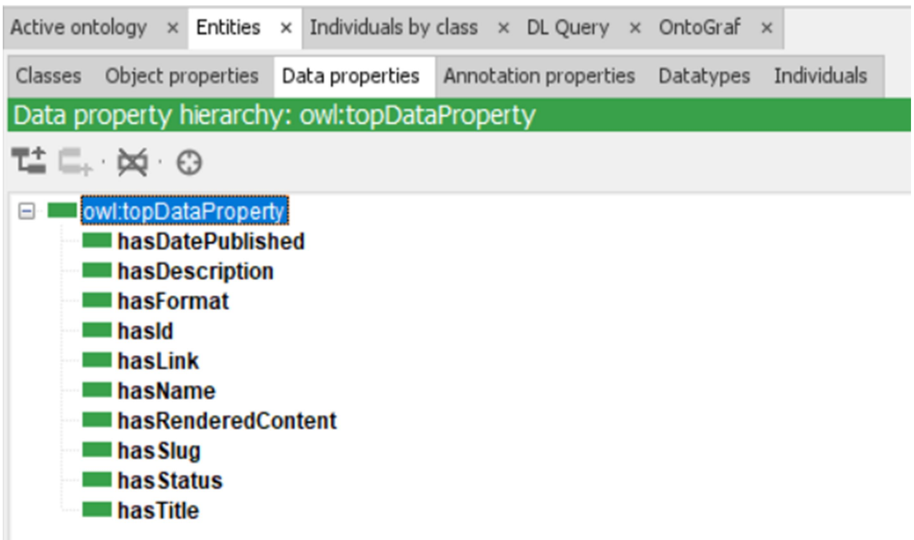

Fig. 6. Axiomatization of attributes (Data Properties)

After configuring the object properties of the ontology, the definition of Data Properties follows, which are means to associate instances of classes with literal data values, e.g., string, integers, and dates. Each data property is attributed domain axioms, indicating the class or classes that can possess a certain attribute, as well as range axioms to ensure data type integrity, which serve for constraining the data type of the literal value using the XML Schema Definition (XSD), e.g. xsd:string, xsd:integer, xsd:dateTime, and xsd:anyURI. The properties hasId, hasName, hasTitle, hasDescription, hasLink, hasSlug, hasDatePublished, hasRenderedContent, hasStatus and hasFormat, as shown in Fig. 6, directly map to the metadata and content fields, extracted from the WordPress REST API and transform raw data attributes into semantically rich ontological properties.

For the population of the ontological model the defined classes in the hierarchy and the object properties were instantiated with concrete data from the WordPress website. This step entailed retrieving valuable information from its API, where each relevant WordPress entity is converted to an individual instance of its corresponding ontological class in Protégé. These individuals are described by assigning specific literal data values through data properties (e.g., hasId value for a Post instance) and by building up relationships with other individuals through object properties (e.g., a 'Post' instance has author a 'User' instance) and this way the gap between raw, heterogeneous data and the semantic, machine-interpretable knowledge model is bridged. The given example of the individuals for post and its author is shown in Fig. 7 and Fig. 8, respectively.

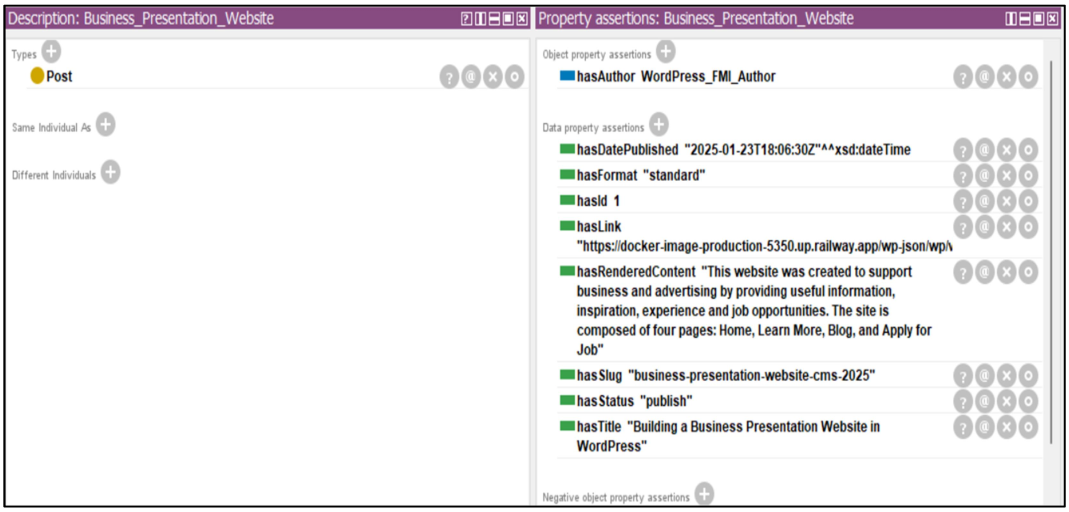

Fig. 7. Example individual of the class Post

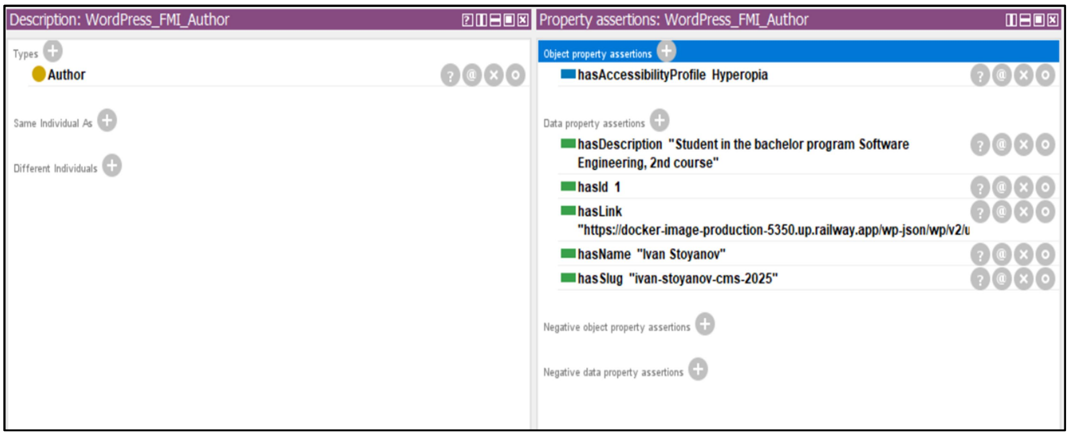

Fig. 8. Example individual of the class Author

To assure the correctness and to deepen the analysis of the populated ontological model, the OntoGraph plugin within the Protégé environment was utilized, with the help of which a graphical representation of the ontology model members and the relationships between them is provided, allowing for a clear visual inspection of the knowledge graph. This visualization, which can be seen in Fig. 9, is indeed necessary for data validation, uncovering potential inconsistencies or unexpected connections, as well as for facilitating the exploration of the semantic structure, querying complex relationships, and gaining more insights into the current state of the conceptual framework.

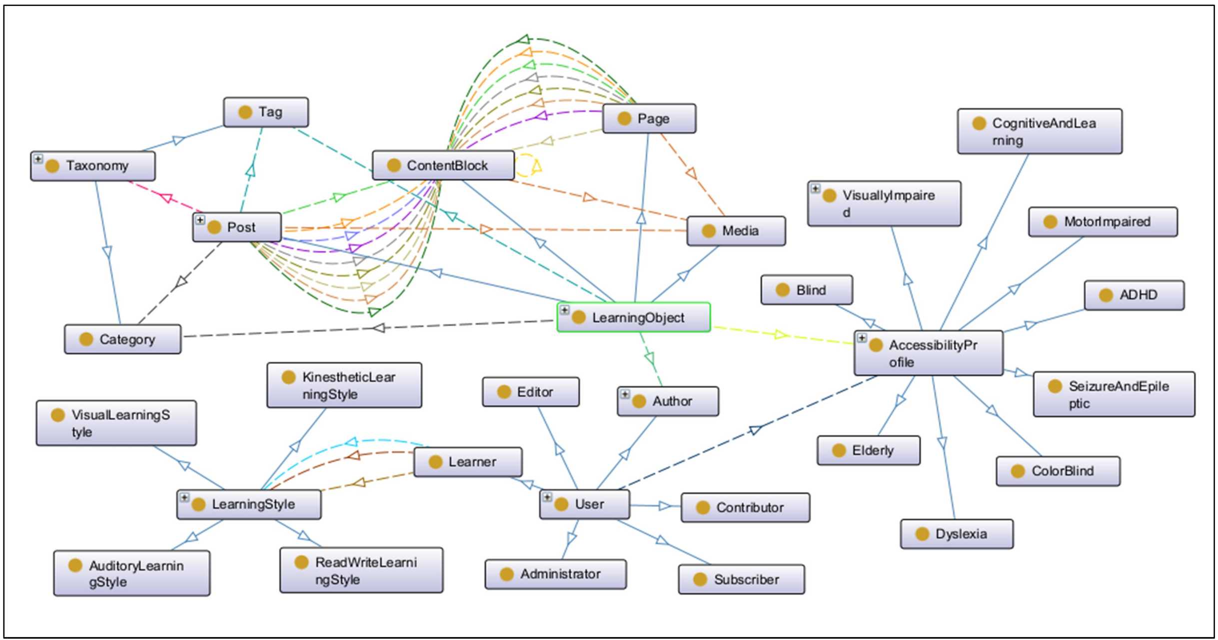

Fig. 9. Generated graph of the ontological model

5. Realization of a Blended Environment through the Inclusive WordPress-based Progressive Web Application

Blended learning is a flexible term to describe any or all varieties of teaching where both face-to-face and online delivery methods are integrated [38]. A primary purpose of the blended education is to promote learning inside as well as outside the classroom [39]. Researchers acknowledge that such combinations can assume different forms, which must be pedagogically sound and should not be regarded as supplementary components to teaching courses. Therefore, blended courses mix online and in-person education with careful planning that brings pedagogical benefits to the learning experiences by not simply uniting but rather trading-off and fusing face-to-face time with online activities, and vice versa [40], [41].

For teaching the students, enrolled in the bachelor degree programs Software Engineering and Information Brokerage and Digital Media in the subjects Content Management Systems and Software and Media Ergonomics the realization of a blended learning environment is aimed, which relies on a digital infrastructure through a WordPress-based progressive web application. It employs a contemporary hybrid architecture that strategically decouples the content management operations from the presentation layer of the progressive web application. Those operations are linked to the creation of posts and pages and the attribution of taxonomies, central to the learning objects of the ontological model, and are executed at a hosted WordPress instance, where registered users with the role of an author can work on their course project documentations.

The posts management section of the WordPress dashboard, shown in Fig. 10, is predominantly visited by the student authors. The client application fetches content like posts, pages, categories, tags, users, content blocks etc. from the public WordPress website and is built with the software framework Next.js. Furthermore, it has a progressive wrapper, illustrated in Fig. 11, which means that it can be installed on existing web and mobile operating systems and can obtain the native features of the concrete environments and for this reason the whole learning platform possesses the capabilities of an ecosystem.

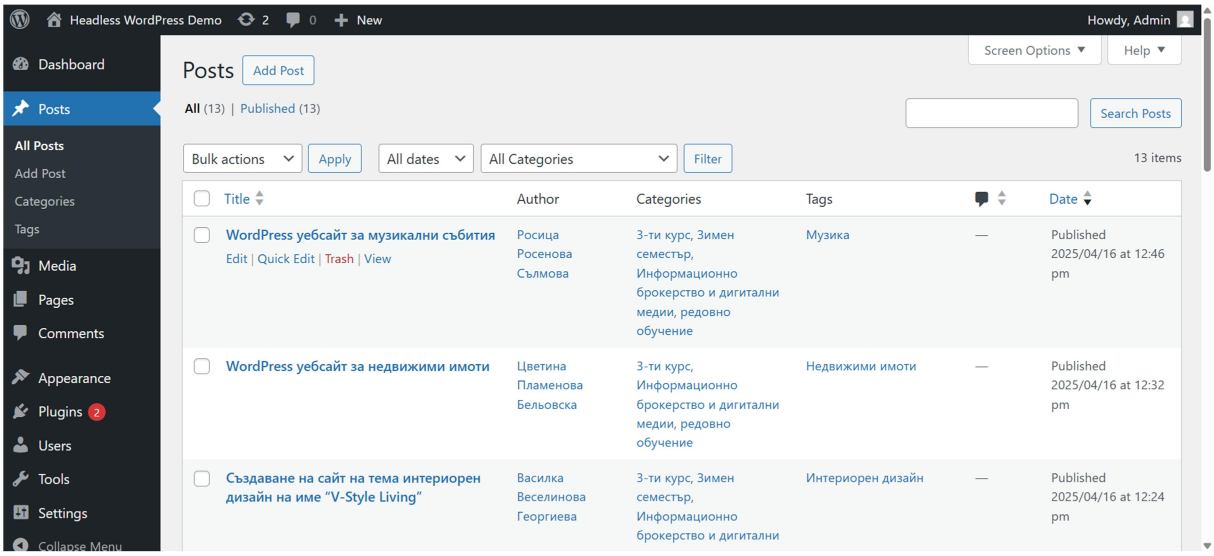

Fig. 10. The posts management section in the WordPress dashboard

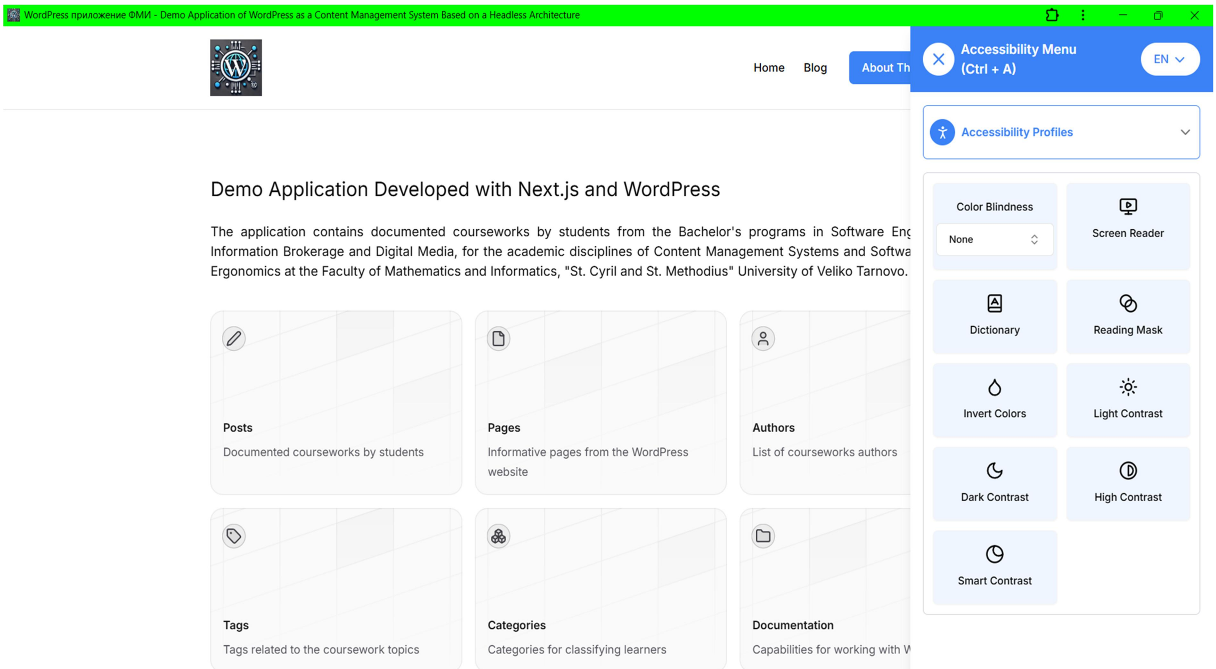

Fig. 11. The progressive web application running in a desktop environment – the home page with open accessibility menu on focus

The progressive web application has inner pages for blog with posts for the coursework documentations (Fig. 12), the published informative pages, the authors, the applied categories, tags, and a technical documentation (Fig. 13). It is used uniquely either during class or remotely at two separate stages over the educational courses:

1) Till the end of the first half of the semester the students are perceived as learners or viewers, who do not actively contribute to the thematical content enrichment of the ecosystem, but rather acquire theoretical and practical knowledge of the university disciplines, drawing inspiration and motivation from the published coursework documentations in the last academic year.
2) When the half of the semester is marked, the students receive their own profiles in the public WordPress website and start gaining hands-on experience by continuingly developing course projects locally and by utilizing the web interface to make drafts and publish the textual part they need to hand in by the end of the semester as a taxonomized post. Concurrently, the tutors of the disciplines hold administrative rights in the WordPress website and observe and guide the progress of the learners.

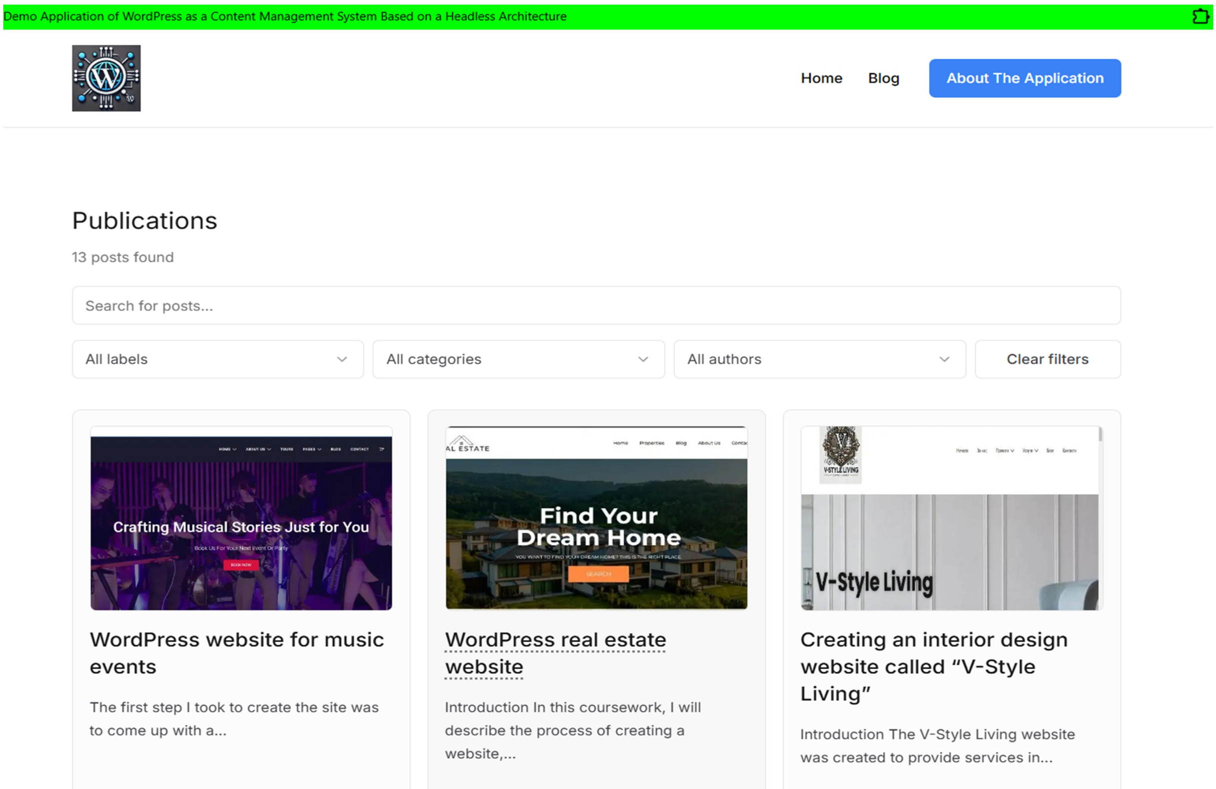

Fig. 12. The blog page with coursework posts

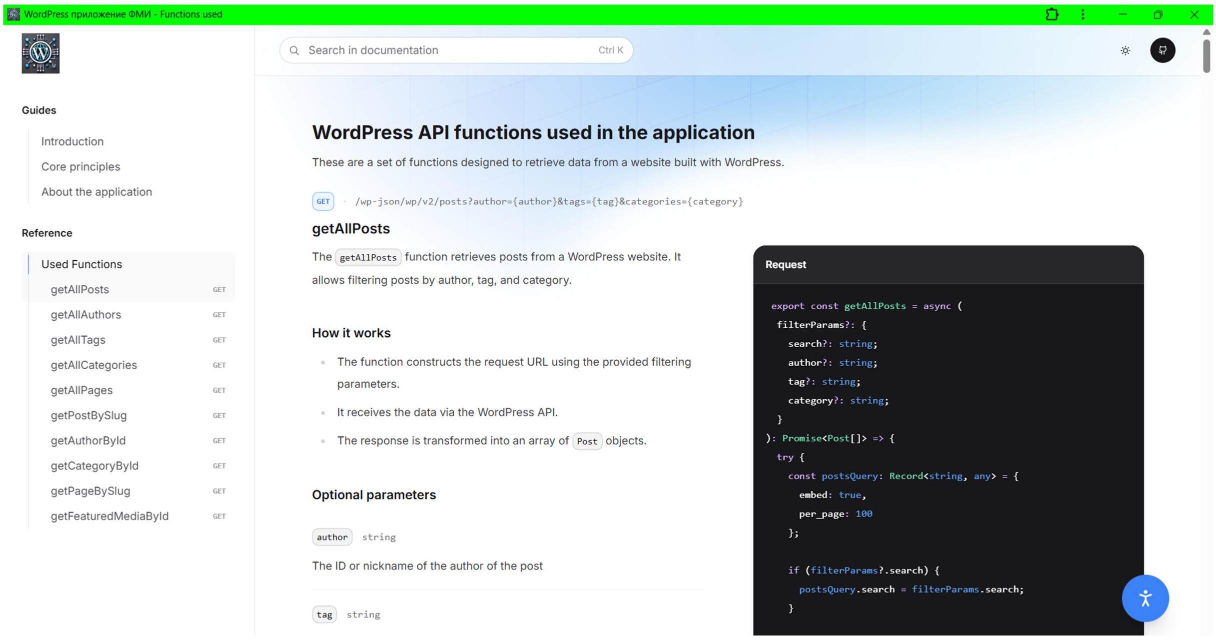

Fig. 13. The documentation page

The ecosystem's design prioritizes strategies for multimodal content presentation, guaranteeing that the educational materials are accessible across diverse sensory channels, consistent with the pedagogical principles of multimodal learning and more specifically with the ones, established by the VARK framework. A key aspect of the blended learning environment's realization is its capacity for learner-centric adaptation, which is directly informed by the communication modes of VARK whose manifestations persist in the ecosystem through the provision of features for its core learning styles classifications, also foreseen in the initially constructed ontology. In other words, the following learning styles provisions can be underscored:

- For students exhibiting a dominant preference for visual learning, the interface of the progressive web application emphasizes the prominence and clarity of visual heuristics. In the pages for single posts and the complementary documentation of the platform high-resolution media like images, diagrams and flowcharts, infographics and conceptual schematics are embedded. Additionally, the user interface offers customizable visual themes that can be adjusted via an accessibility menu widget.
- The learners categorized with strongly preferred auditory learning style can take advantage of the text-to-speech synthesis functionality of the accessibility menu, where a specific voice and rate can be chosen for audio reading of pointed sections on mouse hover. This way the text-to-speech synthesis engine of the application facilitates the information processing with a podcast-style of narration, which can be stopped/resumed with simple cursor selection, thus accompanying the textual content.
- For students who chiefly demonstrate Read/Write learning preferences the posts and documentation sections consist of highly structured, legible, and semantically navigable content blocks, as listed in the ontological model, which they can easily interpret and modify for the use cases of their personal coursework documentations. Moreover, the many advanced filters make certain that the queried results are found fast and highlighted for the convenience of the users.

- To accommodate the needs of the individuals with a main kinesthetic learning style, the interface of the progressive web application can be manipulated with the options of the accessibility menu for themes switching, heading and sections coloring, font size and alignment changes, reading masks, etc. The documentation page also contains code parts, which can be copied for those interested in the programmatic implementation of the ecosystem. Nevertheless, the entire content management cycle in the public WordPress instance is what drastically aids the experience of the kinesthetic learners with a secondary helpful element being the gathering of real-life examples and ideas from previous coursework posts.

The multimodal adaptations described above are critical for the cultivation of STEM/STEAM competencies, since technical concepts are conveyed through visual, aural, read/write and kinesthetic channels. This hands-on, project-based approach to teaching the fundamentals of content management and its representation methods strives to improve the digital literacy, the problem-solving, cognitive, and creative skills of the students.

As far as the other user types in the ontology are concerned, training accounts with the roles of an editor, contributor and subscriber are available within the WordPress system, the restrictions of which are showcased during on-site classes. The accessibility profiles are outlined in the widget and their activation alters the user interface of the client application in accordance with common usability requirements of the noted disability conditions, fostering its inclusive learning focus.

6. Results

The findings from the machine learning analysis conducted on the participant questionnaire data are organized into four subsections: (1) clustering of respondents based on their preferred learning styles – visual, aural, read/write and kinesthetic, (2) clustering of the overall platform feature ratings, (3) linear regression analyses for hypothesis testing where skills improvements aspects depend on preferred learning styles, and (4) qualitative clustering and sentiment analysis of open-ended participant comments. The integration of both quantitative and qualitative insights is a prerequisite for a multifaceted understanding of the engagement of the learners, the effectiveness of the platform and the sentiment, final experience and usability verdict of its users.

K-Means clustering was applied to the four self-reported VARK learning style choices from the third question of the questionnaire to identify latent user profiles. The algorithm determined three distinct clusters: Cluster 0 (11 participants), Cluster 1 (16 participants) – the largest group, and Cluster 2 (13 participants). The centroid values (mean preferences) for each cluster revealed those modality patterns, as shown in Fig. 14:

- The first cluster (Cluster 0) consists of predominantly aural learners, displaying a pronounced preference for the aural learning style, negligible Read/Write engagement and moderate but secondary interest in Visual and Kinesthetic learning. This suggest that while these learners benefit from auditory content, they are less responsive to formats, which are heavy in text or highly interactive ones.
- The multimodal learners fall under the second cluster (Cluster 1), which also represents the respondents with most balanced and diverse learning preferences. This cluster showed maximum kinesthetic engagement alongside equally strong visual and Read/Write preferences and the learners belonging to it appear to

thrive in environments that blend tactile interaction, visual resources, and textual information.

- The third and last cluster has group members with visual & read/write focused learning inclinations. This group prefers Visual and Read/Write modalities over kinesthetic learning, while the aural learning practices also remain low. The generated pattern suggests a reflective, but less physically interactive learning approach.

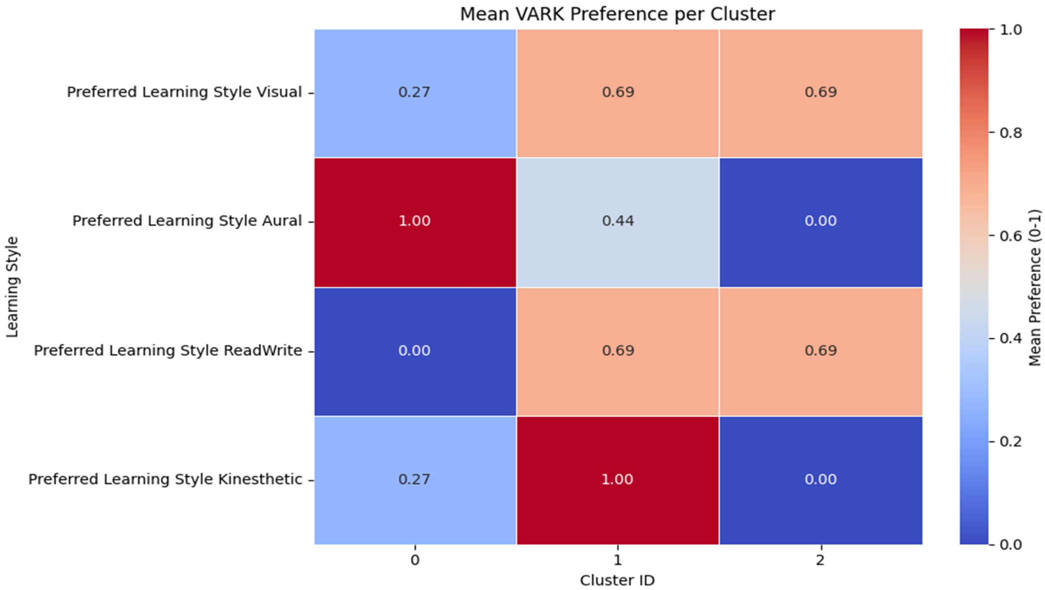

Fig. 14. The centroid values for each VARK preference per cluster

Further examination uncovered that in Cluster 1, where the multimodal group is recognized, the highest mean skill improvement scores are reported: Problem-Solving, Digital Literacy and Creative Skills ranked in order on a 1-5 scale, which is displayed in Fig. 15. Cluster 0 and 2 showed comparatively lower values, with Cluster 0 recording the lowest creative skills improvement.

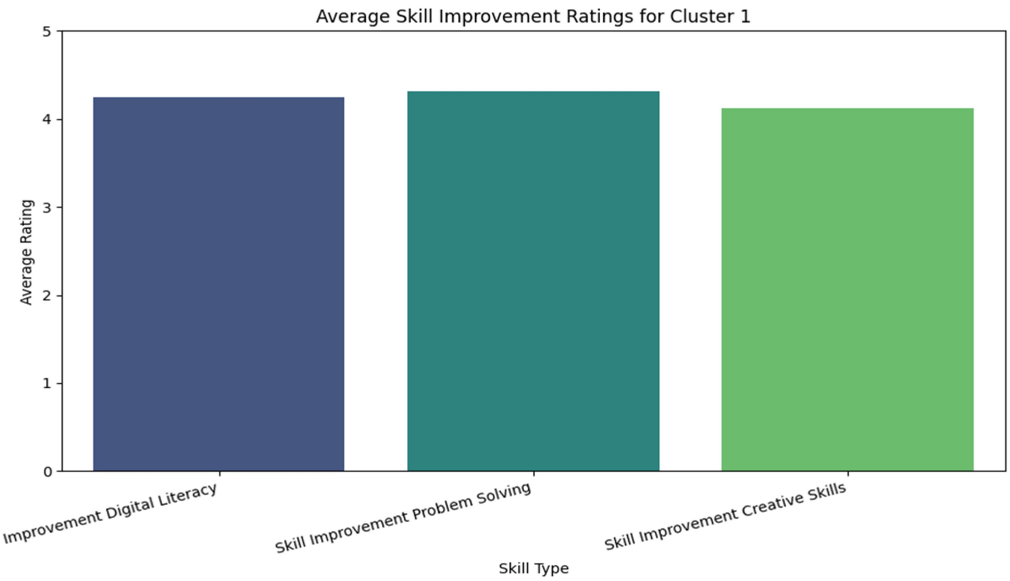

Fig. 15. Mean skill improvement ratings for Cluster 1

A boxplot rating distribution, presented in Fig. 16, confirmed the notable advantage of multimodal learners in self-reported skill development.

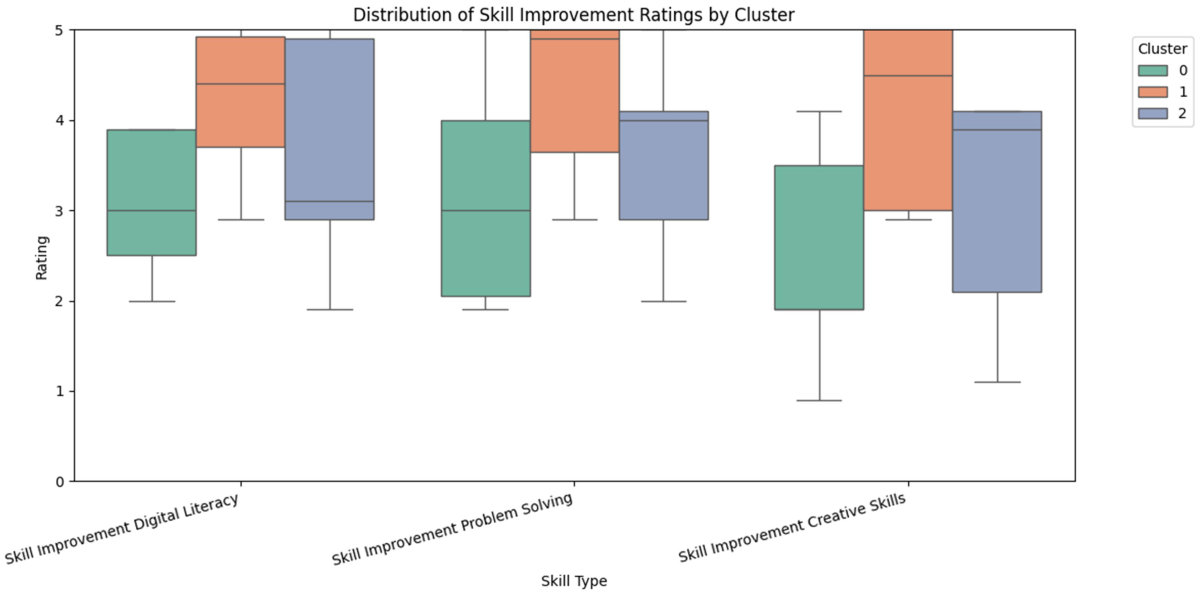

Fig. 16. Distribution of skill improvement ratings by cluster

To gain a holistic perspective on user experience, K-Means clustering was utilized for all ten numeric questionnaire items to evaluate the features of the platform, the usability level, and the perceived educational value. This produced three user satisfaction cohorts, displayed in Fig. 17: Cluster 0 (11 participants), Cluster 1 (18 participants) – the largest group, and Cluster 2 (11 participants):

- Cluster 0 provided mid-range ratings, for instance the ratings for the overall ease of use, the adaptability to the learning styles, the multimodal feature effectiveness, the performance of the platform, and the overall value place slightly above the median range, suggesting the perception of the learners was neutral to mildly positive. While the respondents of this cohort did not identify major shortcomings of the entire learning ecosystem, their engagement lacked the enthusiasm seen in Cluster 1.
- Cluster 1 represents the highly satisfied cohort which demonstrated uniformly high ratings across all features with a perfect score for overall value and almost perfect scores for the implemented multimodal functionalities, the adaptability to the learning styles, the performance of the platform, the multimodal feature effectiveness, and the overall ease of use. Those ratings reflect strong alignment between the design of the progressive web application and the user needs.
- Cluster 2 is the cohort with generally dissatisfied respondents who have consistently assigned low ratings across all features. Key measures such as overall ease of use, overall value, performance, satisfaction with current features, influence on content creation, and advantage over traditional learning management systems indicated that these users found minimal benefit in the platform juxtaposed to established alternative solutions.

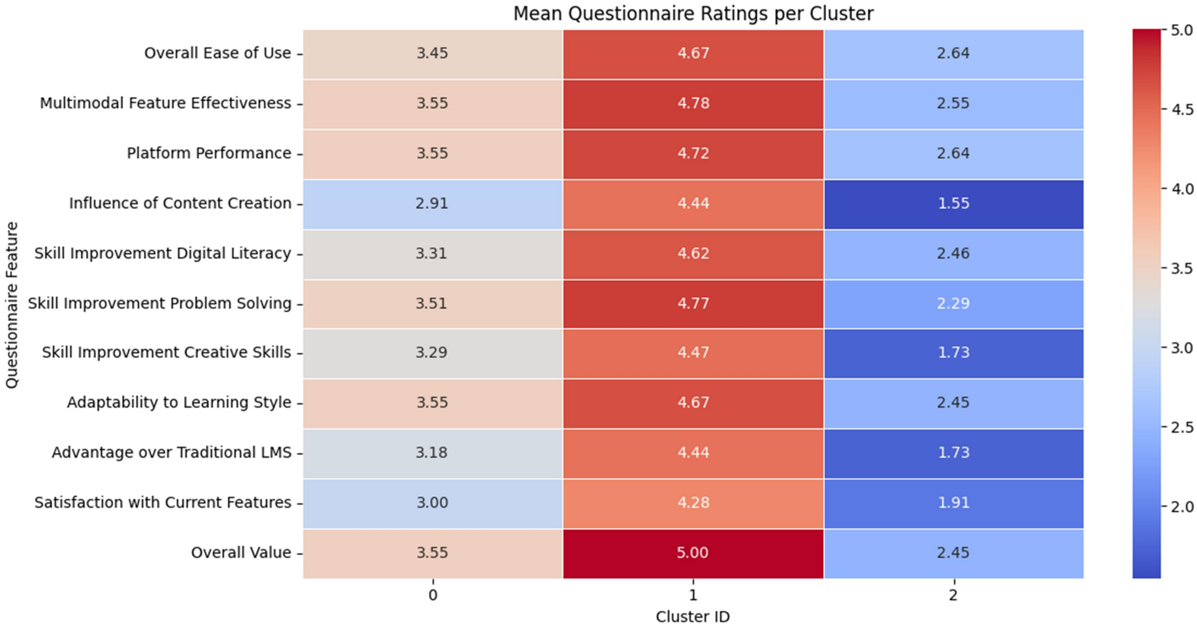

Fig. 17. Mean questionnaire ratings for close-ended questions per cluster

A parallel coordinates plot diagram (Fig. 18) illustrated the multidimensional profile of each cohort, where Cluster 1 exhibits nearly unwavering high ratings across all usability, adaptability, and performance measures, in contrast to the low-profile curve of Cluster 2.

Four linear regression models were estimated to assess the predictive power of specific learning style preferences on skill improvements for which the following hypothesis were formulated: 1) Visual learning preference predicting creative skills improvement, 2) Read/Write learning preference predicting digital literacy improvement, 3) Aural learning preference predicting digital literacy improvement, and 4) Kinesthetic learning preference predicting problem-solving improvement.

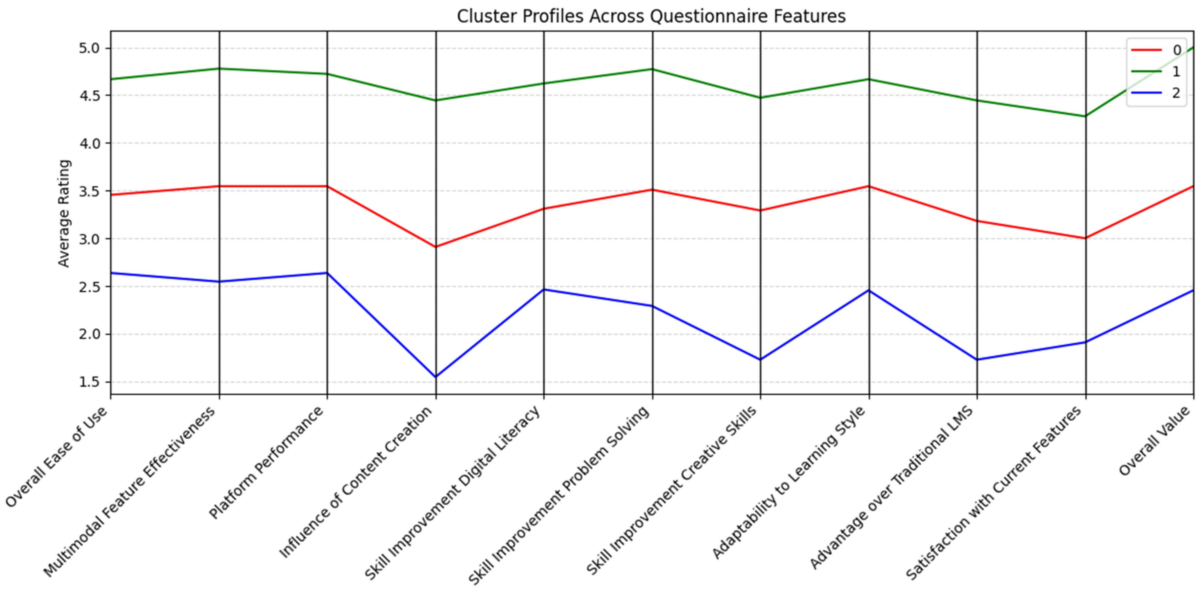

Fig. 18. Cluster profiles across close-ended questions of the survey

Each of the hypotheses were tested to prove:

- The model produced a strong positive coefficient (β = 1.938) with a R2 (coefficient of determination) of 0.632 (Fig. 19) for the first hypothesis, indicating that over 63% of the variance in creative skills improvement could be explained by the preference for visual learning. This finding underscores the role of the visual features of the platform and namely the many diagrams, visual heuristics like coursework screenshots and animation effects in boosting the creativity of the students. Such a high explanatory power suggests that visual learners are not only engaged with the included content in the posts, pages and documentation but are also able to translate their engagement into tangible skill growth. Hence, the visual modality emerges as a primary pedagogical driver in the blended learning environment.

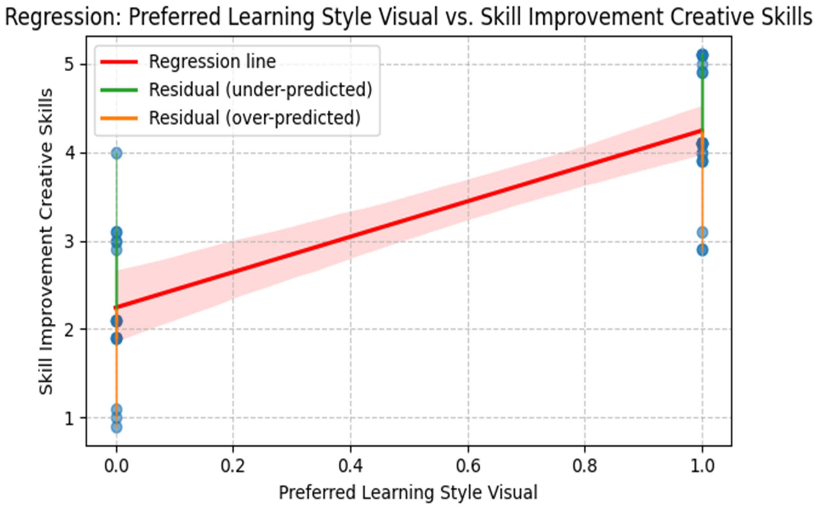

Fig. 19. Linear regression for the first hypothesis

- Although the relationship of the second hypothesis was positive (β = 0.630), the explanatory power was modest (R^2 = 0.083), as seen in Fig 20, which implies that textual learning alone was not a substantial driver of the perceived digital literacy gains. While text-based learning remains an important component of development of digital literacy skills, its isolated use may not offer immersive enough engagement for a big difference in the enhancement of those skills.

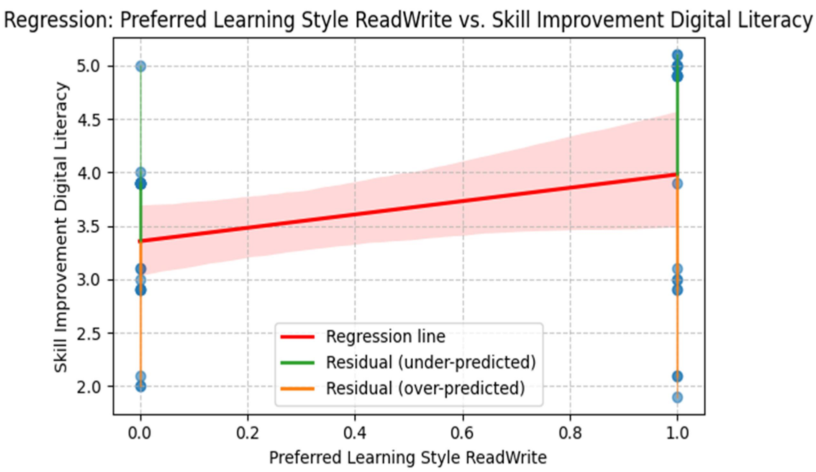

Fig. 20. Linear regression for the second hypothesis

- A positive coefficient was yielded ($\beta = 0.231$) for the third hypothesis which also has a very low R^2 of 0.012, meaning that aural preference is responsible for little of the variance in digital literacy improvement and therefore its predictive power is minimal. Even though the relationship is positive, the effect is small and should be interpreted as marginal from a practical standpoint (Fig. 21). This may indicate that aural elements for speech synthesis play more of a supportive role rather than a main one for enhancing digital literacy skills and thereby their value might instead lie in complementing other modalities, making the learning experience more inclusive.

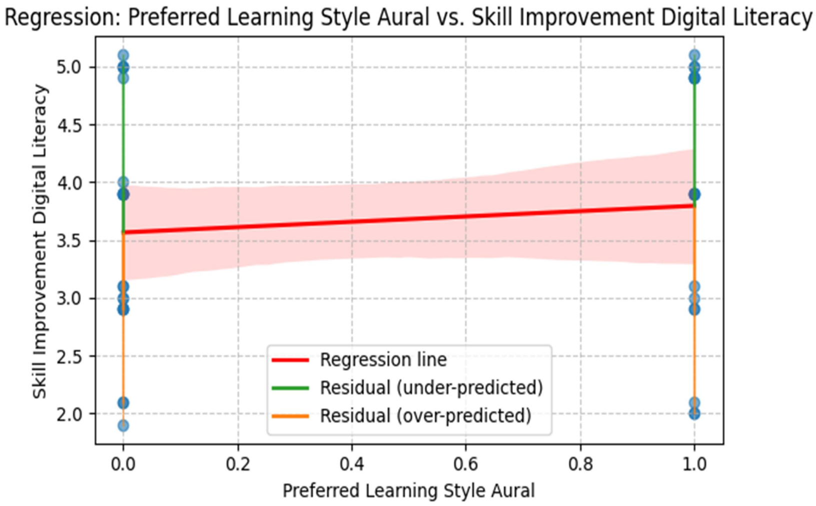

Fig. 21. Linear regression for the third hypothesis

- Similarly to the second hypothesis, the model of the fourth one returned a modest positive relationship ($\beta = 0.656$, $R^2 = 0.080$), which can be viewed on Fig. 22, pointing to the conclusion that the kinesthetic learning preference had some independent predictive value for the problem-solving skill development. While this demonstrates that experiential learning activities can make a measurable contribution, due to the low explanatory power problem-solving is likely influenced by a wider mix of factors, thus supporting the idea of kinesthetic learning being more effective when integrated into a broader multimodal strategy rather than used in isolation.

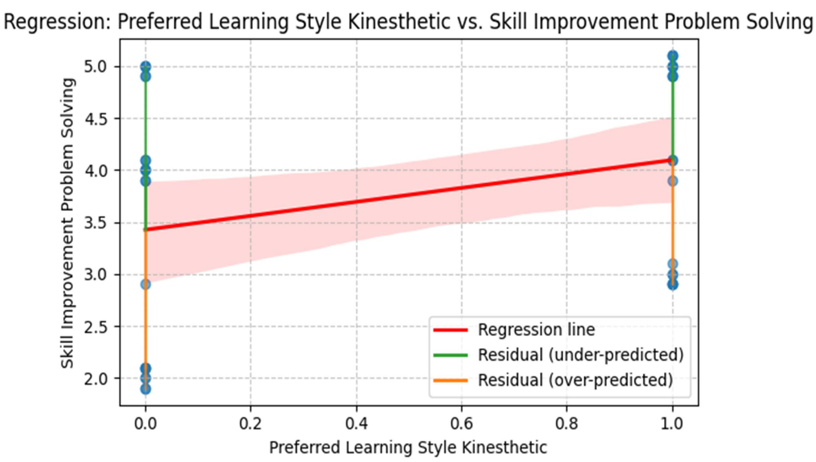

Fig. 22. Linear regression for the fourth hypothesis

The open-ended responses to the additional comments field were analyzed through vectorization and clustered using the K-Means algorithm, leading to the reveal of six thematic groups, shown in Fig 23: 1) Cluster 0 which has positive evaluations of visual features and the quality of the platform, 2) Cluster 1, including comments associated with skills improvement, which often highlight observed personal growth, 3) Cluster 2 contains praise for kinesthetic exercises and particularly for hands-on, practical tasks, 4) Cluster 3 is characterized by mixed assessments with terms that balance positive and negative sentiments, 5) Cluster 4 contains feedback on content creation workflows and intuitiveness along with suggestions for refinement, and 6) Cluster 5 has requests for more interactivity and critiques of excessive text. A dimensional scatterplot (Fig. 24) helps in illustrating the separation between the clusters.

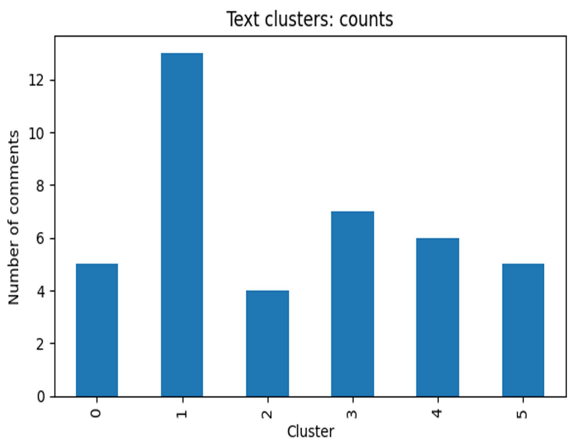

Fig. 23. K-means clustering and vectorization of the open-ended answers – counts

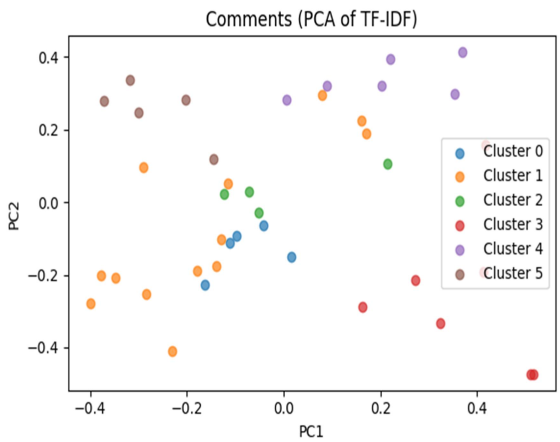

Fig. 24. K-means clustering and vectorization of the open-ended answers – comments

Moreover, sentiment distribution analysis (Fig. 25) showed that 75% of the responses were positive, 12.5% negative, and 12.5% neutral with the remaining 25% of negative comments being concentrated in Clusters 3 and 5, whereas Clusters 0, 2, and 4 had exclusively positive feedback and Cluster 1 a very large proportion of positive feedback and the lowest number of negative sentiments. The most neutral sentiments belong to Cluster 3 and 5.

Fig. 25. Sentiment distribution analysis for each cluster

Finally, a lexical frequency analysis across the clusters (Fig. 26) demonstrated the dominant vocabulary underpinning each group, which provided additional interpretive grounding for the clustering results.

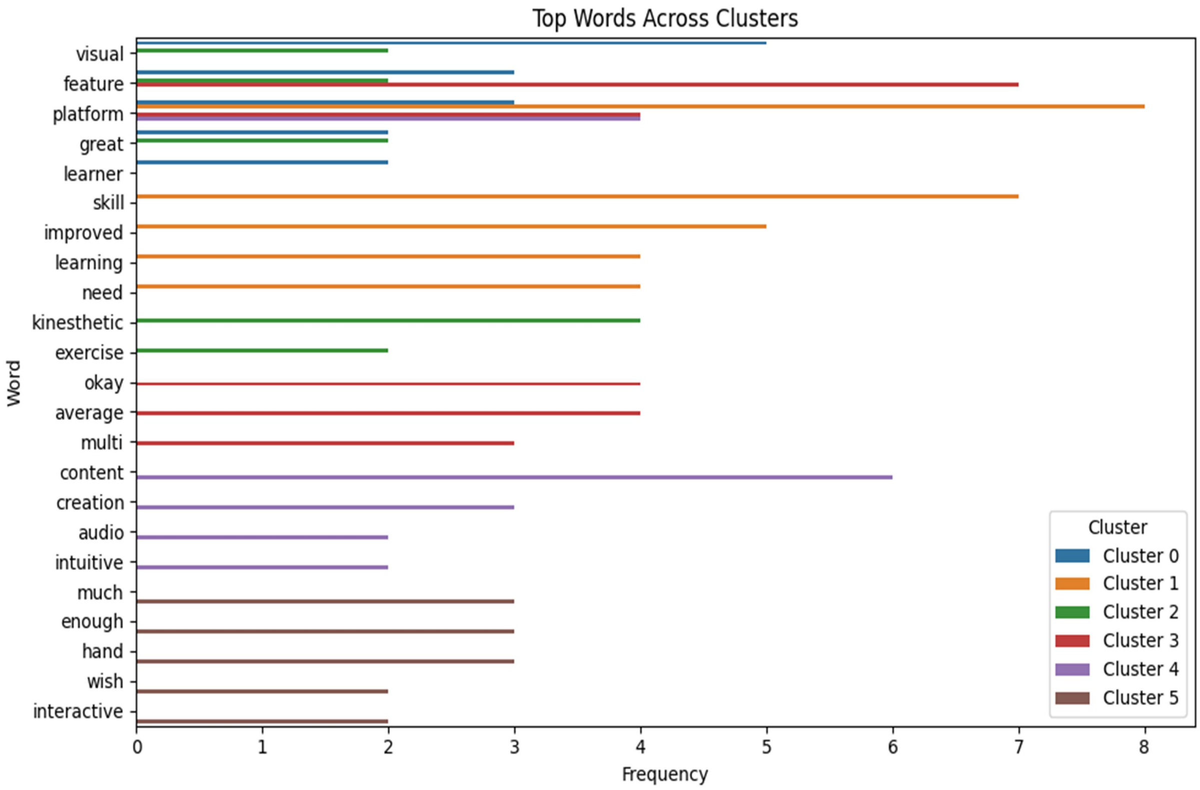

Fig. 26. Most used terms across the clusters

7. Discussion

The findings of this study offer empirical validation of the realized inclusive multimodal learning platform. The qualitative and quantitative analyses exemplify that the progressive web application, built on a decoupled WordPress architecture, leads to an active engagement among the students and aids in the development of STEM/STEAM competencies. These results are highly consistent when contextualized within the four fundamental principles of accessibility for learning management systems, outlined in [42]: Perceptibility, Operability, Understandability, and Robustness.

The research corroborates the central role of multimodal strategies in digital education, and particularly for learning environments with blended aspects. The K-Means clustering of learning preferences revealed that the largest group of users is composed of multimodal learners who reported the highest self-perceived skill improvements, which in turn directly aligns with the principle of Perceptibility, as the platform can present information through diverse sensory channels – visual heuristics, audio narration, textual content, and hands-on tasks corresponding to each of the VARK communication modes. Furthermore, the linear regression analysis highlighted a strong positive relationship between visual learning practices and creative skills honing, implying that the components of the platform's visual layout were very impactful, while the linking of aural and Read/Write preferences to the fostering of digital literacy competencies also proved to be constructive. The established relationship between kinesthetic preference and the gains of problem-solving skills point to the successful adoption of the Operability principle.

The prevailing positive sentiments from the qualitative analysis of the open-ended comments furnish additional evidence for the progressive web application's adherence to the principles of inclusive education. In this connection, all of the gathered affirmative responses from the questionnaire participants regarding the support of means of interaction through a variety of input methods by the progressive web application suggest that its design not only promotes inclusivity and accessibility but also enhances STEM/STEAM skills acquisition.

Overall, the user satisfaction ratings from the most satisfied cohort validate the platform's ease of use, its presentation quality and the adaptability to the preferred learning styles, which indicates a high degree of compliance with the Understandability principle, since its functionalities and purpose are clear and intuitive for the majority of the users. The chosen architectural composition of the hybrid content management system WordPress and the progressive web application provide cross-platform optimization and performance, thus ensuring the alignment with the principle of Robustness of the ecosystem, which itself makes the learning environment more reliable.

However, the limitations of the study should be noted, as well. First of all, the sample size of 40 graduate student participants, while sufficient for the exploratory analyses, restricts the generalizability of the results to a broader population. In addition, the reliance only on self-reported data from the questionnaire may bring a certain level of subjectivity into the findings. It is also important to reflect on the relatively low ratings for the influence of content creation produced in one of the clusters, potentially through the integration of more thematic practical exercises in this direction. Despite the open-ended comments being overwhelmingly positive, a desire for more interactivity and a critique of excessive text are identified, signaling that the balance of modalities could be further optimized, which could be addressed by incorporating more interactive elements like embedded quizzes and visual transitions and in some cases to hide conditionally large blocks of text. Such refinements would help create more dynamic user experience, especially for the learners who are prone to learning activities, which involve a lot of active participation.

8. Conclusion

The study presents the design, implementation and evaluation of the inclusive progressive web application, which is integrated with a decoupled WordPress instance and employs multimodal learning strategies for STEM/STEAM education in a blended learning environment. Drawing upon the multimodality principles, grounded in the VARK learning styles framework, and the constructed ontological model the platform is intentionally designed to deliver learning content through the visual, aural, read/write, and kinesthetic information processing channels, thereby accommodating various learning preferences and encouraging digital accessibility.

The mixed-methods evaluations, which combined K-Means clustering and linear regression analysis on close-ended questionnaire responses as well as sentiment analysis on open-ended textual comments generated several key findings. On the one hand, the clustering results revealed distinct learning profiles, with multimodal learners reporting the highest self-assessed improvements in problem-solving, digital literacy, and creative skills, while the linear regression results underscored the strong predictive role of the visual learning preference in creative skills development and also uncovered that other modalities such as read/write, aural, and kinesthetic had measurable independent predictive effects. On the other hand, the conducted sentiment analysis identified predominant positive user experiences, particularly concerning visual features, kinesthetic exercises, and the platform's impact on skill acquisition, though some users called for more interactivity and reduced textual density.

The future work on the research project should aim at building upon these results in several ways. First, the sustained impact of multimodal blended learning environments on academic performance and skill retention beyond the duration of the university courses could be examined more thoroughly with the introduction of longitudinal studies. Second, by embedding adaptive learning analytics real-time personalization of content modalities based on the individual behavior of the learners and self-paced progress could be enabled, potentially increasing the effect of modalities like aural learning for students with visual or cognitive disabilities. Third, the expansion of the research to include a larger and more diverse student groups across the content management related disciplines would improve generalizability. Finally, a deeper investigation into the developed accessibility features and the participation of disabled students in the survey would optimize the inclusive and accessibility-oriented design strategies for real-world educational settings.

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APPENDIX

STUDENT LEARNING AND USER EXPERIENCE QUESTIONNAIRE OF THE WORDPRESS-BASED PROGRESSIVE WEB APPLICATION

Rating Scales

- **1 = Strongly Disagree / Very Poor / No Influence**
- **5 = Strongly Agree / Excellent / Significant Influence**

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1. **Overall Ease of Use:** The platform's interface was easy to use and navigate.
    - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

2. **Multimodal Feature Effectiveness:** The platform's multimodal features (e.g., visual diagrams, text-to-speech) helped me understand the theoretical and practical concepts of the discipline.
    - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

3. **Preferred Learning Style:** Which of the following learning styles do you feel best describes your learning preferences? (Select all that apply)
    - **Visual** (learning through images, charts, and diagrams)
    - **Aural** (learning through listening to audio narration)
    - **Read/Write** (learning through reading and writing notes)
    - **Kinesthetic** (learning through hands-on activities and practical exercises)

4. **Platform Performance:** The platform's performance and responsiveness were excellent across different devices (e.g., desktop, mobile phone, tablet).
    - (1 - Very Poor | 2 - Poor | 3 - Neutral | 4 - Good | 5 - Excellent)

5. **Influence of Content Creation:** Creating and publishing my own content on the platform improved my understanding of the course material.
    - (1 - No Influence | 2 - Little Influence | 3 - Some Influence | 4 - Strong Influence | 5 - Significant Influence)

6. **Skill Improvement:** My skills improved in the following areas after using the platform for a semester:
    - a) Digital Literacy:
        - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)
    - b) Problem-Solving:
        - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)
    - c) Creative Skills:

- (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

7. **Adaptability to Learning Style:** The platform's content and features felt adapted to my personal learning style/s.
   - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

8. **Advantage over Similar Traditional LMS:** This platform offers advantages over traditional Learning Management Systems (LMS) in the field of Content Management Systems.
   - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

9. **Satisfaction with Current Features:** I am satisfied with the current features and do not see a need for major changes or new features for enhancing the user experience.
   - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

10. **Overall Value:** Overall, my experience using this platform for my studies was highly valuable.
    - (1 - Strongly Disagree | 2 - Disagree | 3 - Neutral | 4 - Agree | 5 - Strongly Agree)

11. **Additional Comments/Suggestions:** Please provide any additional comments, suggestions, or observations about your experience with using the platform for learning.