Guiding the Integration of Multimodal Learning Analytics in the Glocal Classroom: A Case Study Applying MAMDA

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Abstract: This study explores the integration of Multimodal Learning Analytics (MMLA) within the dynamic learning ecosystem of the Glocal Classroom (GC). By employing the MMLA Model for Design and Analysis (MAMDA), our research proposes a conceptual model leveraging the GC's existing infrastructure into an MMLA system to enrich learning experiences and inform course design. Our methodology involves a case study approach guided by the six phases of MAMDA. Building on previous studies, including a systematic mapping of MMLA research and an investigation into MMLA system design. We seek to employ MMLA insights to comprehensively understand the learning experience, identify issues, and guide improvement strategies. Furthermore, we discuss potential challenges, mainly focusing on privacy and ethical considerations. The result of this work aims to facilitate a responsible and effective implementation of MMLA systems in educational settings.

1 INTRODUCTION

Recently, several innovative learning environments have emerged at the intersection of technology and education, such as the Glocal Classroom (GC). The GC is a dynamic learning space that transcends geographical boundaries, fostering collaboration among students from diverse cultural backgrounds (Messina et al., 2014). In line with the development of educational technology, there is a growing recognition of the potential benefits that Multimodal Learning Analytics (MMLA) systems can bring to the design of next-generation teaching and learning environments. MMLA leverages diverse data modalities, including text, audio, and visual inputs, to gain deeper insights into the learning process (Blikstein et al., 2013).

This study presents a conceptual integration of MMLA in the learning environment GC. The motivation behind implementing MMLA in the GC is to enhance the educational experience and optimize course design. By leveraging the multimodal data generated within the GC, MMLA promises to provide a holistic understanding of student engagement, learning patterns, and the effectiveness of pedagogical approaches (Cukurova et al., 2020). This integration aligns with the broader goal of learning analytics for advancing educational practices in line with technological advancements (Ahad et al., 2018). Applying a case study approach, we could examine the GC in depth and develop a conceptual integration of MMLA. This methodology enables a better understanding of the interactions between technology and Glocality principles in education (Patel & Lynch, 2013). We employ the MMLA Model for Design and Analysis (MAMDA) to guide the study and integration of MMLA in the GC. We aim to test and reflect upon this newly developed model in a real-life scenario. MAMDA serves as a framework, addressing the key considerations for responsible data handling, and the overall development of MMLA systems. It offers a structured approach to ensure that MMLA integration aligns with ethical standards and educational objectives .

The remainder of this paper is structured as follows: Section 2 sets the context and introduces the

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GC and MMLA. Section 3 describes the chosen methodology. In section 4, the MAMDA is explained in detail. Following that, Section 5 provides an illustration of the integration of MMLA within the GC setting. Section 6 engages in a discussion, delving into the implications and insights derived from the study. Section 7 reflects on the lessons learned, followed by Section 8 outlines the identified limitations. The paper concludes in Section 9, summarizing key findings and proposing directions for future research.

2 BACKGROUND

2.1 Glocal Classroom and MMLA

The GC is an innovative and dynamic educational environment designed to bridge geographical gaps and foster collaboration among students from diverse cultural backgrounds. Equipped with communication technology, the GC serves as a hybrid learning space (Patel & Lynch, 2013). It features microphones, cameras, projectors, and screens that facilitate participation and interaction both on campus and remotely. In our study, the GC is adopted by multiple universities across four countries, exemplifying its global reach and impact (Christensen et al., 2022). The hybrid learning approach of the GC allows students to engage in courses conducted at partner universities, providing an educational experience that combines the benefits of in-person and remote learning. Our study explores the intersection of MMLA technology and education to enhance the learning experience within the GC. MMLA represents an analytical data-driven approach that harnesses diverse data modalities, including text, audio, and visual inputs, to gain insights into the learning process (Worsley, 2018). As a concept, MMLA has gained prominence for its potential to understand, monitor, and improve educational practices. MMLA provides a holistic understanding of student engagement, learning patterns, and the effectiveness of pedagogical approaches (Blikstein et al., 2013). The integration of MMLA into educational settings has gained traction, driven by its potential to understand, monitor, and improve educational practices. As educational institutions seek to harness the benefits of MMLA, there is a growing recognition of the need for structured frameworks to guide its effective implementation. In terms of understanding, modeling, and supporting learning, MMLA has shown promising results. Multiple research works envision MMLA as a tool for supporting the educational experience and refining learning designs (Cukurova et al., 2020), which motivates us to incorporate MMLA into the GC. With this integration, comprehensive analytics become possible, allowing a variety of perspectives on educational experiences across various scales of time and space. Considering the GC's existing communication technology infrastructure, the foundations are already in place for integrating an MMLA system seamlessly.

2.2 MMLA Model for Design and Analysis

The MAMDA model provides a framework and set of key considerations to guide the development of MMLA systems. Our primary objective is to assess and reflect upon the viability and efficacy of the newly developed model in a real-world case scenario. The provided set of considerations for MMLA design are derived from a previous study (Ouhaichi et al., 2023). As a practical tool, the model will facilitate the incorporation of MMLA into the learning environment at GC. The primary goal of this study is to test and reflect upon the MAMDA model within the dynamic and innovative learning ecosystem of the GC. Understanding how MMLA can be effectively implemented in diverse settings becomes paramount as educational landscapes evolve. With its global reach and collaborative learning model, the GC serves as an ideal case for this exploration. By adopting a case study approach, we aim to assess the applicability of the MAMDA model in guiding the integration of MMLA within the GC. This study seeks to contribute valuable insights into the potential enhancements that MMLA can bring to collaborative learning scenarios and the MAMDA model's adaptability in shaping educational technology's future.

3 METHODOLOGY

The methodology employed in this research adopts a case study approach to explore the GC and investigate the integration of MMLA. This section justifies using a case study approach, outlines its characteristics, and highlights its suitability for investigating the relationship between analytics technology and Glocality principles in education. We chose the case study approach for its ability to provide an in-depth exploration of the GC, offering a better understanding of its dynamics and functionalities. Following established guidelines for conducting and reporting

case study research in software engineering, proposed by (Runeson et al., 2012) and in alignment with practical recommendations from (Hancock et al., 2021) in "Doing case study research: A practical guide for beginning researchers" the case study design is considered appropriate for our research objectives. This approach enables a flexible examination of the GC, considering various dimensions such as its technological infrastructure, user interactions, and the overarching Glocality principles that shape its educational goals.

The data collection methods employed in this study encompass a mixed approach to gain insights into the GC. Observations constitute an initial element involving a first-hand examination of the learning scenarios facilitated within the GC. This includes attending lectures held in the GC, providing an immersive experience to understand the dynamics of student engagement, interaction, and the overall educational environment. In addition, a documentation review is conducted, focusing on digital platforms showcasing the usage of the GC. This digital platform also functions as a booking system, offering insights into the scheduling and utilization patterns of the GC. We used the MAMDA model to guide the case study and inform the data collection process. The motivation behind employing the model is to examine and reflect upon the practical applicability and effectiveness of the newly developed model in an authentic educational context. This approach serves as a valuable means to refine the proposed model, particularly within the complex and dynamic setting of the GC. MAMDA, designed through a qualitative study involving interviews with researchers and experts in the field of MMLA, is applied as a structured framework. The model addresses key considerations across various phases, providing an initial approach to MMLA system design. Each phase of MAMDA corresponds to specific considerations, including learning scenarios, human factors, research orientation, data collection, data management, privacy, and ethics. The application of MAMDA serves as a guidepost, aligning the data collection efforts with the overarching objectives of designing an MMLA system tailored to the context of the GC.

While the GC is present in four different countries across four continents (Sweden, Canada, South Africa, and Australia), the observations and data collection activities are specifically centered on the Swedish instance of the GC. This focused examination allows for a specific exploration of the GC's characteristics, technological capabilities, and the embodiment of Glocality principles in education.

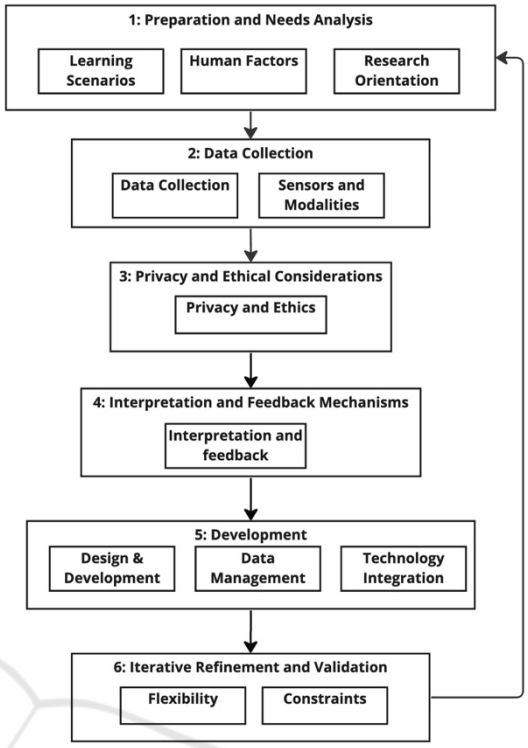

Figure 1: MMLA Model for Design and Analysis.

4 MMLA INTEGRATION IN GC

Aligned with the foundational principles of the Community of Practice (CoP), derived from John Dewey's notions and defined by Lave and Wenger, it is applied to the GC setting (Christensen et al., 2020). the framework leverages CoP's emphasis on shared interests, open dialogue, and collaborative learning within a common domain. In the GC setting, the CoP perspective becomes a catalyst for transformative educational experiences, evolving the GC into a community where global interactions, shared learning, and collaboration form the essence of the learning process. These elements gain heightened significance in an era where interconnectedness and cross-cultural understanding are imperative for education. The synergy between MMLA and the GC's goals is a cornerstone of our framework. MMLA's focus on leveraging multimodal data aligns seamlessly with the GC's objectives, showcasing its adaptability of MMLA and potential to enhance or assess education practices in the GC. This alignment underscores the reciprocal relationship between MMLA and the GC's educational philosophy. MMLA benefits from the GC's infrastructure, while the GC gains from enhanced analytical capabilities

offered by MMLA. This reciprocal enrichment forms the envisioned glocal learning environment, where global insights contribute to local educational excellence and vice versa.

4.1 Preparations and Needs Analysis

We addressed the first three considerations in the initial phase: Learning Scenarios, Human Factors, and Research Orientation. Our aim involved the identification of educational objectives aligned with curriculum requirements and the technical infrastructure. CoP emerged as a fundamental educational framework within the GC. Consisting of students and educators, the CoP shaped the collaborative and community-driven educational practices observed in the GC. The examination also revealed the elements of the basic technological infrastructure essential for communication and collaboration. This included audio and video components and digital platforms that facilitate interactions. The main actors in the GC, namely students and lecturers, are identified as collectively forming the CoP. The implementation details, such as the placement and distribution of communication tools (data streams), become critical considerations. Designing the classroom layout, determining optimal tool placement, and understanding what aspects of interactions to capture are essential for effective MMLA integration. While not delving into an exhaustive technical inventory, the emphasis remains on the minimal yet pivotal technology necessary for CoP and MMLA, ensuring a focused and purposeful approach to the integration framework.

4.2 Data Collection

In the second phase, we address two considerations: Data Collection and Sensors and modalities leading to selecting sensors capable of capturing multimodal data and identifying the appropriate modalities, closely aligning outcomes from the preceding phase. By leveraging the capabilities of the GC's communication and collaboration technology, encompassing microphones, cameras, and digital platforms, we can establish the foundational groundwork for data collection. Importantly, we provide in Table 1 an explicit mapping of CoP learning indicators with digital modalities. This deliberate alignment emphasized modalities associated with communication and collaboration patterns, echoing the collaborative nature inherent in the CoP framework. MMLA leverages the data streams generated by the GC's technological infrastructure. Interaction patterns, both verbal and non-verbal, are captured by cameras, providing insights into the dynamics of collaboration and engagement. Audio data offers a qualitative understanding of the tone, intensity, and frequency of interactions, enriching the contextual characteristics of communication. Screens contribute valuable information on collaborative efforts, displaying shared content and illustrating the evolution of ideas. The data collection types encompass a spectrum of modalities, including visual, auditory, and textual elements. Interaction patterns unveil the social dynamics within the Community of Practice, while engagement levels provide a quantitative measure of participation and involvement. These modalities collectively offer an overview of the collaborative learning process, enabling the analysis of the multifaceted interactions within the Global Classroom.

4.3 Privacy and Ethics

In the Privacy and Ethics phase, our primary objective was to ensure that the selected modalities, aligned with the CoP learning indicators, complied with established privacy and ethical standards. Building upon the pre-established requirements from the previous phases, we validated the alignment of selected data streams concerning GDPR regulations, data anonymization, and transparent data processing policies. Furthermore, we developed a policy outlining the transparent data processing practices adopted in our MMLA system. This policy provided a clear explanation of how data collection and processing contribute to educational objectives. By emphasizing transparency, we aimed to build trust among users, fostering an environment where individuals are aware of and understand the purpose of data processing in the context of enhancing educational experiences.

4.4 Interpretation and Feedback

Based on the outcomes of preceding phases, namely the established CoP, the identified technological infrastructure, the selected modalities for data collection, and the robust privacy and ethics considerations. Building upon these foundations, we determined the nature of feedback and interpretations that the MMLA system should provide in the context of the GC. We envisioned a simple visualization framework to capture individual and classroom performance modalities. These modalities included indicators such as attendance patterns, levels of

activity, and the frequency and quantity of speech within the learning environment. To refine our approach further, we aim to conduct surveys among both students and lecturers, seeking their insights on the initial modes of feedback that the MMLA system should offer. This iterative process allows us to identify and prioritize feedback elements that can be subsequently evaluated and tested for their effectiveness, ensuring that the MMLA system's interpretations align closely with the needs of the stakeholders.

4.5 Development

In the Development phase, we address three considerations namely, Design and Development, Data Management and Technology integration. All activities in this phase culminate in insights and considerations from the preceding phases, encompassing the established CoP learning indicators, the identified technological infrastructure, the modalities chosen for data collection, the privacy and ethics framework, and the envisioned feedback mechanisms. Based on the understanding of these elements, the design and development process, consist often incorporation of data interpretation techniques, including algorithms and machine learning, to provide insights. A key focus is establishing real-time feedback loops, enabling continuous responses to learners and educators based on collected data. This integration not only capitalizes on the available technological infrastructure but also ensured a cohesive learning experience for the diverse CoP. Data analytics is the key understanding collected data about collaborative learning dynamics within the CoP. Natural Language Processing (NLP) techniques decode textual interactions, uncovering themes, sentiments, and emerging patterns in the discourse. Computer vision algorithms analyze visual data, identifying non-verbal cues, group dynamics, and engagement levels. Quantitative analytics, complemented by qualitative assessments, provide a comprehensive understanding of the collaborative learning experience.

Practically implementing the MMLA integration involves a phased approach. Initially, educators and students undergo training to familiarize themselves with the technological tools and the MMLA system. Throughout the course, data collection occurs seamlessly in the background, preserving the natural flow of the learning process. Periodic reviews and reflections on the analytics generated by the system inform iterative adjustments, ensuring continuous improvement and optimization of the learning experience.

4.6 Refinement and Validation

The final phase, Refinement and Validation, represents a continuous improvement cycle, acknowledging the dynamic nature of educational environments. As future work, this phase involves a reflective process that considers the challenges encountered throughout the previous phases. A critical aspect is the evaluation and testing of the MMLA system, which serves as a feedback loop to inform further refinements. The outcomes of this phase are twofold. First, it entails an iterative return to the initial phase, Preparation and Needs Analysis, to address any identified issues, adapt to emerging

Table 1: Mapping of CoP learning indicators and digital modalities.

Learning Indicator	**Modality**	**Data Format**	**Sensor/Data Source**	**Feedback/Output**
Learning Interactions	Speech patterns, collaborative activities, frequency of contributions	Audio, Video, Interaction logs	Microphones, Cameras, Digital Platforms	Real-time feedback on group communication
Knowledge Sharing and Construction	Shared documents, contributions to discussions, collaborative problem-solving sessions	Text, Interaction logs, Screen sharing	Documents, Digital Platforms	Visualizations of collaborative activities
Social Presence and Community Engagement	Attendance patterns, frequency of interactions, participation in collaborative activities	Interaction logs, Video	Digital Platforms, Cameras	Notifications in case of lack of presence
Problem-Solving Strategies	Interaction patterns during discussions, key contributors, effectiveness of solutions proposed	Interaction logs, Screen sharing	Digital Platforms, Cameras	Individual profile analytics
Role Identification and Collaboration	Contributions, expertise-based interactions, distribution of responsibilities	Interaction logs, Screen sharing	Microphones, Cameras	Visualization of roles dynamics
Reflection and Feedback	Individual contributions, responses to feedback, evolution of ideas	Interaction logs, Video, Text	Microphones, Cameras	Mapping reflections and feedback with earlier activities.

constraints, and ensure ongoing flexibility in the MMLA system. Second, the validation of the conceptual model is achieved through continuous refinement, incorporating expert input and addressing potential limitations. This process ensures the alignment of the MMLA system with real-world applications and scholarly discourse, contributing to the effectiveness of analytical systems in diverse educational settings such as the GC.

5 MMLA MODEL FOR THE GLOCAL CLASSROOM

Building upon the foundational principles of MBOX (Ouhaichi et al., 2021), an IoT-based system allowing the collection and processing of multimodal data from collaborative learning tasks. We present a tailored MMLA model specifically designed for the GC. This model envisions a dynamic and adaptive system that integrates seamlessly with the unique characteristics of the GC environment. Drawing inspiration from the three-layered architecture of MBOX, our model revolves around the Users Layer, Communication Interface Layer, and Processing Layer.

5.1 Model Components

The model is made up of three layers. The users layer constitutes the first tier engaging students, teachers, and various stakeholders such as researchers and education managers. In the GC, this layer represents participants interacting within the collaborative learning space across multiple remote classrooms.

The users layer serves as the focal point for capturing diverse perspectives and interactions within the GC. Second, comes the sensing interface layer, which represents communication technology embedded in the GC, functioning both as a facilitator of interactions and a data capture mechanism. Communication tools, including microphones, cameras, and projectors, form the technological infrastructure of this layer. This interface serves a dual purpose, enabling seamless communication among participants while also capturing multimodal data generated during the collaborative learning process. The arrow connecting the users' layer to the sensing interface symbolizes capturing interactions and communication within the GC, creating a bridge between human engagement and data collection. At the top of our model lies the processing layer, where data storage, management, and MMLA activities unfold. This layer is the hub for processing multimodal data collected from the sensing interface. Leveraging the insights gained from MBOX, this tier could adopt a multi-level architecture, comprising edge, fog, and cloud layers. The edge layer handles real-time data processing at the group level, facilitating immediate feedback through local mechanisms. The fog layer extends the perspective to the classroom or school level, offering additional insights and feedback mechanisms. Finally, the cloud layer processes data at a global level, contributing to a comprehensive understanding of collaborative learning experiences within the broader educational system.

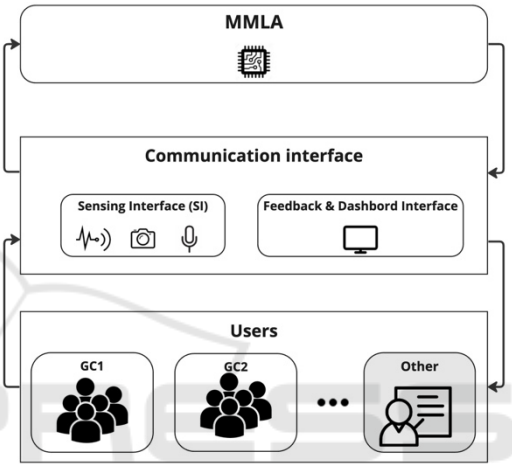

Figure 2: MMLA model for Glocal education spaces.

The arrows in our model illustrate the cyclical nature of MMLA within the GC. Data flows from the users' layer to the sensing interface, where interactions are captured. This data is then directed to the processing layer, where MMLA activities, including analytics and interpretation, take place. Feedback and outputs generated are then looped back to the users, completing the cycle.

5.2 Usage of Integrated MMLA

The integration of MMLA into the Glocal Classroom transforms the user experience for students, educators, and researchers. For students, the MMLA integration introduces a personalized learning journey. Real-time feedback mechanisms from the edge layer provide instant insights into collaborative efforts, allowing students to adapt and optimize their learning strategies. The Sensing Interface Layer captures nuanced interactions, providing a detailed view of their participation and engagement. Educators benefit by gaining a more holistic perspective on collaborative learning dynamics. By

capturing both verbal and non-verbal cues, educators can better understand group dynamics and tailor their teaching strategies. This enhanced view facilitates informed decision-making, allowing educators to refine their pedagogical approaches. Researchers now have access to a wealth of multimodal data, fostering in-depth analyses and scholarly contributions. The multi-level architecture of the Processing Layer provides a scalable and adaptable framework for researchers to explore human learning across various scales. The cyclical flow of data enables continuous refinement, aligning the MMLA system with real-world applications and scholarly discourse. The integrated MMLA model serves as a valuable tool for advancing research in the field of educational technology.

6 DISCUSSION

In this study, MAMDA serves as a foundational guide for integrating MMLA into the GC. The adaptation of the MAMDA model reveals crucial insights into the dynamics of the learning environment, prompting necessary adjustments for a more effective integration. Notably, the repositioning of Data Management considerations to the Development phase and the relocation of Sensors and Modalities to the second phase of Data Collection exemplify a more coherent workflow that aligns with the dependencies of educational technology integration (Ouhaichi et al., 2019). The phased consideration of Interpretation and Feedback acknowledges the distinct production workflow of educational systems, enhancing the responsiveness of the learning environment (Messina Dahlberg & Bagga-Gupta, 2014). These modifications not only refine the MAMDA model but also address challenges associated with privacy and ethics, providing a more robust framework for responsible MMLA integration. The study's insights contribute to the ongoing evolution of MMLA systems, opening avenues for future research and advancements in smart learning environments.

Researchers can leverage our model as a comprehensive guide and template for integrating MMLA into diverse learning environments, especially those characterized by global communication and collaborative learning. The structured six-phase approach outlined in our model, derived from MAMDA, serves as a roadmap for researchers seeking to understand, implement, and refine MMLA systems. By employing our model, researchers and other practitioners can navigate the complexities of data collection, ethical considerations (Alwahaby et al., 2021), and technological integration within learning environments. The adaptable nature of our framework allows researchers to tailor it to different educational settings, ensuring relevance across various cultural and geographical contexts. Ultimately, our model provides a methodological foundation for advancing the exploration and implementation of MMLA, fostering a deeper understanding of collaborative learning experiences and paving the way for further innovations in educational research and technology.

7 LIMITATIONS

While integrating MMLA into the Glocal Classroom presents a promising avenue for enhancing collaborative learning, certain limitations inherent in this study must be acknowledged.

The success of the MMLA model relies heavily on the existing technological infrastructure within the GC. Limitations in the hardware, network capabilities, or compatibility issues may impact the integration and functioning of the MMLA system (Blined). Variability in technology across different instances of the GC may introduce challenges in achieving uniform MMLA implementation. The case study approach employed in this research focuses specifically on the GC setting, representing a unique implementation of Glocality in education. While the findings contribute valuable insights within this context, the generalizability of the MMLA model to diverse educational environments remains a consideration. Variations in classroom structures, cultural nuances, and technological setups may affect the applicability of the model in other settings. The mapping of CoP learning indicators with MMLA modalities is a complex task. The accuracy and relevance of this mapping may be subject to interpretation and could impact the fidelity of learning insights derived from the MMLA system. Further refinement and validation of this mapping process are essential for ensuring the robustness of the model. Acknowledging these limitations is crucial for a comprehensive understanding of the study's scope and implications. Future iterations of MMLA integration in diverse educational contexts can build upon these insights to address and overcome these limitations, contributing to the continued evolution of collaborative learning analytics.

8 CONCLUSION

In this paper, we present a case study exploring the integration of MMLA into the GC. Guided by the MAMDA model, our study unfolds six phases: Preparation and Needs Analysis, Data Collection, Privacy and Ethics, Interpretation and Feedback, Development, and Refinement and Validation. The main contribution lies in demonstrating the practical application of MAMDA in the GC, offering insights into the integration of MMLA to enhance collaborative learning experiences and inform educational practices. Through this study, we tested the application of MAMDA within the dynamic educational ecosystem of the GC. We also critically examined and refined the model to better align with the dependencies of educational technology integration. The strategic repositioning of key considerations, such as Data Management, Sensors and Modalities, and Interpretation and Feedback, attests to the adaptability and responsiveness of the model in real-world scenarios. As a result of this systematic approach, we have demonstrated how MMLA can be embedded into the GC context, leveraging various data sources. The incorporation of MMLA aligns with the CoP principles within the GC, fostering a collaborative and community-driven educational environment. To illustrate the resulting conceptual integration, we present a three-layered architecture that facilitates the capture, processing, and analysis of multimodal data.

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