International Cartographic Association
Association Cartographique Internationale

Addressing characteristics of environmental context - challenges and potential for location-based mobile learning applications

Friedrich Striewski [a], Carolin Bronowicz [a], Susanne Bleisch [a]

[a] *FHNW University of Applied Sciences and Arts Northwestern Switzerland, Institute Geomatics*
friedrich.striewski@fhnw.ch, carolin.bronowicz@fhnw.ch, susanne.bleisch@fhnw.ch

Abstract: Complexity, uniqueness, and dynamism are intrinsic characteristics of the physical environment that must be carefully addressed in the development of location-based, context-aware mobile learning applications. Designing such applications to deliver meaningful spatial experiences and support learning in extracurricular, field-based education requires identifying and overcoming challenges stemming from these properties, as these challenges influence not only the application's design and content but also the overall quality of the user experience. We identify and discuss three distinct challenges: (1) the complexity of accurately modeling the form and relationships of spatial phenomena, (2) the constraints imposed by rigid formats and top-down approaches that fail to capture the distinct and inherently unique attributes of contextual entities, and (3) the need to manage the dynamism and ongoing changes in the environment throughout the application's lifecycle.To address these challenges, we propose solutions grounded in template-based modularity, customizable experiences, and an adaptive, automated architecture. These approaches aim to support educators in authoring, publishing, and maintaining their applications efficiently. Through the demonstration of a prototype framework, we illustrate how these strategies can be implemented in practice while highlighting existing limitations and areas for further development.

Keywords: location-based services, context-aware systems, mobile learning, web-applications, spatial education

1. Introduction

Location based mobile learning (LBML) is a subset of the mobile learning domain, where location- and context-aware technology is used to accompany and facilitate 'in situ' educational or informal learning *with* and *in* the physical environment[1], that is, outside of traditional study locations like schools or classrooms (Brown, 2010). While educators or facilitators are usually present for traditional 'field trips' or 'excursions', this role is partially or completely substituted by technology and a system that handles the responsibilities of guidance, instruction, scaffolding or contextualization (Medzini et al., 2015). In LBML, both learner and system are *mobile* during use and learning takes place within the physical environment. Through these characteristics, this type of educational activity can also be distinguished from the format of 'Virtual Field Trips', where the physical environment and location are replaced by fully digital representations or simulations through virtual means and user and system remain fixed (MacCallum and Parsons, 2022). With the exponential growth of mobile device distribution, processing power, global positioning and network availability, the potential for facilitating extracurricular learning through mobile systems has greatly increased in the last decades (Garzón et al., 2024). One key insight from the multitude of approaches to mobile learning has been the requirement of a solid pedagogical design for the educational experience and an appropriate implementation through context-aware technology (Brown, 2010). Efforts to achieve effective context modeling have largely focused on integrating intelligent system-user interactions and embedding educational principles such as constructivism and collaboration in the experience (e.g. Patten et al. (2006)).

From our perspective, the defining characteristic that sets location-based learning apart from other educational activities — and the primary justification for relocating learning into the field — is the 'spatial experience'. By this we mean a learning process that takes place through a purposeful interaction with and within the physical environment, or, in the words of Squire (2007, 374) the "*creation of meaning in situ*".

To fully enable such interaction, greater attention must be given to modeling the context entity of the (physical) environment. This encompasses modeling the "*objects under observation*" (Constantinidis et al., 2013, 180), including their conceptual and cartographic representation, as well as its requirements, challenges, and implications for the design of location-based learning systems.

This paper examines three critical factors influencing the design of location-based learning applications: the inher-

[1] In this paper we use the term *physical* environment to distinguish it from a virtual, computational or conceptual, e.g. educational, environment. The term is intended to include both nature as well as the anthropogenic sphere, e.g. the build environment.

ent complexity of spatial phenomena, the challenge of uniqueness in modeling interactions between the environment and learners, and the dynamic requirements for system operation and maintenance. Through the presentation and analysis of a prototype framework, we propose strategies to address these challenges and to potentially enhance the effectiveness and usability of location-based mobile learning (LBML) applications.

2. Related work

Location-based mobile learning applications are *context*-aware systems as they deliver services and information tailored to users' specific situations and tasks (Schmidt, 2003). Thus, they need to be described and analyzed based on a definition of context.

2.1 Context definition and dimensions

In the conceptual framework of Dey et al. (2001), context is defined as a comprehensive collection of information used to describe the situation of entities, including an entity's state, its properties, or interactions with further entities. Such entities are for one the system, user and environment, but also any other object involved in the exchange of information between them. For an educational context as discussed here, 'user' entities are mainly educators and students. The 'system' entity includes the technical infrastructure, software and any sensors used by them. 'Environment' entities include the social, educational, institutional and physical settings in which users and systems operate.
Schmidt (2003) provide a context classification along dimensions of 'self', which encompasses a user's or system's state, capabilities, and properties, 'activities', which include tasks, behaviors, and interactions, and 'environment', which incorporates location, infrastructure, and conditions. This classification highlights the interconnected nature of entities, emphasizing that they do not exist in isolation but continuously interact with each other and their surrounding environment. Conversely, entities are also shaped by the environmental and activity-related dimensions. A similar perspective is presented in the operational definition of context by Zimmermann et al. (2007). Among the five fundamental categories of contextual information, the authors identify 'activity' as the primary determinant of the situational relevance of context entities. In the same definition, 'individuality and 'relations' describe entities and their interconnections, while 'time' and 'location' function as dimensional factors influencing the exchange of information.
In the context of education, it can be argued that the creation, transfer, and consumption of information constitute the predominant activity that determines the relevance of contextual elements. Moreover, when learning is location-based, the location, or more precisely, the physical surroundings, becomes a defining factor of the activity. Brown (2010, 7) characterizes this process as an "*interactive negotiation by the learner with their natural environment*". While the learner's characteristics are shaped by various factors, including the educational setting, discipline, learning objectives, and individual user-specific parameters, the role of the physical environment in this negotiation must also be carefully considered.

2.2 Implications from environmental context

Challenges and risks associated with mobile learning applications have been extensively documented in systematic reviews by Mehdipour and Zerehkafi (2013), Garzón et al. (2024), and others. However, the studies cited in these reviews often lack specificity regarding location-based mobile learning, where the physical environment plays a crucial role in the design and modeling process (FitzGerald et al., 2009).
A second body of literature originates from research on context-aware sensors, which acknowledge the physical environment as a fundamental context entity (see 2.1). While these studies address challenges and limitations, they primarily focus on technological perspectives rather than the specific activity of mobile learning. Environmental parameters and their effects are, for instance, included in the context model of Schmidt (2003). Sailer et al. (2015) more specifically distinguish between predictable factors, such as environmental and seasonal conditions, and less controllable ones, such as weather, accessibility, traffic, and safety, which lie beyond the influence of teachers or designers. In analyzing uncertainties in dynamic physical environments, Iglesia (2012) draws a critical distinction between 'known unknowns' and 'unknown unknowns', emphasizing the inherent unpredictability in both development and use phases of mobile learning systems. The author underscores the importance of mitigating risks through assumption-backed strategies.
In summary, we observe a notable gap in addressing the environmental implications and requirements specific to LBML application design. In our view, the diverse and dynamic nature of the physical environment influences context across multiple levels and throughout various stages of an LBML application's lifecycle—from initial planning and design to implementation, usage, maintenance, and subsequent adaptation or reuse.

3. Challenges in modeling environmental context

In the following, we will focus on the challenges posed by a multifaceted and dynamic environment and their implications for the design of location-based learning applications. Building on the five dimensions of context information outlined in the operational definition of Zimmermann et al. (2007) (see 2.1), we identify three specific factors of impact:
For 'location' and 'relation', the challenge of distinguishing *complex* spatial phenomena from one another and adequately modeling their structure, relationships, order, or hierarchy (challenge **C1**). For the factors of 'individuality' and 'activity', the issue of addressing *uniqueness* in learning stations and learning behavior through strict schemas and generic, immutable and predefined structures (challenge **C2**). For 'time', the challenges of temporal variability in environmental *dynamism*, which can negatively impact content relevance and the overall lifecycle of the learning application (challenge **C3**).

32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-30-2025 |

3.1 Complexity - the risk of oversimplification and overgeneralization (C1)

A review on the body of literature on implementations of location-based mobile learning applications (e.g. Constantinidis et al. (2013), Mauro et al. (2024)) indicates that the prevalent and almost exclusively used conceptual model of outlining location-based learning is that of a graph, where learning 'stations' or 'Points Of Interest' (POIs) are represented as nodes and the connecting route in between as edges. Such a graph is either sequential and linear (if a strict order and chronology is desired), or a network (where users are allowed a higher degree of freedom in choosing topics and order of information). Beyond the conceptual level, a clear node-edge distinction between fixed positional learning and mobility between stations is embedded in the data modeling, cartographic representation, and technical implementation. Once the specific coordinates of a POI are successfully matched against the location of the user, the application switches from routing to the display of station-bound content or activities. In our view, such a reduction oversimplifies spatial phenomena and imposes a (self-)limitation on the ways interaction and activities can be facilitated:

Firstly, it relegates the route between stations to a merely intermediary role, shifting the focus away from the creation of meaning through the exploration and investigation of authentic surroundings (Constantinidis et al., 2013) and instead prioritizing efficient and safe navigation. However, the route itself, conceptualized as a 'Line of Interest' (LOI), can also hold meaning: certain gradual changes in the environment cannot be fully understood from a single point but require movement along a path of transformation. Similarly, activities such as a 'fox-trail' or 'treasure hunt' inherently have defined start and end points, yet the core experience unfolds along the journey. Supporting this experience requires the application to actively facilitate user engagement, for instance, by directing attention to relevant features along the route. These examples challenge a strictly binary distinction between route (navigation) and station (content, activity), highlighting the need for a more integrated approach.

Secondly, when considering the true spatial dimensions of entities, learning stations are rarely mere points but rather *Areas* of Interest (AOIs) where learning takes place. With defined extent, shape, and boundaries, aspects of topology and spatial relationships become relevant — not only in relation to other stations, but also within the AOI itself. A more accurate modeling approach therefore necessitates de-generalization, ensuring that observed objects are represented by their actual spatial feature types and that their geometric properties are appropriately managed by the technology.

3.2 Uniqueness - the problem of top-down solutions and inflexible models (C2)

Uniqueness is the highest degree of variation, as it means difference on all aspects. As such, it poses a great challenge for technology, which is usually based on rigid data models, predetermined structures, clearly defined sequences and unambiguous logic. Through classification and generalization, a simplification can be achieved, which is based on common features or properties that are equal or at least sufficiently similar within given bounds. In this process, character and information are inevitably getting lost.

Two strategies are common in data modeling (Kung et al., 2012): The top-down approach first constructs a conceptual model of format and structure before applying it to the data. The bottom-up approach analyzes shape and attributes first and builds a common data model out of similarities and groupings of entities.

In the context of LBML, uniqueness is inherently present in both the physical and social environment, as well as in the individuality of the learner, in alignment with a constructivist learning model. The term of a "*negotiation*" (Brown, 2010, 7) between these entities raises the question about the role of technology as a facilitator and mediator of this interaction:

Meek et al. (2013) suggest that LBML should not be driven by technology but designed around it, while a review of various studies by DeWitt and Storksdieck (2008) shows that a balance between freedom of choice and a moderate degree of structure yields the highest cognitive and affective learning gains. Accordingly, they recommend incorporating customizable experiences centered on individual exploration and discovery as a best practice in educational design. Rigid formats have also been acknowledge as an obstacle for content implementation by Webb and Stafford (2013), Giemza and Hoppe (2013) and others.

As the primary decision-maker, the designer (educator, author) must thoughtfully define both the 'what' (content, scope, and boundaries) and the 'how' (technology, tools, and methods) of the experience, also ensuring that technology enhances rather than overwhelms or distracts from the experience (Constantinidis et al., 2013). This task goes beyond defining the overarching theme and encompasses detailed decision-making at the station level. A bottom-up approach demands granular and flexible tools to accommodate local uniqueness, measures of choice and to facilitate a stronger individualized experience.

3.3 Dynamism - the challenge of actuality and availability (C3)

The environment is rarely in a fixed or singular state, but affected by ongoing changes due to physical or anthropogenic influence on various (spatio-)temporal scales and patterns of occurrence. Relevant physical factors include atmospheric effects or surface conditions that influence the state, availability, or safety requirements in the field. Anthropogenic factors encompass changes in administrative, legislative, or political conditions, as well as long-term impacts such as the modification or destruction of objects, areas, habitats, and landscapes. And even if the environmental context is assumed to remain relatively stable for the intended learning purpose, our perspective on its educational affordances may not. Variables such as administrative requirements, learning levels, goals, and curriculum specifics are inherently dynamic within an educational framework (DeWitt and Storksdieck, 2008).

These examples illustrate that merely embedding the cur-

rent state as it exists at the time of creation into the content is a risky and potentially costly strategy. Depending on the chosen setup and technical parameters, maintenance and updating content can become a challenge in itself - particularly when physical components at a location need to be replaced or a new software version must be distributed across multiple channels.
Beyond technical decisions, there is also an implicit impact on content selection during the planning and creation phase. Short-lived or fluctuating phenomena are likely to be excluded from selection when the expected maintenance is deemed too complex or time-consuming, making it not worth the effort to incorporate such material.
These aspects require an architecture that is built with update-cycles in mind. The specific demand for cost-efficient solutions, with a low technical barrier and a great degree of autonomy have been identified by authors like Webb and Stafford (2013), Giemza and Hoppe (2013), Sailer et al. (2015), and Mauro et al. (2024).

4. The DidaKRuLO framework

To investigate strategies for addressing the challenges outlined in the previous section (3), we developed a prototype that integrates potential solutions into its architecture and functionality. This section introduces the foundational components of 'DidaKRuLO' (engl.: 'Didactic Concepts for REDULO[2], a prototype framework designed for the authoring and automated publishing of LBML web applications. A more in-depth analysis of its features and limitations is provided in the subsequent sections (5 and 6).
The DidaKRuLO framework is composed of three primary building blocks (fig. 1):

1. A 'Builder' application for content authoring, allowing educators to design learning trails, to position and describe stations, and to attach content using a set of predefined templates.
2. An automated, Git-based processing pipeline that manages app building and deployment by integrating data from the Builder with the source code of the target application, stored in an external Git repository.
3. A ready-to-use mobile web application, generated as the final output of the processing pipeline, containing a single learning trail as its core content.

The following section will provide a detailed description of these individual building blocks:

4.1 'Builder' application

The 'Builder' is a single-page web application built with TypeScript and ReactJS, enabling componentization, internal state management, and high-performance UI interactions. All logic and data processing are handled in the frontend, utilizing React's state management during authoring. Input data can be stored in three ways: temporarily in browser memory, as a downloadable JSON file for offline editing at the trail or station level, or as a git commit

[2] 'REDULO' is an internal name for the underlying technical components.

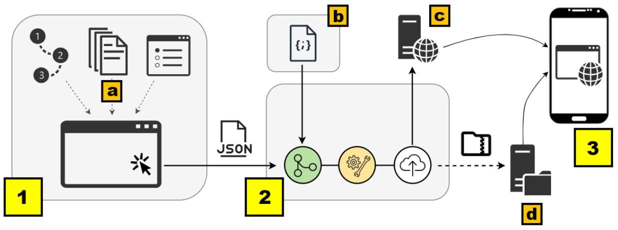

Figure 1. The DidaKRuLO framework comprises three main components: (1) the *Builder*, which facilitates content authoring and configuration (a); (2) a *processing pipeline* that integrates the Builder's output with application source code (b) from a separate repository, compiles the *web-application* (3), deploys it to Google Firebase (c), and generates a .zip file for manual PWA hosting (d).

triggered during the app-building process, which creates or updates a branch based on the project's name. Content can be authored in the builder on the conceptual levels of trail, station and template:
On the trail level, any metadata of the trail as well as global settings for the behavior of the target application are defined. These are for instance permissions to skip stations or to visit them remotely. On the station level, the number, order and location of stations can be defined. The actual content is assigned to a station from a catalog of so called *templates*, which are predefined building blocks of functionality and fill-able blueprints for the most common needs, like media embedding, quizzes and scaffolding features, but also specialized tools or activities. A single station can receive multiple templates, with quantity, type, volume and order being at the author's discretion. On the template level, individual definitions are made for the selected template. Depending on the template type this includes the authoring of texts, linking of media, and definition of quiz parameters, including learning goals, scaffolding features and supportive hints. A preview shows how the template would appear on a mobile screen and enables interactive experimentation, simulating its behavior in the final app.
After completing authoring, authors can trigger the processing pipeline from the context menu to start the app-building process. They will be notified of the status and receive the built app upon success. Content loading and saving are also available from the same menu.

4.2 Processing pipeline

DidaKRuLO follows a serverless model, replacing both server and database with a Git-based, cloud-hosted architecture. It uses GitLab's CI/CD automation pipeline and hosted runners for processing, with the repository serving as the content data store. The builder app interacts with GitLab's REST API to trigger branch creation, app building, and retrieval of the ready-to-deploy app code in .zip format. GitLab handles authentication and authorization, requiring an access token to trigger the pipeline. User management is independent, allowing organizations to control permissions for content authoring and publishing. Repository settings secure the content against external access. Each successful pipeline run merges the source code with builder data and uses the cross-platform Capacitor runtime to build the final app. In addition to hosting the app on Google Firebase, a .zip file is generated for manual 'Progressive Web Application (PWA)' deployment.

4.3 Learning application

Apps generated through the DidaKRuLO 'Builder' pipeline are mobile web applications, built with TypeScript, ReactJS, and utilizing Ionic and Capacitor technologies. If manually uploaded to a web server with HTTPS enabled, they mimic native apps, running full-screen as a PWA, but still requiring a working network connection for retrieving content. The app can also access device sensors like GPS, gyroscope, camera, and microphone. Though designed primarily for mobile devices (phones, tablets), the UI is responsive and works on larger screens as well.

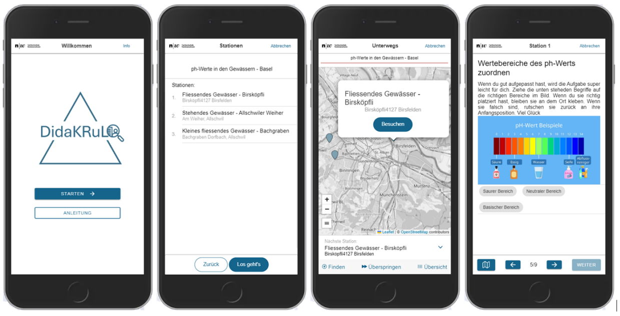

Figure 2. Different screens of the DidaKRuLO learning application illustrating the user flow, from the introduction and overview to navigation and a template of a visited station.

The application (fig. 2) consists of two main types of views: supportive screens and actual content. The supportive screens include a general introduction, trail overview, imprint, the user manual, and a final screen indicating trail completion. Contrary to these, the actual content is flexible and adjusts to the settings made by the author in the builder application. For routing purposes, a navigation map shows the users' position, the location of stations and assists in the selection of information through various tools. Users are notified through a haptic impulse and a visual message when their position intersects with a station's geofence and can then switch into the station view, composed of an individual selection of templates and their content. Alternatively and depending on the specific permissions, stations can also be visited remotely from outside of the geo-fence.

5. Addressing context modeling challenges with DidaKRuLO

In this section we demonstrate how the framework prototype 4 could address the challenges of complexity (C1, see 3.1), uniqueness (C2, see 3.2) and dynamism (C3, see 3.3) encountered in environmental context modeling. The proposed strategies include architectural considerations, application features, and the implementation of specific templates.

5.1 Recognizing complexity through tailored tools (C1)

While DidaKRuLO conceptually follows the model of a network graph with mobility along edges and content at nodes, its implementation diverges from this principle in several aspects:
In DidaKRuLO, learning stations are defined solely as Areas of Interest (AOIs), rather than Points of Interest (POIs). While coordinates serve as a visual reference on the trail map, the station's shape and boundaries are defined by a polygonal geofence, which transitions users from navigation to station-specific activities. Authors can derive LOIs and POIs from the AOI by reducing the geofence's extent in one or two dimensions.
With a specifically designed template (fig. 3), we further deviate from the traditional model of mobility on routes and static positions at stations. In the Builder application, the 'navigation template' allows authors to define a polygonal area as the user's target location. For learners, this template provides a compass and a distance meter, indicating the range and direction to the nearest point of the polygon and guiding the user to the intended position.

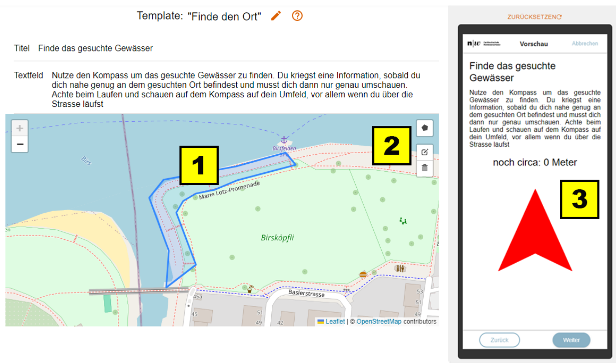

Figure 3. The 'navigation template' allows the author to define a polygonal area (1) with a set of vector based tools (2). The app preview on the right shows how the template is rendered for the user: A compass needle and distance meter (3) guide the user to the target area.

While originally designed for precise user positioning, this tool can also be combined with other templates to create a sequence of waypoints within the station's AOI. Not only can 'fox-trail'- or 'scavenger hunt'-type activities be enabled this way, the template also affords a second hierarchical layer of 'sub-stations' and 'sub-routing' and a stronger blend of content, activity and fine-grained positioning within the 'umbrella' of the station's overarching context. Defining LOIs at this level emphasizes knowledge transfer and differentiates activities from routing tasks between stations. Informative templates can support instructions or activities along the route, with audio media being particularly effective for relaying information unobtrusively while users are in motion, provided ambient conditions are suitable.
As elaborated further in section 5.2.2, DidaKRuLO supports various modes of traversing the trail's network graph, enabling both structured, linear sequences and free-form exploration for users. Combining these features enables

Advances in Cartography and GIScience of the International Cartographic Association, 5, 30, 2025.
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-30-2025 |

the management of a wide range of geometric shapes and spatial relationships within the application, allowing for the design of tailored learning experiences.

5.2 Accommodating uniqueness by modularity and measures of choice (C2)

Using technology to address the uniqueness of environmental entities and the diversity of learners inevitably requires some level of abstraction and generalization. However, shifting from generic, fixed-structure models to a compositional approach, built on predefined but granular building blocks, introduces greater flexibility in the design and a better fit between entities.

5.2.1 Content side: Modular structure and template-based content

A fundamental design decision in developing the DidaKRuLO framework was the adoption of an unopinionated, bottom-up strategy for content creation and structuring. This approach involved deconstructing and segmenting common features into granular, versatile and self-contained building blocks ('templates'). These content elements can be freely selected, arranged, and reassembled by authors to create highly customized and individualized compositions. Such a template-based approach offers several advantages over rigid, uniformly structured content presentations:
At the station level, it enables precise tailoring of the learning experience to the unique conditions and affordances of the physical environment. This allows for a closer representation of local characteristics, independent of the requirements or constraints of other locations.
On a broader scale, templates ensure the framework's domain independence. By separating internal logic from content, the framework supports diverse applications across various fields, topics, and target groups. The catalog-based provision of templates further enhances scalability and extensibility. Generic and specialized template types coexist seamlessly, and new templates can be integrated without disrupting existing compositions.

5.2.2 User side: Customizable experiences

To afford measures of choice for the user, the DidaKRuLO Builder allows educators to define varying degrees of freedom in the target application. A key decision for authors is whether stations should follow an ordered, sequential structure or allow more open exploration. A structured trail, where stations are presented in sequence, is beneficial when an obvious 'best' route exists or when a didactic progression is necessary. In this setup, the next station is highlighted on the routing map, with its location and address communicated to the user. Conversely, unordered stations facilitate free exploration and personal discovery strategies. In this mode, no visual cues for the next station are provided, but progress is still tracked and displayed by graying out visited stations and updating a progress bar toward completion.
A second setting enables learners to visit stations remotely by accessing content from the routing map. Currently, this setting applies globally rather than to individual stations. While remote visits may deviate from the intended in-situ learning experience, they support several use cases: for instance, revisiting stations to reinforce content, either in the field or during classroom follow-up. Together with the third setting, which allows users to skip stations, these features provide flexibility in adjusting itineraries based on individual relevance, preferences, or time constraints.
On a more fine-grained level, we can support decision-making and personal content preferences by employing a specific template (fig. 4). DidaKRuLO's 'decision tree' template guides users through a sequence of questions (nodes), where each decision (edge) leads to the next question until a final outcome is determined. Initially developed for activities such as species identification, this template can also be adapted and combined with the 'unordered station' setting, enabling users to navigate to their next station based on their responses.

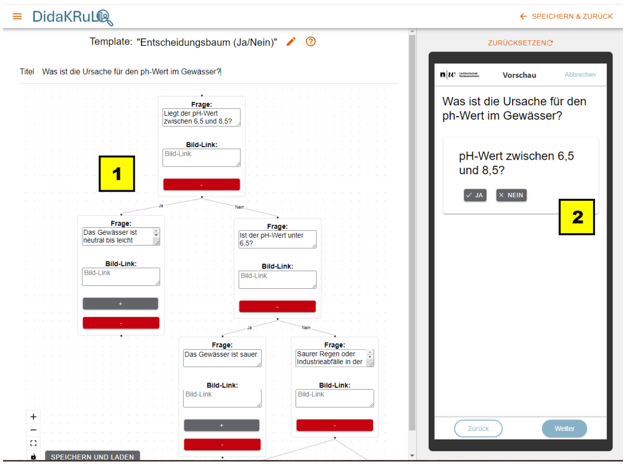

Figure 4. The 'decision tree' template consists of a set of questions and binary choices that are navigated until a decision is reached. Graph view as seen by the author (1) and preview of a question as it looks for the user (2).

5.3 Handling dynamism through low barriers for iteration (C3)

Change is an inherent challenge when addressing environmental factors. To extend the lifespan, relevance, and accurateness of educational experiences, tools must account for the temporal dimension. To achieve this, we adopted a strategy that enables educators to update and re-publish their applications within minutes, with minimal cost and dependency on external support. This strategy is built on a cloud-based, low-cost infrastructure, the automation of the update cycle as well as independent and reusable content components that allow for focused and contained adjustments. Leveraging a version control system like Git enables efficient rollback of changes and seamless version management with minimal effort. A shared and extensible data model across all applications is a prerequisite for this approach. By the decoupling of application data (content) from source code, we separate authoring updates from technical maintenance and afford low-barrier iteration for non-technical users. Ideally, this process reduces the need for third party intervention from technical staff,

32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-30-2025

allowing authors greater ownership and autonomy over content creation and distribution. An architecture built on web technology streamlines the update process, as the latest version is automatically retrieved from the server. A web-to-mobile approach eliminates the need for platform-specific modifications and reduces time-consuming adjustments due to a single, unified code base.
Besides the strategy of easing the updating process, we also foster the efficient reuse of existing content. For this, the Builder application includes functionality to enable / disable, re-order, and download station content for external editing. This feature allows information to be restructured to new compositions, as required by environmental changes, or adaption necessary for diverse target audiences, varying timeframes or changing administrative constraints. Information can also be preserved, shared, or collaboratively edited outside of the framework, ensuring flexibility and independence from the underlying technology.

6. Discussion

The DidaKRuLO framework was developed to address the multifaceted challenges of modeling context in location-based mobile learning applications. Our proposed solutions emphasize a lean, openly accessible, cost-efficient, and extensible architecture. By separating content creation from complex technical specifics, the framework provides modular, flexible, reusable, and unopinionated tools for designing learning experiences tailored to inherently complex and dynamic environments. Applications built with DidaKRuLO are domain-independent and can be utilized in diverse contexts, including curricular teaching at universities and schools, individual lifelong learning, or even as interactive marketing and communication tools that highlight specific topics. As an LBML application, DidaKRuLO is particularly well suited for learning scenarios that emphasize spatial perception and tangible experiences within the physical environment - as it is central to disciplines like e.g. most (applied) natural sciences, architecture and construction, archaeology and history.
However, our design choices also introduce certain limitations. The use of a Git-based architecture imposes constraints on file sizes and types, as repositories are not intended for large-scale file storage. Although widespread access to affordable mobile data plans has mitigated this limitation in many settings, DidaKRuLO apps may not be suitable for elementary or middle schools (K–8) that rely on pre-configured devices with restricted internet connectivity or limited access to third-party applications.
In addition to considerations regarding architecture, the proposed solutions (see 5) to address environmental context challenges (see 3) leave room for refinement:
While offering greater flexibility and enabling bottom-up design approaches (challenges **C1** 3.1 and **C2** 3.2), templates shift the need for generalization and simplification from the station or trail level to the template itself. It is therefore reasonable to anticipate that the design assumptions underlying templates will only partially align with the specific requirements of an author, inevitably leaving room for further customization and adaptation. One potential strategy to address this limitation is to outsource the template catalog to an independent open-access platform. This approach would enable designers to collaboratively contribute to and expand the repository, thereby broadening the range of available templates and enhancing the diversity of options.
A restriction by design is that templates in DidaKRuLO are self-contained and displayed sequentially, which, however, limits the potential for conditional logic or dynamic content selection at the station level. Introducing cross-template dependencies, while expanding functionality, would introduce the risk of incompatibilities or errors, and therefore increase maintenance complexity and costs.
Another commonly requested feature in educational applications is user communication and collaboration, as well as integrated tools for data capture, processing, and exchange. However, we align with the perspectives of Constantinidis et al. (2013) and Gore et al. (2022) that replicating such functionalities, which are already available in specialized third-party applications, would be both technically and economically inefficient. Today's users are adept at managing multiple applications simultaneously, reducing the need to duplicate these features. Furthermore, features like task submission, grading, and individual feedback, often desired in educational domains, were excluded from DidaKRuLO templates due to their incompatibility with the chosen serverless architecture. Although such features are common in specialized mobile learning solutions, their implementation typically requires specific knowledge of - and adaptation to - the existing institutional educational infrastructure. Ultimately, we contend that the core objective of LBML is to facilitate and enrich the spatial experience. Technology should be directed toward supporting and enhancing this goal, rather than replicating tasks that could be performed as effectively in a traditional classroom setting or by other means.
When addressing temporal variations arising from known unknowns and identifiable patterns, as discussed in the context of **C3** (see 3.3), more advanced technologies are expected to play a pivotal role in enabling autonomous monitoring, thereby reducing the reliance on manual updates. With the proliferation of commercially available Large Language Models and Artificial Intelligence, significant advancements in pattern recognition and predictability through machine learning can also be anticipated for the LBML domain. At the level of adaptive solutions, the work of Mauro et al. (2024) highlights the potential of self-aware systems. Their approach, centered on automated scheduling support and itinerary optimization for field trip planning, suggests a framework that could be extended to also account for temporal patterns and changing availabilities. This could be achieved through data models enriched with attributes such as time frames and expiration dates.
However, it is crucial to carefully weigh the benefits of reducing manual maintenance and publishing burdens against the associated risks. These risks include increased system complexity and potential dependence on third-party services. Achieving a balance between automation and flexibility will be critical to maintaining the adaptability and usability of such systems.

7. Conclusion

Designing location-based mobile learning experiences requires careful consideration of the characteristics inherent to the physical environment in which learning occurs. Factors such as environmental complexity, unique settings and dynamic conditions must be addressed alongside the individuality and diversity of learners. By employing bottom-up approaches and adaptable tools, we can create spatial learning experiences that are both meaningful and effective. This paper outlined a framework prototype built on the principles of modularity, flexibility, and reusability to address the mentioned challenges. Key features include the separation of the authoring tool from the learning applications, a template-based approach to content design and the automation and abstraction of intricate processes to simplify update cycles. By leveraging freely available tools, cloud-based storage, and externalized computational resources, the framework minimizes costs while granting authors and organizations full ownership and control over its deployment - addressing obstacles that are commonly cited as barriers to integrating mobile applications into educational curricula.
However, it is important to note that while tools can serve as valuable aids, they cannot fully relieve educators of the responsibility to conceptualize content and design meaningful extracurricular activities that offer additional value. The extensive body of literature on educational principles and best practices indicates the great range of perspectives and the inherent complexity of these tasks. Rather than providing tailored guidelines for specific learning cases we deliberately choose the more holistic approach of an unopinionated, yet flexible framework, that leaves decision making and ownership in the hands of the educator. Additional work is needed to further validate our assumptions and the overall feasibility and benefits of our approach.

8. Acknowledgements

This research was partly funded by a ’FHNW Lehrfonds’ grant. Additionally, we would like to thank Marvin Rees and the FHNW School of Education for their advice and feedback in the development process.

References

Brown, E., 2010. *Education in the wild: contextual and location-based mobile learning in action*. LSRI, Nottingham. OCLC: 751703450.

Constantinidis, D., Smith, W., Chang, S., Lewi, H., Saniga, A. and Sadar, J., 2013. Designing Fieldwork with Mobile Devices for Students of the Urban Environment. *ASCILITE Publications* pp. 178–188.

DeWitt, J. and Storksdieck, M., 2008. A Short Review of School Field Trips: Key Findings from the Past and Implications for the Future. *Visitor Studies* 11(2), pp. 181–197.

Dey, A. K., Abowd, G. D. and Salber, D., 2001. A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications. *Human–Computer Interaction* 16(2-4), pp. 97–166.

FitzGerald, E., Sharples, M., Glahn, C., De Jong, T. and Specht, M., 2009. *Location-based and contextual mobile learning*.

Garzón, J., Kinshuk, Burgos, D. and Tlili, A., 2024. Advantages and challenges associated with mobile learning in education: a systematic literature review. *Journal of Computers in Education*.

Giemza, A. and Hoppe, H. U., 2013. Mobilogue – A Tool for Creating and Conducting Mobile Supported Field Trips. In: *12th World Conference on Mobile and Contextual Learning (mLearn 2013)*, Hamad bin Khalifa University Press (HBKU Press), College of the North Atlantic-Qatar, Doha, Qatar,.

Gore, J., Peters, S. and Weber, D., 2022. A participatory trail web map based on open source technologies. *International Journal of Cartography* 8(2), pp. 223–242.

Iglesia, D. G. d. l., 2012. Uncertainties in Mobile Learning applications : Software Architecture Challenges.

Kung, H.-J., Kung, L. and Gardiner, A., 2012. Comparing top-down with bottom-up approaches: Teaching data modeling. *Proceedings of the Information Systems Education Conference, ISECON*. GardinerKung2013.

MacCallum, K. and Parsons, D., 2022. Integrating Mobile Mixed Reality to Enhance Learning Before, During, and After Physical Field Trips:. *International Journal of Mobile and Blended Learning* 14(2), pp. 1–11.

Mauro, N., Ardissono, L., Cena, F., Scarpinati, L. and Torta, G., 2024. An Intelligent Support System to Help Teachers Plan Field Trips. *International Journal of Artificial Intelligence in Education* 34(3), pp. 793–824.

Medzini, A., Meishar-Tal, H. and Sneh, Y., 2015. Use of mobile technologies as support tools for geography field trips. *International Research in Geographical and Environmental Education* 24(1), pp. 13–23.

Meek, S., FitzGerald, E., Priestnall, G. and Sharples, M., 2013. Learning on field trips with mobile technology. MeekFitzGeraldSharples2013.

Mehdipour, Y. and Zerehkafi, H., 2013. Mobile learning for education: Benefits and challenges.

Patten, B., Arnedillo Sánchez, I. and Tangney, B., 2006. Designing collaborative, constructionist and contextual applications for handheld devices. *Computers & Education* 46(3), pp. 294–308.

Sailer, C., Schito, J., Kiefer, P. and Raubal, M., 2015. Teachers Matter: Challenges of Using a Location-Based Mobile Learning Platform. Publisher: Unpublished.

Schmidt, A., 2003. Ubiquitous Computing - Computing in Context. PhD Thesis. ISBN: 9798691298851 Publication Title: PQDT - UK & Ireland.

Webb, J. and Stafford, R., 2013. Location-based mobile phone applications for increasing student engagement with field-based extra-curricular activities. *Planet* 27(1), pp. 29–34.

Zimmermann, A., Lorenz, A. and Oppermann, R., 2007. An Operational Definition of Context. In: B. Kokinov, D. C. Richardson, T. R. Roth-Berghofer and L. Vieu (eds), *Modeling and Using Context*, Vol. 4635, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 558–571. Series Title: Lecture Notes in Computer Science.