Towards a Mobile, Intelligent, Personalized and Adaptive E-learning System Considering Learners' Context in Semi-nomadic and Conflict Zones

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Abstract. According to the UNESCO (2023), the sub-Saharan Africa has the highest rate of out-of-school children for economic, cultural, socio-political and geopolitical reasons. Improving school attendance rates in such areas requires a preliminary study to understand the local realities and meet the expectations of learners and, above all, their parents, who have the power to decide whether or not to send them to school. In this paper, we study and design mobile-based, intelligent, personalized and adaptive e-learning solution in semi-nomadic and conflict zones. This solution is part of the AMI (Intelligence-Mediated Learning) project which aims to design, develop, and implement a mobile learning system made up of educational applications accessible from micro terminals (such as smartphones, tablets, and other devices). To properly assess the learning needs in such context, four field surveys were carried out in Kalani, a community in northern Mali, located in a conflict zone with a high rate of non-schooling and out-of-school children, where both sedentary and nomadic families live. These surveys made it possible to collect, analyze and process data of 100 Kalani children aged between 6 and 11, to build up a model that guide the implementation of our proposed educational solution. The data analysis revealed a strong link between the learners' interests and the needs expressed by the community.

Keywords: Education · sub-Saharan Africa · children · conflict zones · multi-sectoral and interdisciplinary research · mobile learning system · pedagogical engineering · data science

1 Introduction

According to the UNESCO (2023), the number of out-of-school children has increased by 6 million since 2021 and now stands at 250 million, revealing that progress in education continues to stagnate worldwide. Sub-Saharan Africa hosts nearly 30% of the world's out-of-school children, with 1 in 5 African children not attending school (19.7%), according to UNESCO (2023).

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The populations most affected include girls, people with disabilities, indigenous people, and children in conflict zones and areas disadvantaged by population mobility and difficult access to educational resources. The latter one is the target population of the AMI (Intelligence-Mediated Learning) research project, on which several researchers and PhD students have been working since 2020 to meet the learning needs of children in Kalani, in northern Mali, aged between 6 and 11, who are the most affected by this situation, for a variety of reasons: geopolitical (conflicts, class closures, etc.), economic (high cost of schooling, lack of means of transport, etc.), cultural (unsuitability of schooling to local contexts, local traditional cultures, negative perception of western schooling, etc.). To meet these multiple challenges with a focus on the local context, researchers in information technology and computer science, human and social sciences, along with a local team made up of sociologists, teachers, psycho-pedagogues and linguists are working within the AMI project to develop an intelligent, personalized adaptive mobile e-learning system. This system aims to provide educational access to all children who lack formal schooling due to conflict zones and areas with limited resources and population mobility. However, a prior study of educational needs is necessary to guarantee the adoption of future solutions to be proposed. That's why, in this paper, we have carried out a study among children aged 6 to 11 and their parents to find the most appropriate pedagogical and technological solution for the Kalani context, characteristic of semi-nomadic and conflict zones.

The first part of the article outlines the context of our research, including the geographical context that motivates the choice of Kalani, and the presentation of the AMI project. The subsequent part delves into the challenges related to cross-sector development: from the methodology to the presentation of results. Thirdly, we address the dual engineering aspects of the proposed solution, both educational and technological. Finally, we discuss the solution within a global, scientific approach.

2 Background

2.1 Presentation of the Geographical Context of the Study

The choice of Kalani was motivated by its status as an at-risk area, disadvantaged by climate, poor access to resources, poverty, the nomadic nature of its inhabitants' lifestyle, and its high level of militarization, as well as the conflict-ridden nature of the region in which it is located. It is a district with several islands. Kalani falls within the administrative jurisdiction of the Bourem commune, the capital of the Bourem cercle, in the Gao region, where the Songhay, Touareg, Arab, and Peulh communities live. Their main activities include farming, livestock breeding, commerce, and fishing. The Songhay community is the most represented and the Songhay language the most spoken. Kalani is a community living between nomadism and sedentarism, due to the islands and the economic life linked to livestock farming. Kalani is located in an area straddling the desert and the river, where the exclusion rates for school-age children are due to the absence of schools, the semi-nomadic and semi-sedentary way of life, the insecurity that has caused schools to close and teachers to flee, and the culture of the communities.

In addition, the learning ecosystem in Kalani is inherent to internal factors (the child himself) and external factors (his environment), both endogenous (local realities,

values, etc.) and exogenous (the influence of systemic trends inherited from Western colonization and Arab Islamization (Sanogo 2002). There are also several other factors, linked to the family's economic and educational situation, the parents' vision and opinion of education, and the needs and interests of the community, starting with the family (Maiga, A.A. et Hotte, R. 2021).

All these factors constitute major barriers to the adoption of existing educational systems coming essentially from the West.

2.2 Presentation of the AMI Project Framework

The AMI project (Hotte, R., et al. 2023) stems from the research program of the UNESCO Chair in Global Smart Disruptive Learning (GSDL, 2019-2023), creating and implementing a mobile learning system that is adapted for individual self-learning and designed to meet the needs of all learners (children, youth and adults) who have been excluded from the existing formal and informal education system. AMI aims to develop learning units, adapted to the local context of Kalani and integrated into educational pathways, based on activities drawn from local practices and meeting the learning objectives of the target community. Themes include food, health, environmental protection, understanding mathematics in local languages, learning trades, learning foreign languages such as French and English, local stories and more. This curriculum should introduce the community to multiple forms of knowledge and allow expression of local cultural values through adapted pedagogical activities in local languages.

AMI is an educational technology (EdTech) solution which is at the crossroads of 2 research disciplines: the humanities and social sciences (ethnography, linguistics, and educational sciences) and the natural sciences and engineering (computer science, software engineering, and artificial intelligence). As a result, successful implementation required collaborations from diverse teams across these various disciplines.

The contribution of the local human and social sciences team has left its mark on the entire AMI system, by collecting community and learners' profiles. Based on these data, a monographic profile of a child in Gao was created (Maïga and Hotte 2021), for whom the AMI solution is designed, including identity, psycho-social profile, family, and community ties, living environment, preferences, educational profile, and interests. Community meetings and discussion groups fostered trust and adoption of the AMI solution. Beyond this ethnographic dimension, linguistics is also an integrating factor in the AMI system. All field exchanges occur in the local language, understood by the entire Kalani population (Songhay), regardless of their community (Songhay, Tuareg, Bozo, etc.). Responding to the demand from residents and experts, the use of the local language ensures its preservation against the influence of other languages. Additionally, it encourages French language learning for children who already have a grounding in the local language. AMI is actively translating learning units created during the project. This approach ensures that content is available in both French and the local language. Surveys are conducted by a researcher from the same community where they were born, grew up, and still have family ties.

The AMI project, focused on educational technology for disadvantaged children, integrates insights from educational sciences. Field surveys and discussions with children and the community led local experts to recommend an integrative pedagogical approach

that combines different disciplinary contents. This interdisciplinary strategy promotes knowledge integration (Lenoir, Y. and Sauvé, L. 1998) and offers theoretical insights across various practical domains. By blending endogenous and exogenous knowledge, including local and foreign languages, the AMI solution aims to be inclusive and adapted to expressed needs while optimizing time spent on education.

Xavier Roegiers (2011) explains integrative pedagogy as a framework aligning educational system goals with everyday teaching practices on the other. However, field research has made it possible to question the aims of the education system in favor of the community expressed needs. In the AMI system, community priorities— shaped by parents, children, socio-cultural realities, and values—take precedence. This approach diverges from politically defined orientations Rogiers (2011), focusing on locally relevant training and its impact on children's development and autonomy in daily life. The contribution of arts and culture is crucial. To propose a solution aligned with community needs, we leverage images, sounds, and language variants. A multimedia team conducts a thorough study proposing a contextualized product that considers the learner's physical, social, linguistic, and cultural realities. This artistic endeavor aims to engage the community and foster playful motivation for children's learning. Ensuring that users feel comfortable and can sustainably utilize the product is essential.

The research team, comprising software engineers, graduate students, and data science experts, focused on structuring and preprocessing collected data. Their goal was to create an intelligent, personalized, and adaptive e-learning system that is sensitive to local context (Hotte, R, et al. 2002). The AMI solution emphasizes contextualized data interpretation and aims to provide relevant recommendations aligned with learners' interests and the local context.

3 Study of Inter-sectoral Educational Challenges in Semi-nomadic and Conflict Zones

The project is based on three field surveys carried out in Kalani. The fieldwork involved personalized interviews, community meetings, focus groups and periodic validation sessions following data processing.

3.1 Data Collection

Two field surveys directly involving 100 pre-selected children were carried out after obtaining a certificate of ethics and following a series of community meetings attended by their parents/guardians and local stakeholders. The first survey, held in the spring of 2022, was designed to build up a database that would enable a detailed profile of future AMI users to be drawn up. Among the variables used in the survey form were the child's identity, living context, link with school, competencies acquired and targeted, interests, etc. (see Table 1 presenting responses from two children A093 and A089). The second survey assessed each child's knowledge and interests. It aimed to validate their basic or threshold competencies which are crucial data for identifying and classifying typical profiles. These profiles serve as the foundation for the AMI system's adaptability, aligning with the learner's cognitive profile and adjusting pathways as needed during

Table 1. Overview of skills assessment results

Categories: 39 questions (Q)	A093	A089
Recognizing numbers and letters	A	D
Recognizing numbers and letters (Q1)	1	0
Recognizing numbers from 0 to 50 (Q2)	1	0
Order from smallest to largest from 1 to 9 (Q3)	1	0
Recognizing the signs	A	D
Recognize the sign of addition (Q4)	1	0
Recognizing the sign of subtraction (Q5)	1	0
Recognizing the sign of multiplication (Q6)	1	0
Performing operations	I	D
Add [less than or equal to 10] (Q7)	1	0
Add [less than or equal to 20] (Q8 et Q9)	1	0
Subtract [less than or equal to 10] (Q10 et Q11)	1	0
Subtract [less than or equal to 20] (Q12)	0	0
Multiply [less than or equal to 30] (Q13 et Q14)	1	0
Multiply [less than or equal to 70] (Q15)	0	0
Divide [less than or equal to 10] (Q16, Q17 et Q18)	0	0
Color recognition	I	D
Identify Red, Black, Blue, Yellow, Green (Q19 à Q23)	1	0
Categories: 39 questions (Q)	**A093**	**A089**
Differentiate between green and black; green and yellow; green and blue (Q24 à Q26)	1	0
Recognize the flag of Mali (green-gold-red) (Q27)	1	0
Recognizing colors in Malian cows (Q28)	0	0
Read color names (Q29 à Q32)	0	0
Recognizing geometric shapes	D	D
Identify rectangle (Q33)	0	0
Identify triangle (Q34)	0	0
Identify square (Q35)	0	0
Identify circle (Q36)	0	0
Identify straight line (Q37)	0	0
Identify broken line (Q38)	0	0
Identify curved line (Q39)	0	0

learning. The questions are designed to define learning programs based on the diagnosis made and the learner's profile. They focus particularly on reading, writing, numeracy and problem-solving skills, and on the child's interests. It was also an opportunity to validate with parents the information linked to the socio-cultural context and the values they hold dear, without discontinuity with the training needs already expressed during the preliminary surveys (between 2021 and 2022). We assume that the content to be developed will be contextualized, i.e. we want to focus on children's interests to arouse, preserve and maintain their motivation, anchored in community and parental interests. Not to mention that content inspired by the learner's life reality and interests would generate a playful interest and could enhance his or her motivation to learn.

To measure the knowledge levels of the children we interviewed and categorized them into beginner (D), intermediate (I) and advanced (A) levels according to criteria adapted to their realities. These criteria consider the following variables: school environment, level of schooling, level of literacy. However, many children are helped in the local language during the test, to take account of their poor access to quality education and the total absence of schooling (Paquette 2002b).

Thus, any child who has not attended school or who has dropped out is considered a beginner if he/she has obtained a positive score of less than half the questions per domain (50%). Schooled children can be considered beginners if they score none or only 1 positive mark for 3 questions. Schooled children are considered intermediate if they obtain a positive mark equal to or greater than half the questions per area and less than 80%, and if they obtain 2 positive marks for 3 questions only. Advanced children are in school and have obtained a positive score greater than or equal to 80% of the questions per domain, and 3 positive scores for 3 questions only. Context being at the heart of this research, interactions with children during the second survey are also considered as a subjective measure (Paquette 2002b). For example, some children were able to answer certain questions with the help of only one other child.

The data collected guides the design of the knowledge model for each learning path to be integrated into the AMI system, by the software and data engineering team. It feeds the recommendation system for selecting or modifying a typical pathway. This is a recommendation system based on a selection of algorithms, using artificial intelligence and machine learning techniques (Chen and Wang 2021; Jeevamol Joy and Renumol Vemballiveli Govinda Pillai 2022). The aim is to offer the most suitable and appropriate learning path for a given learner's profile.

3.2 Correlation Analysis of the Learners' Attributes

Skill Levels

5 skills areas were used in the field tests: identifying numbers and letters; differentiating mathematical signs; solving mathematical problems (addition, subtraction, multiplication, and division); identifying colors and being able to read color names; recognizing geometric shapes. These choices were inspired by Bloom's taxonomy as revised by Anderson et al. (2001): identify, recognize are among the verbs linked to the first level of skills (I know what I'm talking about), followed by a second level of understanding (I know how to talk about it) and a third level of application where the learner can, for example, solve a problem, and so on.

Figure 1 below shows that most future AMI learners (92%) have a beginner's level (zero skills) in the simplest mathematical operations tested in the field: addition, multiplication, and subtraction with digits and then with numbers and differentiating between digits and numbers. Only one child out of the 100 was able to perform the mathematical operations correctly, and 6 children were able to obtain a few correct answers.

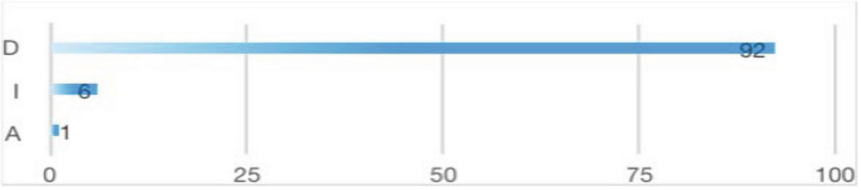

Fig. 1. Children's scores in mathematical operations test

Interests

Analyzing the fields of interest expressed by the children is crucial for designing effective learning paths and recommendation systems. There are three main categories of interest:

- **Community interest**: The community's expectations for the AMI system are multifaceted. They prioritize mobility, recognizing the population's diverse lifestyle—spanning both sedentary and nomadic contexts. Additionally, the system should be cost-effective, avoiding transportation expenses associated with conventional schooling in isolated areas. Internet access costs should also be minimal, considering the low-income levels. Furthermore, adherence to local traditions, language, and cultural values is crucial. The system's content must be tailored to meet the specific needs of the local population, emphasizing quality and practical relevance.
- **Playful interest** or entertainment value on the part of the personalized learner is expressed in the learner interest attribute. Expected values include cooking games, building houses out of banco, storytelling, drawing, playing with animals and other expressed needs such milking, counting, reading and writing; Interestingly, the cow emerges as a favorite animal among the children.
- **Pedagogical interest**: The local team, consisting of a psycho-pedagogue, linguist, sociologist, and teachers, emphasizes a pedagogical approach for the AMI system. This approach integrates diverse learning units into varied pathways, allowing learners to acquire multiple skills within short timeframes. Addressing the time challenge of keeping children in school, an integrative pedagogy strategy combines both local and external knowledge, emphasizing context and quality of education.

4 An Interdisciplinary Pedagogical and Engineering Solution in Semi-nomadic and Conflict Zones

4.1 Pedagogical Engineering Dimension

The AMI educational solution adapted to Kalani's needs can be framed around eight (8) courses according to expectations expressed in the survey data: an introductory course and seven (7) specific courses. These include courses on animal husbandry (knowing the different types of cows and how to market them, for example), food health (hygiene, cooking, the virtues and drawbacks of local fruit and vegetables), community life (respect, cultural values, living together), finance (arithmetic, currencies, business basics, customer loyalty tips), international languages (French, Arabic and English), animal health (animal symptoms, animal diseases transmissible to humans, animal nutrition) and the environment (protecting biodiversity, combating silting-up, among others). To design the prototype of the AMI educational system, the introductory course and a course integrating breeding and trade, entitled Discovering Malian cows, were chosen from among the 8 courses. These courses are therefore interrelated, and the choice of the following courses is justified by the results obtained.

Firstly, because these courses offer content linked to the interests expressed by the children during the field surveys: selling, counting, knowing about cows, being in the company of animals, among others, their interests are thus linked to areas related to trade and animal husbandry, two very frequent and useful areas of activity in Kalani's socio-economic life. Secondly, these courses consider the fundamental concerns of parents, namely respect for local socio-cultural values and the need for their children to receive training directly linked to their professional activities. Finally, it is an approach that responds adequately to the pedagogical approach proposed and discussed with local expertise, particularly the pedagogy of integration.

The pedagogical and media models will be inspired by these different aspects. While this approach gives the AMI education system an informal character, not based on conventional models, its relevance lies in its adaptability to a singular context. For example, the AMI system will offer a media environment similar that that in which the learner lives (river, bush, fields, island, Sahelian animals, wild date palms), in the local language and French to reinforce the skills of the targeted children. In this sense, a learning path that combines the children's interests and target skills with their sociocultural context is highly relevant. The choice of test courses and a story to support the course on the Malian cow are justified in the following Table 3.

Table 2 clearly shows that values such as storytelling, animal husbandry, trade, and arithmetic (calculating, counting) recur very frequently in the research results compiled in the AMI database. These values are associated with the children's interests and information obtained from other community members (parents/guardians, community leaders, local team) during the various phases of data collection. All these values are of the very frequent order in the database, i.e. they are expressed very frequently during the collection of information on the learner.

Table 2. Choice of test path

Selected values	The child's interests and target skills	Social, economic and cultural context
Arithmetic	How to count, calculate	Local market influenced by transactions/merchandising, children commissioned at the market, in the store, children keeping the parents' business and future heirs
Trade	Know how to sell, become a shopkeeper, help parent	Strengthening local trade for the community, reducing youth unemployment, making the project sustainable and anchoring it
Breeding	Know animals, know how to milk, be in the company of animals	Strengthening the local way of life (between nomadism and sedentarism), making the project sustainable and firmly rooted
Tale	Preference expressed by children	Moral to remember at the end of the tale, reality of life close by, oral civilization reinforced

4.2 Technology Engineering Dimension

This solution will be inspired by a domain model for a plural learner in a context of adaptation and socialization rooted in local socio-cultural values. The AMI domain model illustrates cross-sectoral work of the AMI project. The humanities and social sciences team brought their expertise to bear on the social, economic, cultural, community, educational and family aspects of the learner in this domain model. These aspects enriched the profile of the learner as an individual situated in a particular socio-cultural context and as a family (cousin, brother, sister, father, tutor, aunt, etc.). The team then provided the domain model of aspects related to the skill levels and interests of children and the community based on data from the field surveys. These data will be used to design the knowledge, pedagogical and media models on which the first prototype of the AMI system will be built. Supported by a visual arts and culture team, the team provides contextualized learning materials (text, audio, images, video).

The data collected during the requirements engineering phase will feed into the system implementation. Assuming that access to the internet or cloud computing will most likely be nonexistent or very limited, applications will be designed to operate entirely in an offline environment. The system will therefore be designed to be completely autonomous and independent of any network or network access. Access to the mobile learning system will be provided through mini terminals such as smartphones and tablets.

The team focused on the learning tool (i.e., the personalized adaptive systems) according to two dimensions: attributes of systems to support adaptive/personalized learning and the hardware where the system will be deployed (web-based application). Personalized adaptive e-learning recommender systems assist the learners by learning

units' recommendation and adapts to the learning needs, interests, and performance of the learner (Raj, N.S. and Renumol, V.G. 2018; Xie, H., et al. 2019).

Meeting users' needs and interests is an ongoing challenge in developing personalized e-learning systems. The collected attributes to support personalized and adaptive learning are represented by six dimensions capable of accommodating most of the information describing the user, their interests, and skills, and as investigated in the literature (Hemmler, Y. M., et al. 2022). By leveraging artificial intelligence and natural language processing techniques, we can create intelligent algorithms that analyze the combination of the learner attributes, identify patterns and trends, and provide personalized recommendations and interventions. This would enable a more dynamic and tailored learning experience for everyone, addressing their unique needs and maximizing their learning outcomes.

In the AMI system, this dynamicity is embodied in two intelligent components: (1) an intelligent selection of one or more typical learning pathways, based on needs, on the economic, social, cultural, community, and academic profile and on the skills developed by the learner during his or her learning or, even, prior to that learning with family, friends, or community (2) updating the learning path according to the difficulties and progress of the learner in the current course (dynamic path in relation to the profile, difficulties, and level of advancement) (Hotte, R., et al. 2022).

The design of the mobile learning system (web-based application or portal) is based on the hybridization of educational and software engineering, to build an e-learning system to support personalized and adaptive learning. The user interfaces (UI) are designed to be user-friendly, intuitive, and functional, ensuring a seamless experience for all users (Hotte, R., et al. 2022). The software and data engineering team provides the domain model, the web-based application with its intelligent components.

5 Discussion

The field surveys revealed a close alignment between the community's expressed training needs and the interests of the interviewed children. Notably, there exists a significant disparity between these needs and the content typically taught in schools. The AMI system addresses this by prioritizing community concerns—such as respecting socio-cultural values and educational requirements—while tailoring content to children's interests. The AMI system is designed to be mobile, responding to the community's lifestyle (sedentary and nomadic) and given the widespread use of cell phones. This solution is locally supported by the expertise of the community and local players. The learning paths were proposed by the community. Drawing from local expertise, the pedagogical approach incorporates storytelling, the use of the local language alongside French, a virtual environment, and familiar characters. These elements enhance engagement and alignment with socio-cultural realities.

The AMI system offers contextualization tailored to each community's needs and socio-cultural realities. By prioritizing learners' interests, which closely align with community values, it becomes an adaptable and non-formal solution. As a result, children in Kalani—the target audience of this study—can thrive without assimilating into foreign cultures. They acquire practical skills relevant to local employment demands, reducing vulnerability to unemployment—a fertile ground for armed groups. Additionally,

young girls can learn while remaining connected to their mothers and future husbands, potentially becoming vital supporters of education through their life experiences. For example, the AMI system may recommend courses in dietary health for a learner who wants to understand the virtues and evils of local fruits (wild dates, jujubes, etc.) to take good care of her future husband. Just as she may want to learn new skills in hygiene or fish sales to help her mother make a profit.

In the case of AMI, where learning is informal, it is taking into account the cultural context and locally expressed concerns that makes it relevant and sustainable: taking into account the local language, endogenous knowledge, the mobile nature of the lifestyle, the integrative approach in the design of models and the implementation of learning scenarios, the disconnected and simple nature proposed due to poor access to Internet and electricity, among others. This was not and will not be possible without the collaborative work of an AMI team made up of players from different disciplines. Interdisciplinary research is itself defined by the engineering of intersectorality, drawing on practices in engineering and the natural sciences on the one hand, and the humanities and social sciences on the other: software engineering, educational engineering and data engineering associated with artificial intelligence.

6 Conclusion

In this paper, we studied the multi-sectoral dimensions of the design, development and implementation of a learning tool for children in a community living in difficult and disadvantaged circumstances such as Gao, in northern Mali. According to the local realities and the trends emerging from data analysis, we need to innovate in terms of (1) pedagogical engineering, by designing adaptive and personalized content and pathways, and (2) technical engineering, by offering a mobile solution based on emerging technologies such as artificial intelligence.

Future work will involve the experimentation of our solution on the topics of interest identified in our study. The concrete usage of AI tools will also be explored and their added value assessed. A cloud-based architecture for hosting the system will be proposed and will strengthen accessibility and foster collaboration between the different stakeholders.

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