Personalized and Adaptive Context-Aware Mobile Learning: Review, challenges and future directions

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Abstract

Due to the outbreak of COVID 19, digital learning has become the most efficient learning and teaching technique adopted across the world. The pervasiveness of Personalized and Adaptive Context-Aware Mobile Learning (PACAML) technologies is improving the academic performances of learners by providing an efficient learning platform that supports social interactivity, context sensitivity, connectivity, and individuality in a ubiquitous manner. Several studies have demonstrated the efficacy of PACAML in a modern and innovative educational environment. Based on the recent studies and development of mobile learning technologies, there is clearly a gap in the research that provides a comprehensive body of knowledge on PACAML. In this paper, a review has been conducted on the existing PACAML, analyzing the recent research and development progress using Kitchenham et al. (2009) for systematic reviews. The review was conducted on 25 papers which were selected using the PRISMA technique to put forward the quality criteria that are based on the research aims, objectives and knowledge relevant to the study of PACAML. The results identified the contextual information used in the PACAML studies, the infra-structural requirements of PACAML, the application of PACAML in functional educational settings and the major methodological approaches applied in the studies of PACAML. Finally, the paper presents challenges and future directions that will be of interest to researchers in the educational technologies in the context of PACAML.

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1 Background

Digital learning is encouraged due to the COVID-19 pandemic, and the ensuing state of emergency, a shift to digital learning process has been necessitated as it gained greater importance after the temporary closure of schools and educational institutions which is challenging for the learners (Chukwuemeka et al., 2021 & Todoranova et al., 2020). The study carried out by Khan (2021) revealed that learners are more interested in digital learning and thus the willingness to adapt to the modern fulfilling educational system. Moreover, mobile learning technologies had already aroused the interest of many learning partners such as researchers, tutors, and learners (Hwang, 2018 and Adly et al., 2018). Mobile learning can create a learning experience that transcends the classroom learning environment and improve the effectiveness of teaching and learning (Al-Hunaiyyan et al., 2017). The proliferation of mobile devices can define new pedagogical strategies that could use learners' contextual information to bring forward a proactive learning environment using mobile technologies (Glahn and Gruber, 2020). The purpose of contextual adaptivity is to enable the system to dynamically adapt the learning environment according to the educational needs of a variety of learners with individual skills and interests (Pensabe-Rodriguez et al., 2020).

Digital learning systems are being explored by researchers to bring effective contributions to be able to overcome the challenges faced by modern mobile learning systems (Nassoura 2020). The objective of learning analytics is to determine the educational areas where the learner needs improvement and redefine new strategies to adapt the personalized learning process ubiquitously (Dhingra et al., 2019). The application of learning analytics has mainly the following steps capture, report, predict, act, and refine (Atasoy et al., 2020). There is a research gap in the PACAML approaches that suit the needs of learners (Alyami et al., 2020). Thus, this paper will give a detailed review of the advancements in PACAML applications using dynamic contextual adaptation for personalized mobile learning. The paper consists of a research methodology section, detailing the steps followed to conduct the review of the existing PACAML by elaborating on contextual adaptation and personalization of mobile learning. The result section provides the data collected from the review of the PACAML applications based on the mentioned research questions and the main findings are presented in the discussion section. The challenges, future directions, and limitations of PACAML are then discussed. Finally, the conclusion section concludes the review.

2 Research methodology

The review provides an insight into the research gap for PACAML technologies that suit the needs of learners. Following the trend in PACAML studies, considerable research on PACAML has been carried out, but there is a lack of investigation specifically on main components such as contextual information, infrastructural requirements, educational context, and methodological approaches related to PACAML for a substantial body of knowledge. This review will help researchers to have better visibility of the dominant personalized and adaptive mechanisms and approaches for context-aware mobile learning. The Kitchenham method (Kitchenham et al. 2009) has been used to perform the review based on recent PACAML applications. The review is conducted according to using three steps, namely Planning the review including the derived research questions, Conducting the review including data sources, search terms, quality assessments, and inclusion and exclusion criteria and finally Reporting the review where the result is documented.

2.1 Planning the review

This study highlights the high impact factors such as contextual information, infrastructural requirements, educational context, and methodological approaches in the application of PACAML. A review of recent studies and approaches related to mobile learning systems is then derived and analyzed for challenges and proposes directions for further intervention.

The main research questions related to the investigation of PACAML are as follows:

- 1) *What contextual information is used in the application of PACAML?*
- 2) *What are the infrastructural requirements for PACAML?*
- 3) *What are the functional educational settings that are harnessing PACAML?*
- 4) *What are the major methodological approaches applied in the studies of PACAML?*

2.2 Conducting the review

The purpose of this study is to conduct a review related to PACAML. The literature review is a way of obtaining a body of knowledge in the field and appraising the extent of research activities related to PACAML.

2.2.1 Search strategy

The search strategy aims to identify the most relevant and recent works carried out related to PACAML and at the same time filter the number of publications to conduct the review. Google Scholar was estimated to be the most comprehensive

academic search engine (Gusenbauer, 2019) since it indexes papers from various scholarly publishers and professional societies. However, to ensure completeness of the literature review, the keyword search was also applied on some popular databases namely: ACM Digital-Library, IEEE XPLORE, SpringerLink, and ScienceDirect. The advanced search option and a combined list of keywords are used to search related content in the database. The search formula used: (Mobile Learning) OR (Context-Awareness) OR (Personalized Mobile Learning) OR (Adaptation Strategies) OR (Learning Analytics).

2.2.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria are used to filter the published articles related to PACAML.

Inclusion criteria:

- Papers from 2016 to 2021.
- Articles related to the impact of the pandemic COVID-19 on mobile learning.
- Articles related to adaptive context-aware mobile learning, review and survey of existing mobile learning systems and learning analytics.
- Articles were peer-reviewed.
- Full article published in the English language

Exclusion criteria:

- Articles that describe systems that do not contribute original research such as general context-aware mobile systems
- The mobile device must not be a laptop or Netbooks
- Articles that describe a theoretical prototype without implementation

2.2.3 Quality assessment

A quality assessment is conducted after filtering the pre-selected studies through inclusion and exclusion criteria to meet the research quality criteria. The research was narrowed down using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) technique to put forward the quality criteria based on the research aims, objectives, and knowledge relevant to the study of PACAML (Moher et al., 2015). The following questions are used as a checklist to measure the research credibility and validity:

- Does the study contribute to the knowledge of PACAML?
- Are the findings of the study credible with valid information on PACAML?
- Are the research aims and objectives clearly articulated to bring a proper body of knowledge on PACAML?

Fig. 1 PRISMA representation

Since all the quality assessment criteria are important in the context of the research questions, only 25 studies had been selected for the final review (Fig. 1).

2.3 Reporting the review

This section provides the findings of the data gathered from the related studies of PACAML according to the research questions. The results identified the contextual information used in the PACAML studies, the infrastructural requirements of

Table 1 Mobile & Learner contextual elements

Context	Elements
1. Intrinsic context	
Learner profile	Competence Profile, Semi-permanent Personal Characteristics, and Learning Behavior
Learner temporal information	Learning Style, Interest, Motivations, Cognitive Load
2. Extrinsic context	
Learning design	Subject, Learning Objectives, Pedagogical strategy, Learning Activities, and Learning Resources
Device	Wearable & Handheld, Hardware and Software Resources. Configuration and Physical Properties
Surrounding	Nearby Resources, Learning Partners, Activities

PACAML, the application of PACAML in functional educational settings, and the major methodological approaches applied in the studies of PACAML.

2.3.1 RQ1. What contextual information is used in the application of PACAML?

There are several types of contextual information that a PACAML may use to adapt to the learning environment (refer to Table 1). The important aspects of contextual information, according to Sarker (2019), which can determine the surrounding information is by locating the learner, finding out with whom the learner is, and what resources are available nearby. Most of the existing mobile learning system considers the contextual information of the learner, device, and environment, to dynamically adapt the learning experience to improve the learner's performance. Context can be categorized into two types: intrinsic and extrinsic context (Pinjari et al., 2018).

2.4 Intrinsic context

Intrinsic context is contextual information that is related to the learner's profile including the knowledge level, concentration, motivation level, learning style, cognitive load, and learning behavior. Some of the most focused intrinsic contexts derived from the reviewed PACAML studies are described in this section.

2.4.1 The knowledge Level

Meaningful learning requires the learner's prior knowledge combined to accomplish a specific task wisely. Curum and Khedo (2019) suggested techniques to make use of the learner's previous knowledge efficiently in a situated context while using limited working memory capacity. Appropriate learning objectives can be defined if the knowledge gap is identified. Various assessment techniques have been proposed in different studies of PACAML to identify the knowledge gap. The learning objectives can be defined if the knowledge level is measured according to the performance and progress of a learning activity. The knowledge level is a dynamic context that requires to be tested progressively to make sure of the context reliability. Bicans and Grundspenkis (2017) estimate the level of knowledge by requesting an assessment at the start of a learning activity. The assessments are based on the current learning activities and conformity with the reviewed results of the past learning activities (Baccari and Neji, 2016). The objective of the assessments is to regularly update the knowledge level estimated before the corresponding learning activity. Premalatha et al., 2016 suggested a classification based on the learner's knowledge level, namely novice, beginner, intermediate, and experts. The thresholds can be set by tutors to evaluate the results of the assessments depending on the learner's knowledge level.

2.5 The Motivation Level

The motivation level is a complex context and rarely considered in the PACAML approaches as there are no standard measurement techniques to capture the motivation level of a learner. A survey carried out by Demouy et al., 2016 mentions that mobile learning technologies can be entertaining and interactive which arouses curiosity in learners, hence learners' engagement for the technology can be noticed. Van Vliet (2020) considered the use of mobile learning technologies to enhance learners' motivations based on interactive applications and entertaining games to gain the attention of the learners. A gamified-educational application is then proposed as a combination of gaming and education-related applications to enhance learners' participation, motivation, and engagement based on the ubiquitous aspects of mobile learning technologies.

2.6 The Concentration Level

The level of concentration during a learning activity is crucial as the learner tends to be distracted by the surrounding environment while using a mobile learning system. The learning performance of the learner depends on the engagement and attention given during the learning activities. In mobile learning, learners tend to multitask as they can be on the move at the same time in comparison to the traditional classroom context (Schneegass et al., 2018). However, Fortenbacher et al. (2017) proposed a mechanism to keep track of the level of concentration and attentiveness of a learner during a mobile learning activity. Some studies in this review used physiological aspects such as facial expression or eye movement and heart rate tracking as contextual information of the learner that can be used to determine the level of concentration. This information can be derived from a camera-based tracking system which can help capture the level of attentiveness of the learner. Physiological sensing is gaining a lot of momentum in the recent studies of PACAML as there are devices that support human sense tracking to be more precise and develop in a real-world context.

2.7 The Learning Style

The learning style can be defined by the preferential way in which the learner receives and processes the learning activity. The learning preferences of the learner can be determined by the results in terms of performance, motivation, and satisfaction (Madhubala and Akila, 2017). Most of the studies in this review used the Felder Silverman learning style model (FSLSM) consisting of techniques that can be used to determine the preferences of the learner (Ennouamani et al., 2020). FSLSM categorized the learning preferences into different dimensions mainly Active and Reflective Learners, Sensing and Intuitive Learners, visual and verbal learners, sequential and global learners. Saryar et al. (2019) proposed the implementation of the FSLSM in an android mobile learning application. The application combined the learning styles and preferences according to the learner's activities and adapted the learning

objects. Kolekar et al., 2014 proposed the questionnaire-based and literature-based methods to determine the dynamic nature of the learner's learning style by keeping track of the learner's activities and the learning performance.

2.7.1 The Cognitive Load

The cognitive load is the amount of working memory that a learner can allocate during a learning session. The cognitive load can be alleviated, according to Yu and Liu (2020), by adapting the learning environment accurately to the personalized needs of the learner and providing high-quality learning resources. The learner's cognitive architecture can be improved by using a learning resource recommendation mechanism to enhance participation and motivate the learner to maximize the use of the working memory. Curum and Khedo (2019) mentioned that cognitive load management is not explored enough and is limited in terms of pedagogical contexts. The delivery of learning objects in PACAML should be more flexible, for example, using multiple mediums of learning materials to engage the learner in the learning activities and thus, an improvement in the learning performances. Radhakrishnan and Akila (2021) proposed a system that analyses the learner's preferences and recommends the most efficient learning objects with some specializations according to the learners' cognitive load.

2.7.2 The learning behavior

Learning experiences may shape and change the ways that learners use mobile learning technologies. Thus, mobile technology shapes user behavior, and that behavior, in turn, affects the way that learners perceive the learning activities. PACAML can offer more adaptive supports to the learners by considering their learning behaviors (Madhubala and Akila 2017). Xiao (2019) captured the learner's interactive learning behavior to form a visual analytics dashboard as an evaluation of the learning effects. There are defined phases to form behavior analytics that is based on the collection and organization of data. The data is then processed and applied to the learning process. Vallejo-Correa et al. (2021) mentioned analytical techniques based on artificial intelligence, learning algorithms, and data mining that can acquire and process the learner's behavior into computerized variables to personalize the learning needs of the learner and hence provide an efficient learning environment.

2.8 Extrinsic context

The extrinsic context is contextual information that is related to the learner's current state of the surrounding which is always varying the whole time depending on the day events and how this information can be to the advantage of his learning experience. (Thüs et al., 2012). Some of the most focused extrinsic contexts derived from the reviewed PACAML studies are described in this section.

2.8.1 The Location-Aware Context

Location-awareness is defined as the surrounding influencing factors such as the current environment which is a volatile context of the learner. (Louhab et al., 2019). The location of the learner is vital context information that provides information to enhance the learning experience. A location context-aware mobile application can recommend nearby learning partners or learning resources that can be effective for the learner. Yao (2015) proposed a similar context-aware mobile learning recommendation system that notifies the learner about the nearby learning materials available and provides access to those materials anytime and anyplace by using the current mobile location. Sarker (2019) use an intelligent algorithm that enables a context-aware mobile learning application to provide a comprehensive learning recommendation depending on the learner's surroundings. Erazo-Garzón et al. (2019) proposed another possibility of the application by identifying the nearby learning partners and recommending the learner to join the virtual learning resources for social mobile learning.

2.8.2 The Content-Format Context

Different media formats and vast educational content are accessed at improved streaming network speed using mobile learning technologies and providing the learner with efficient learning materials in the desired format is essential to the learning management system (Radhakrishnan and Akila, 2021). Louhab et al. (2019) recommended adaptations that are done based on the dimension of the mobile device such as the screen's size and resolution, battery level, connectivity, and installed software. The course content format is adapted based on the parameters accordingly, for example, a device having a small screen, the system will recommend text and presentation format over video format or concerning limited connectivity, audio and video are less favored and for having low battery, the system promotes the use of text and presentation formats since they do not consume much energy compared to audio and video format. Neffati (2021) proposed augmented reality to adapt the learning objects using different mediums such as virtual multimedia and graphics.

2.8.3 User interface

Amasha et al. (2021) mentioned that the maximum usability of a mobile learning application is important and should be adapted to the learner's functional requirements for an effective learning experience. The learner can be frustrated and cause discomfort during the learning sessions if the learning application's interface is not user-friendly. Hamzah et al. (2018) argue that the user interface is a prime factor to consider while implementing a mobile learning application as it affects various development elements of how the application would be convenient for the learner and user acceptance. Due to the ubiquity aspect of mobile devices, they are independent of the surroundings and time, thus it will affect the concentration level of the learner during the learning activities. Therefore, taking into consideration the

learner's contextual information while designing the user interface of the application is important for an efficient mobile learning experience.

2.8.4 The Learning Design

Yu and Liu (2020) proposed a set of rules that should be applied while creating or adapting mobile learning objects. Considering the dimension of a mobile device, the first rule is to present the learning objects into a miniaturized form while still being comprehensive for the learner. The second rule involves the different characteristics of the mobile learning resources such as learning objective, situation, weaknesses, and setting tasks. The mobile learning resources should be directional and flexible with the purpose to enable learners to find the direction of exploring knowledge. The third rule involves consistency in the design of learning objects and knowledge within a standardized range. Finally, the fourth rule is to enable the construction of learning resources to be versatile for future adaptations to the changing requirements and context.

As shown in Table 1, several types of contextual information are considered in PACAML studies that are used to adapt to the mobile learning environment. The intrinsic context is as essential as the extrinsic context that is used to derive contextual adaptation more accurately in the development of PACAML applications. Following the trend of the contextual elements considered in the reviewed PACAML studies, there is scope to explore more types of contextual information such as a social and cultural context that support communication and interaction between learners.

2.9 RQ2. What are the infrastructural requirements for PACAML?

As stated before, contextual information is an essential component of PACAML. There are various methods to capture context information of the learner's current situation. Appropriate infrastructural requirements should be used to capture the relevant contextual information based on the intended context adaptation to be achieved (van Vliet, 2020). Table 2 illustrates the general system infrastructures for PACAML.

Table 2 Infrastructural requirements

Infrastructures	Elements
Hardware & Software Resources	Mobile device, Screen, Battery, and Operating system
Sensors	Environmental sensor, Biosensor, and Activity sensor
Network	Bandwidth
System infrastructure	Cloud computing, Desktop server

2.9.1 Hardware & Software Resources

The characteristics of mobile devices are essential in the implementation of mobile learning applications as the contextual information is gathered by the device for learning adaptations. The context data is acquired by the available hardware and software of a mobile device and the information captured varies significantly depending on the capacity and quality of the components. Louhab et al. (2019) recommended adaptations that are done concerning the dimension of the mobile device based on the parameters such as device screen's size, screen's resolution, battery level, diverse connectivity options, and installed software. The learner can find the user interface more comfortable if a higher screen resolution of the mobile devices is used to implement the mobile learning applications. Mobile devices having powerful processors and computing memory can execute tasks such as streaming complex learning objects in augmented reality applications. The battery life of the mobile device is essential as it should be able to hold up to a reasonable amount of time when performing heavy computations.

The software technologies used in mobile learning provide plenty of tools to enhance the applications. Android is popular while considering the implementation of mobile learning as it provides a ready-made, low-cost, and customizable operating system in such learning applications. An android mobile application was proposed by Ennouamani et al. (2020) using context-aware adaptation based on the device's features such as keyboard, proximity, internet connection, barometer, camera, accelerometer, touchscreen, gyroscope, luminosity, and location to set up a comprehensive mobile learning environment for the learner. The device's features allowed the application, based on a context-adaptive framework, to predict suitable learning objects and recommendations.

2.9.2 Sensors

Most of the contextual data in learning applications are captured using the sensors available in the mobile device. The mobile sensors can be classified into three main categories, namely environmental sensors, biosensors, and activity sensors (Kumar and Sharma, 2019). The use of environmental sensors in the development of mobile applications is mainly to capture the surrounding context information. The present location or situation of the learner is common contextual information that is figured out by the mobile global position system or the fused location API and geofencing using the location sensors (Sun and Chang, 2016). Xiao (2019) uses the video sensor to take pictures or record the current learning space of the learner and try to recognize familiar learning objects or enable augmented reality adaptations. Other environmental information can be acquired by light sensors to capture the illumination intensity and audio sensors to measure the noise level.

Biosensors are still being explored in mobile learning as the raw data captured from the sensors are not directly related to the learning experiences of the learner. The raw data about the cardiac rate, skin conductance, body heat, and respiratory rate are all non-invasive measurements of the learner's physiological

features (Fortenbacher et al., 2017). The raw context capture from the biosensors can be computerized to determine the contextual information related to the learning experiences such as cognitive load, motivation level, emotional arousal, and stress level. Other anatomical features can be captured using wearable physiological sensors, suitable particularly for the development of non-computerized learning environments.

The physical activities of the learner can be captured by activity sensors in the mobile device. The activity recognition API in the android learning application uses motion sensors to sense acceleration forces and measure the movement of the device and it is possible to get the information of the physical activities of the learner (Curum and Khedo, 2019). In virtual augmented reality, the current indoor environment is determined using foot-mounted inertial sensors. The layout of the arena can be calculated by the software using the information of the learner's walking speed and direction.

2.9.3 Network

In mobile learning applications, the delivery flow of the learning objects is crucial to keep the learner concentrated. The fluctuations in the bandwidth can cause difficulties to deliver learning objects conveniently. Curum et al. (2017) allocated network priorities to the learning objects and, depending on the bandwidth, the flow of delivery is adapted for a smooth and convenient learning experience. The network priorities of the learning objects based on the receiving context data include low, medium, and high. Content adaptations are made according to the network priorities, for example, for low bandwidth, live-streaming of the learning objects is restricted, and delivery of low stream format is possible.

2.9.4 System infrastructure

Cloud computing is the most convenient infrastructure for the implementation of mobile learning technologies as it allows dynamic scalability at a reduced cost. Elstohy et al. (2021) proposed an effective mobile learning model using cloud computing resources. The implementation of the mobile learning system consists of learning object offloading facilities on an android based platform. Computation offloading is the process of sending computation-intensive application components to a remote server. One of them is public cloud computing and another one is a nearby desktop server. Offloading dynamically select the most convenient system and the decision is taken at runtime according to adaptation condition.

2.10 RQ3. What are the functional educational settings that are harnessing PACAML?

Most of the educational institutions across the globe adopted mobile learning in their educational contexts and considered it to be appropriate over the traditional classroom setting because of the COVID-19 pandemic crisis (Akour et al., 2021). Mobile technologies support smart features that support learning activities in a

different educational context such as adaptivity, ubiquity, context-awareness, and location-awareness.

2.10.1 Formal and Informal educational contexts

Previous studies indicate that mobile learning is identified as both a formal and informal method of learning (Pedro et al., 2018). Learners are recognized to be constantly near their mobile devices which are convenient as they can access the learning materials and interact with the content, potentially contributing to tearing apart the existing barrier between learning and real life. Sung et al. (2016) reported that formal and informal educational contexts could be enhanced for facilitating more innovative pedagogical strategies using mobile devices. The derived mobile learning strategies facilitate the learner's comprehensive ability for the subject content learning and may also enhance the learner's personal development in terms of communication through social learning, problem solving, creativity, and other high-level skills. Collaborative learning approaches in mobile social networking apps enable flexible delivery of learning materials that complement formal classroom learning settings (Khaddage et al., 2016). Virtual learning interactions can take place via mobile learning applications and group meetings can be organized where learners can communicate, engage, and create, then gain ideas and learning resources that they obtained in one location and apply or develop them in another space representing a classroom environment in a formal educational setting (Kaliisa and Picard, 2017). However, schools or educational institutions should provide tools and devices for students to facilitate the mobile learning environment in classrooms that support flexibility and portability (Asiimwe and Gronlund, 2015). The constraints of using mobile learning in formal and informal educational contexts are centered on issues such as the school policies on restricting the use of mobile devices, current school infrastructures that are not compatible with modern mobile technologies, and pedagogical skills for creating and using mobile learning applications.

2.10.2 Mobile Language Learning (MLL)

Studies and applications of MLL have been steadily increased together with the trend of creating short learning activities that made language learning more ubiquitous in the recent advancements in mobile technology (Schneegass et al., 2018). Due to its ubiquity and context adaptability, MLL applications are recognized to be a feasible tool and provide an appropriate mobile learning environment for learners (Morales et al., 2015). Mobile technology has been popularized for its effectiveness in the learning of the English language (Elaish et al., 2019). The trend of learning the English language as a foreign language via a mobile learning application has been growing in recent years. Al-Razgan and Alotaibi (2019) proposed the development of a personalized mobile language learning system for teaching and improving spelling. The learning application is designed based on the feedback of language teachers. Using mobile gaming technology, the application allows the learner to practice specific spelling rules and a game component that scores the progress of the learner while playing a spelling game. An education system has been developed by Bourekache and Kazar (2020) to learn the English language in a ubiquitous learning

environment to encourage learners to be more involved in the learning activities at their own pace. The mobile application is adapted to provide the right and accurate learning objects at the right time and in the most efficient way for the learner by monitoring learning activities and allowing multi-point interactions. Another English MLL application is proposed by Sun and Chang (2016) based on context-aware mobile learning. The investigation on the learners' learning requirements revealed that text and images, presented on mobile devices, are the most preferred learning materials and that the user interface should be comprehensive (Dashtestani, 2016). Sevkli et al. (2017) proposed a context-aware mobile learning application based on three dimensions, namely location, time, and profile as contextual information of the learner. The prophetic narration texts are used as learning materials and are considered a very important source in the Islamic culture. Hongthong and Temdee (2018) presented an MLL application that enhances digital literacy for Thai youth, particularly for the information and cyber security aspect. Primary school students evaluated the MLL application and most of them were satisfied with the personalization support as it enhances the learning efficiency significantly.

2.10.3 Mobile Analytical Learning (MAL)

MAL promotes the acquisition of knowledge in mathematics and scientific-educational context because of its adaptability, comfort access, and different intellectual capabilities (Bano et al. 2018; Crompton and Burke 2018). Computer programming courses based on mobile technologies could be more complex to adapt for novices if the development of the MAL application does not cater to learners' individualized needs, preferences, and cognitive capability. Jaguš and Botički (2019) developed a mobile learning application to learn mathematics and the framework consists of an adaptive framework that considers the learners' current situation, engagement, history data, interests, academic performance, behaviors, and their motivations. The adaptive mobile learning system tracks users' activities to calculate the average time a learner consumes to solve a particular task. Castro et al. (2016) proposed an approach for the implementation of a PACAML application that includes mobile learning materials for the development of basic disciplinary skills in mathematics and computing for high-school education. The design includes learning monitoring and personalization services characterized by using SMS, social networks and provides educational content based on context and learning styles. A mobile learning

Table 3 Classification of methodological approaches

Layers	Purpose
Application layer	The user interface, Communication, and Navigation
Context sensing layer	Mobile Sensors, Context processing and Relational or ontology data
Content adaptation layer	Context adaptation, Personalization, and Learning materials management
Knowledge layer	Test & Quizzes, Performance tracking, Evaluation, Subject matter, and Feedback

tool for computer science education known as MobileEdu was developed by Oyelere (2018). According to this author “The idea of the MobileEdu app is not only for use in programming education but also other computer science courses, such as system analysis, design, algorithms, etc.”. This mobile solution was aimed to provide support towards learning computer science courses using mobile technologies in Nigeria. Santhosh et al. (2015), proposed an approach having an innovative pedagogy for the development of a MAL application for teaching computer programming. Learners enhanced their learning experience by using the mobile learning application and they could easily understand programming concepts, interface development, programming architecture.

2.11 RQ4. What are the major methodologies applied in the studies of PACAML?

Most of the proposed PACAML frameworks can be categorized into a four-tier abstraction, namely the application layer, context sensing layer, content adaptation layer, and knowledge layer. Table 3 shows the classification of methodological approaches.

2.11.1 Application layer

The application layer focuses on the learners’ interactions with the graphical user interface of the system such as gathering contextual information and instructions to the adaptation framework and delivering convenient learning materials. Curum and Khedo (2019) defined the application layer to provide appropriate communication approaches, navigation through the system, and assist the learners throughout the learning activities. Moreover, Tortorella et al. (2017) considered the type of mobile device, the system infrastructure, and the connection types in this layer. Yu and Liu (2020) proposed to have various types of users with different authorities to use the system. For example, an administrator who is responsible for the management of the system should have full access to all functionalities. Learners can have access to the adapted mobile learning objects and finally, tutors can guide learners in their learning activities and have authority to resource learning objects and give feedback (Appendix Table 4).

2.11.2 Context sensing layer

The context sensing layer is an essential part of the implementation of mobile learning applications. The raw context data acquired from the sensors available on the mobile devices are processed and represented as relational or ontology data that is convenient to be computerized by the system (Kumar and Sharma, 2019). Hasanov et al. (2019) derived the context sensing layer into three fundamental steps to attain context acquisition. The first step is to acquire the information directly captured through the device’s sensors and the information manually input

by the learner (Agbo and Oyelere, 2019). The raw context information is then categorized into a relational or ontology manner, for example, according to the user profile, the knowledge level, learning preferences, and interest. The derived contextual information is then used in adaptive learning engines that perform the context adaptations accordingly and determine the most efficient learning strategies and therefore deliver the adapted mobile learning resources to the user interface (Lamia et al., 2019).

2.11.3 Content adaptation layer

The content adaption layer is the core layer of the mobile learning application as it consists of the context-adaptive mechanism and algorithms which dynamically adapt the learning objects according to the contextual information and manage the learning objects to the user interface (Yu and Liu, 2020). The content adaptation is initiated when the learner chooses a subject and the adaptive engine processes the computed contextual information and learner's profile information (Ennouamani et al., 2020). These parameters are processed to determine the most convenient learning materials that are retrieved from the database and supply to the learning user interface (Agbo and Oyelere, 2019). Furthermore, El Guabassi et al. (2018) also adapted the format of the presentation of the mobile learning objects.

2.11.4 Knowledge layer

The knowledge layer processes all the behavioral, pedagogical, cognitive characteristics of the learner including the relevant contextual information acquired and processed from the context sensing layer (Agbo and Oyelere, 2019). The knowledge layer makes use of analytic and intelligent decision making, communicated to the adaptation engine, to enhance the learning experiences by providing comprehensive learning objects based on the individual learning characteristics and peculiarities. Ennouamani et al. (2020) proposed to assess the learner through a test before the usage of the context-aware system to determine the learner's knowledge level based on the learning objects. Baccari and Neji (2016) use an assessment mechanism to evaluate the knowledge of the learner. Saryar (2019) proposed the concept of self-evaluation through tests and quizzes to enable the learning system to keep track of the learning performances and progress. Kakosimos (2015) adapts the learning objects based on the learner's feedback and the progress of the learning activities. The feedback information is collected through the methodology of micro-adaptive instruction and used to adapt the learning objects for the next learning activity.

3 Discussion

The findings of this study provide a comprehensive body of knowledge related to PACAML showing the importance of the research for the development, and recommendations for future research. The review was conducted using the three main steps

in the guidelines proposed by Kitchenham et al. (2009). The review was planned based on four derived research questions with the key components of PACAML that included the acquisition of context information, infrastructural requirements for mobile learning application, functional educational context, and major methodologies for context adaptations. The review was then conducted from various data sources using derived search terms and narrowed down using the PRISMA technique to put forward the quality criteria based on the research aims, objectives, and knowledge relevant to the study of PACAML. Finally, the review was documented with the findings according to the research questions. After analyzing the results, the following findings are discussed.

The results of RQ1 show several types of contextual information that are essential for context adaptations in PACAML. Most of the existing mobile learning system considers the learner's skills, the device's capabilities, and the surrounding environment to dynamically adapt the learning experience to ensure the learner's positive performance and learning attitude. The contextual information is represented as relational and ontology data and categorized into two types, namely intrinsic and extrinsic contexts. Intrinsic context is contextual information deduced from the characteristics of the learners and the focus was mainly on the knowledge level, the concentration & motivation level, the learning style the cognitive load, and learning behavior. Extrinsic context is an important aspect of contextual information that englobes the surrounding information by locating the learner, the personalized content format, the user interface, and learning design.

The results of RQ2 show the various means to acquire relevant contextual information through mobile technologies. The capabilities of mobile technologies are essential as the quality of contextual information acquired through the mobile sensors affects the adaptation of the educational content to improve the learning environment of the learner. The features of mobile technologies are important to be considered when it comes to the implementation of learning applications. The mobile device consists of sensors, screen size, operating system, connectivity, and infrastructural system. The sensors provide non-invasive measurements figures of the learner's physiological features to be able to determine complex contextual elements related to cognitive load, emotional arousal, and stress level. In terms of infrastructure systems, cloud computing is appropriate for the development of PACAML applications with its dynamic scalability and low cost.

The results of RQ3 show that foreign languages and computer science & mathematics are the most common learning objects in the existing PACAML applications. The existing learning system is categorized into two types, namely mobile language learning and mobile analytical learning. Mobile language learning was used in countries where learners were able to learn a foreign language via mobile applications. Most of the learning applications are designed to support learners to carry specific learning courses with predefined learning objects.

The results of RQ4 show that there is a diversity in the design framework based on which the existing PACAML applications are implemented. In this study, the different types of the framework are analyzed and categorized into a four-tier abstraction, namely the application layer, the context sensing layer, the content adaptation layer, and the knowledge layer. The application layer handles the interactions of the

learner with the mobile system. The context sensing layer processes the contextual information of the learner. The content adaption layer manages the learning objects according to the learner's learning context. The knowledge layer keeps track of the behavioral, pedagogical, and cognitive characteristics of the learner.

4 Challenges and research directions

Mobile learning technologies offer great capabilities to deliver PACAML applications but there is still room for improvement in the learning adaptations using complex contextual information such as pedagogical strategies and psychological aspects. A proper assessment of the knowledge level using appropriate pedagogical strategies is essential to identify the knowledge gap. Appropriate learning objectives can be defined if the knowledge gap is identified accurately. The existing mobile learning applications rarely consider learners' learning characteristics in their adaptation to context. Learners having different interests and needs in terms of learning objects provided by the learning application could cause discomfort in the learning process of the learner. Few studies have used the FSLSM to determine the learning style of the learner (Ennouamani et al., 2020 & Saryar et al., 2019). The different dimensions proposed in the FSLSM should be further exploited using pedagogical strategies to deliver more flexible learning objects through multiple mediums of learning objects to engage the learner in a personalized and dynamic mobile learning environment. Using augmented reality, learning objects can be adapted using different mediums such as virtual multimedia and graphics. Smartwatches and smart goggles are wearable technologies that are supporting mobile learning technologies and are affordable to be considered in the implementation of mobile learning applications. The raw data captured from physiological sensors could be computerized to determine complex contextual information such as cognitive load, motivation level, emotional arousal, and stress level.

For mobile language learning, most of the reviewed studies concentrated on the English language as they were implemented in countries that use it as a second language. The learning outcomes showed are well-suited for demonstrating PACAML, yet other potential educational settings where PACAML could be considered such as deep learning in virtual environments using more innovative computational techniques, specifically applying deep learning in virtual learning environments (Vallejo-Correa et al., 2021). The existing PACMAL applications mentioned, are mostly designed to conduct contextual adaptations for specific learning courses with predefined learning objects. A learning object adaptation mechanism could be established to adapt the specific learning objects according to the subject or the diverse educational setting. The study of a generic framework could be further extended that can allow the development of several kinds of PACAML applications. Finally, a standard measurement approach to evaluate PACAML applications is essential to investigate the efficacy. This would also improve the accuracy and reliability of the PACAML applications.

5 Conclusion

Due to the COVID-19 pandemic, digital learning is favored in most of the educational sectors across the world (Biswas et al., 2020). Mobile learning has been one of the most significant advancements in educational technology in the past few years. Mobile learning technologies can provide personalized learning assistance based on the learners' context to enhance the learning experience. Smartphones, tablet devices, and wearables offer smart features such as the ability to capture and process the contextual information of learners using a derived context-adaptive mechanism to create a proactive mobile learning platform (Muna, 2019). The review provided a summary of the studies of PACAML including contextual information for mobile learning, infrastructure requirements for the development of mobile learning systems, the application of mobile learning in the educational context, and major methodologies for mobile learning adaptations. Nevertheless, further research in the application of PACAML is required in the educational sector. Thus, this study is useful to build a comprehensive body of knowledge to assist the researchers working in this area. This study presents a review of the recent studies related to personalized and adaptive context-aware mobile learning. This review will enable researchers in the related field to get an overview of the recent advances of adaptive mobile learning technologies. Important aspects of learning context information are discussed, and the infrastructural requirements are identified. The application of mobile learning technologies in the educational sector has been discussed and the major methodologies for context adaptations are listed and classified. Further investigation on PACAML approaches can be extended on complex contextual information in terms of pedagogical strategies and psychological aspects to enhance mobile learning experiences.

Appendix

Table 4 Overview of Personalized and Adaptive Context-Aware Mobile Learning Systems

PACAML systems	Adaptation type	Context acquisition	Goal	Description
Agbo and Oyelere (2019)	Learner's preferences and needs	Sensors Derived User input	Personalize learning and recommendation	A smart mobile learning environment with adaptivity and context-awareness features that take into cognizance the learner's preferences and needs.
Al-Razgan and Alotaibi, 2019	Content adaptationPersonalization-Feedback and support	Derived User input	Enhancing learners' motivation and engagement	Personalized mobile learning platforms to enhance student learning using mobile gaming technology.
Amasha et al. (2021)	Feedback and support Content adaptation	Derived	Increase achievement of learning goals and decrease learning time	The development of a Java-based mobile application for learning mathematics.
Bourekache and Kazar (2020)	Communication and interaction	Derived User input	Enhance the knowledge of learners in foreign languages	A mobile learning system that provides the opportunity for students to learn the English language outside the classroom.
Curum and Khedo (2019)	Context adaptation	Sensors User input	Improving learner's learning experience	A mobile learning system that performs an adaptation of learning contents based on the actual environment and conditions of the learner.
Curum et al. (2017)	Content adaptation	Sensors Derived User input	Enhance the learners' experiences by recommending learning content	A mobile learning system that acknowledges different user situations and delivers the best-adapted learning content to the learner.
El Guabassi et al., 2018	Content adaptation	Derived User input	Provide dynamic and most effective learning materials	A mobile learning system that personalizes course content in ubiquitous learning, considering learning styles and context-awareness.

Table 4 (continued)

PACAML systems	Adaptation type	Context acquisition	Goal	Description
Elstohy et al., 2021	General adaptation	Derived	Optimize responsiveness by leveraging public cloud server	A cloud computing resources and capabilities in proposing an effective mobile learning model.
Ennouamani et al., 2020	Feedback and supportFormat and content adaptation	Sensors Derived User input	Provide personalize learning and recommendation	A dynamic mobile adaptive learning content and format that considers the learner's knowledge level and learning styles to provide suitable learning materials.
Erazo-Garzón et al. (2019)	General adaptation	Sensors Derived User input	Improving learner's learning experience	A mobile learning system that provides personalized and relevant academic information in the current context of the study.
Fortenbacher et al., 2017	Navigation and sequencing	Sensors	Improve learning experience	A mobile learning companion aims at supporting learners through learner-centered learning analytics using physiological sensor data as well as environmental sensors
Glahn and Gruber (2020)	General adaptation	Sensors Derived User input	Utilize the ubiquitously available technologies for leveraging on the learners' contexts	Context-aware mobile learning and operationalizing the concept of seamless learning for planning and orchestrating contextual information.
Hamzah et al. (2018)	User interface adaptations	Derived User input	Optimize user interface to improve the learning experience	A proposed mobile learning application based on design principles, usage context, hardware specifications, and modeling language to optimize the learning user interface.
Hongthong and Temdee (2018)	Personalization	Derived User input	Ensuring the learning enhancement ability	A mobile learning system for enhancing digital literacy.

Table 4 (continued)

PACAML systems	Adaptation type	Context acquisition	Goal	Description
Jaguš and Botički (2019)	Content adaptation	Derived User input	Collaborative learning with pedagogical adaptations	An architectural approach to modularizing and extending existing lessons using adaptive or collaborative pedagogies.
Louhab et al., 2019	Context and content adaptation	Derived User input	Enhance educational resources	A context-aware mobile learning approach that provides learners with an adapted course content format.
Neffati (2021)	Communication and interaction	Sensors Derived User input	Incorporate visual stimulation during learning	An approach to making digital learning practice easier by focusing on learner's requirements and instructor relationships to maintain communicative development-based learning.
Oyelere, 2018	Communication and interaction	Derived User input	Improve learners' interactions, motivation, and engagement	A mobile learning system that enables aid teaching and learning of computer science.
Pinjari et al. (2018)	General adaptation	Derived User input	Reduces the latency and the time complexity in mobile learning application	Using fog computing in mobile learning to achieve efficient context-aware learning.
Radhakrishnan and Akila (2021)	Content adaptation	Sensors Derived User input	Providing required content or materials in the desired format to the learner	A mobile learning system that personalized the learning experience of the learner according to the learner's preferences and recommends the desired learning objects.
Saryar et al. (2019)	Content adaptation	Sensors Derived User input	Using a recommendation system to recommend relevant course material to the user	A mobile learning application that provides seamless availability of course material to the learners ubiquitously.

Table 4 (continued)

PAC/AML systems	Adaptation type	Context acquisition	Goal	Description
Schneegass et al., 2018	Personalization Content adaptation	Sensors Derived User input	Increase achievement of learning goals, motivations, and learner's satisfaction	A flipped classroom framework to provide learners with an adapted course content format based on their feedback and context.
Sevklı et al. (2017)	Content adaptation	Derived User input	Enhance the knowledge of learners in foreign languages	A novel context-aware mobile learning application to encourage and promote hadith learning.
Xiao et al., 2019	General adaptation	Sensors Derived User input	Provide ubiquitously learning	A mobile learning system using learning analytics with Augment Reality.
Yu and Liu (2020)	General adaptation	Derived User input	Provide rich learning resources and improve the individuality and autonomy of learners.	An approach for the development of a mobile learning resource platform, which can reduce the risk of system requirements and improve development efficiency.

Availability of data and material (data transparency) Not applicable

Code availability (software application or custom code) Not applicable

Authors' contributions Not applicable

Declarations

Conflicts of interest/Competing interests (include appropriate disclosures) Not applicable

Ethics approval (include appropriate approvals or waivers) Not applicable

Consent to participate (include appropriate statements) Not applicable

Consent for publication (include appropriate statements) Not applicable

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