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Context aware mobile learning application development: A systematic literature review

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Abstract

Context Aware Mobile Learning Applications (CAMLA) are an emerging field of research, they provide educational resources tailored to educational needs and particular circumstances of the learner. Despite the increase in the number of applications being developed, there is a lack of study that provides comprehensive knowledge on the development of CAMLA. Motivated by this shortcoming, Systematic Literature Review (SLR) was conducted to establish a body of knowledge that describes the key components of CAMLA that includes; context information extraction and representation, context adaptation and different types of applications developed. SLR was conducted on 24 papers retrieved from seven databases. The results identified different types of context amongst which learner, location and time are the most widely used in the development of CAMLA. The context data is collected using virtual and physical sensors and mostly represented as relational or ontology data. CAMLA provides different types of adaptation where adaptation to learning resource and location are very common. The results are useful to position future research activities to scientifically strengthen this field.

Keywords Mobile learning · Context aware mobile learning · Systematic literature review

1 Introduction

Mobile learning is accessing learning content using mobiles devices such as smart phones, and tablet pc, it allows access to learning where ever and whenever you want

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(Kumar and Mohite 2017; Kumar and Goundar 2019). Within the mobile learning domain, Context Aware Mobile Learning Applications (CAMLA) have become an important research area. CAMLA can extract and use context information such as time, location and physical condition etc. to tailor users learning based on available context (Nuzhat et al. 2018). Developing context aware mobile learning applications is a challenging task due to the complexity of capturing, representing and processing the context information (Shcherbachenko and Nowakowski 2018). In literature, there are papers on the development of CAMLA but there is a lack of review papers that provide details on the development of these applications. Motivated by this shortcoming we established a body of knowledge by reviewing the literature on the development of CAMLA, to assist researchers working in this field. The review was carried out using papers retrieved from seven commonly used databased in the field.

SLR method was used because it is rigorous and has a well established guideline to conduct and report reviews. It identifies a problem, formulates research questions and critically evaluates different studies to answer the research questions (Kitchenham 2004). SLR will give a fair, credible and unbiased evaluation of context aware mobile learning application studies. The guidelines of Kitchenham and Charters (2007) has been used with the aim to build a body of knowledge that describes the key components of CAMLA that includes; (i) context information used, (ii) context extraction and representation, (iii) context adaptation and (iv) different types of CAMLA developed. The results of SLR revealed eight different types of context amongst which learner, location and time are most widely used in the development of CAMLA. The context data is collected using sensors (physical and virtual) and mostly represented as relational or ontology data. CAMLA provides six different types of adaptation where adaption to learning resource and location are common. The results were used to position future research activities in identified areas to scientifically strengthen the field.

The main contributions of this study to the field of CAMLA include; (i) assessing the context aware mobile learning application to establish a body of knowledge on the development of CAMLA, (ii) consolidating the findings to set future research direction to scientifically strengthen the field. This paper is organised as follows; the background section explains the concept of context aware mobile learning and prior work done in the area. The methodology section provides details of the processes used to conduct SLR. In the results section, we analysed the data collected according to the research questions. The discussion provides an interpretation of the findings together with the opportunity for future research in the selected areas. Limitations section highlights certain limitations on the interpretation and generalization of results. Finally, conclusion and future work are presented.

2 Background

Mobile technologies are constantly evolving, early incarnations of mobile devices included mobile phones without internet connectivity, the recent advancement include smartphones and tablet devices which offers the ability to access the internet and includes additional capability such as touch screen, camera, downloadable applications, location awareness and GPS etc., with these technological innovation, use of mobile

devices in educational process has been one of the most significant advancements in the field of educational technology in past few years (Fulantelli et al. 2015; Reddy et al. 2017; Reddy and Sharma 2018). The new generations of mobile devices offer options to exploit ubiquitous connectivity. Mobile devices are emerging technology that has the potential to facilitate learning by exploiting learner's context. There is an increased interest in the development of context aware mobile learning applications since it is an effective way to provide learning resources that suits the circumstance of the learner (Sevkli et al. 2017). Recently there has been increased interest in the personalised learning that shits from teacher-centred to student-centred learning. Context aware mobile learning seems to be an excellent solution to mobile learning.

Context aware applications have conscience of the environment, an application is considered context aware if it uses context information to give relevant information to the user (Dey and Abowd 2000). Context is any information that is used to characterize the situation of an entity. In mobile learning context can be information about learner (personal information, preferences, interests etc.), place (location, learning setting etc.), time (time of the day, availability, task duration etc.), device (smartphone, tablet, PDA etc.) and physical environment (noise level, illumination level, weather condition etc.) (Yao 2017). The new generation of mobile devices can sense, track and monitor the learners surrounding and transmit the contextual information to mobile learning applications that can extract, interpret and use context information to tailor users learning based on available context (Liu and Hwang 2010).

Context information is very important for applications that change the environment frequently (Aloui and Gargouri 2012). In mobile learning, it can be useful to enhance the applications to provide information that is relevant to the user (Aziz et al. 2010). Mobile devices can sense and track the learner's environment and collect and transmit the contextual elements in the learning systems (Zhang et al. 2016). The mobile learning applications make use of the context information to make dynamic adaptation to learning activities. The adoption of context awareness in mobile learning has become an important area of research due to the mobility of learners that results in changes in the environment. It is important that mobile learning systems react dynamically to these changes and provide appropriate learning resource in changing context (Curum et al. 2016).

Various studies reported in literature attempted to model context information for mobile learning applications. Zervas et al. (2011) studied the previously proposed context model and divided the context into two parts; learning context and mobile context. Learning context is made up of learning design and learner profile. Mobile context includes people, place artefact time and physical condition. Economides (2008) classified context into four major classes of technical, physical, personal and situational context. Christopoulou (2009) modelled the mobile learning context into five dimensions; place, artefact, time user temporal information, and physical condition. In prior work, Baldauf et al. (2007) studied context aware applications in general and categorized the sensors used to collect data into two types of physical sensors and virtual sensors. Physical sensors are hardware sensors for e.g. gyroscope, and temperature accelerometer sensors. Virtual sensors read the context data from users mobile phones. Logical sensors are usually a combination of logical and physical sensors. In modern smartphones it is possible to find all these sensors.

3 Research method

This research was conducted based on the guideline proposed by Kitechenham and Charters (2007). The systematic literature review process included three phases planning, conducting and reporting the review. The planning phase involves identifying the need for a systematic literature review and developing the review protocol. The conducting phase includes selecting and reviewing studies to present the results. Reporting phase includes writing up the review results and communicating to the research community. The SLR process is depicted in Fig. 1.

3.1 Planning

3.1.1 Identifying the need for SLR

In the last decade number of context aware mobile learning applications have been developed and reported in the literature. There is no comprehensive study that examines context aware mobile learning applications to provide a substantial body of knowledge to aid researchers working on this field. SLR is a technique that can summarise all existing information in an unbiased way and critically evaluate and integrate the findings of individual studies to build a substantial body of knowledge on CAMLA development that explains context information used, how context information is extracted and represented, how adaptation is made based on context information and finally different types of application developed.

3.1.2 Developing a review protocol

A review protocol was developed by having a meeting with all the researchers, this helped us to state the aims and objectives of the study clearly and establish a review protocol to avoid researcher bias.

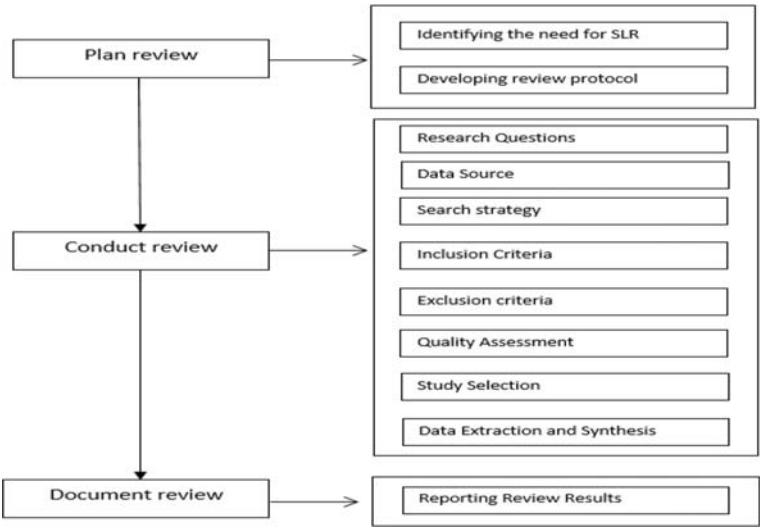

Fig. 1 Systematic literature review process overview

3.1.3 Conducting the review

After the review protocol has been established we started the review proper, it included the following steps; identifying research questions, relevant data source, establishing search strategy, creating inclusion criteria exclusion criteria, quality assessment and, data extraction and synthesis. Each stage was executed in a sequential manner.

3.2 Research questions

Research questions are an important part of SLR it sets the basis for data analysis. The research questions were formulated based on the aim and objectives of the study. Table 1 shows the research questions formulated for this study.Table 1Research Questions

ID	Question
RQ1	What context information is used in the development of CAMLA?
RQ2	How context data is extracted and represented in CAMLA?
RQ3	What are different types of adaptation made on derived context?
RQ4	What are the different types of CAMLA developed?

RQ1 was motivated by the need to understand various context information used in the development of CAMLA. RQ2 was established to discover how the context information is gathered and represented using different data models. RQ3 investigates different types of adaptation made in CAMLA. RQ4 investigates what are different types of applications developed to see how CAMLA is used in the real world?

3.3 Data sources

Seven electronic databases that are relevant to our field of research were selected. Since we are interested in good quality studies we selected the digital libraries that are relevant to our research.

• ACM	http://dl.acm.org
• IEEE	http://ieeexplore.ieee.org
• Science Direct	http://sciencedirect.com
• Springer	http://springerlink.com
• Wiley InterScience	http://onlinelibrary.wiley.com/
• Taylor and Francis	http://www.tandfonline.com
• Inderscience	http://www.inderscience.com

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3.4 Search strategy

The search strings were developed to capture results from the databases. The search string should provide maximum coverage but of manageable size (Schardt, 2007). The search strings were based on the research questions identified earlier. It was developed using three different domains of study in this research. 1) Mobile learning as the main field of study. 2) Context as the subtopic under study. 2) Development as the specified category. Table 2 shows the search strings used.Table 2Search String

Scope	Source title
Mobile Learning	(mobile learning OR m-learning) AND
Context aware	(context OR context aware)
Development	(development OR implementation)

The search strings listed in Table 2 above were executed on the seven different databases. The search strings were added, discarded and rerun to ensure that all relevant papers are retrieved.

3.5 Inclusion criteria/ exclusion criteria

Inclusion/Exclusion criteria were developed to assess the selected papers. Only those papers that meet the criteria listed below were selected.

The inclusion criteria are as follows;

IC1. The paper reports on context aware mobile learning development.
IC2. The paper is scientifically sound.
IC3. The paper can be used to sufficiently answer the research questions.

The papers that conformed to at least one of the following criteria were excluded:

IC1. The paper is not written fully using English as the main language.
IC2. The paper has already been selected from another database

Table 2 Search String

Scope	Source title
Mobile Learning	(mobile learning OR m-learning) AND
Context aware	(context OR context aware)
Development	(development OR implementation)

Table 3 Quality Assessment Checklist

Question	Yes	No
QA1 Research aims and objectives are clearly articulated?		
QA2 Is there clear justification on aims of the research?		
QA3 The findings of the study are credible with supporting data?		
QA4 Does the study contribute to knowledge?		

3.6 Quality assessment

Quality Assessment was conducted using a checklist to measure the research credibility and validity. Table 3 provides the Quality assessment checklist.Table 3Quality Assessment Checklist

Question	Yes	No
QA1 Research aims and objectives are clearly articulated?		
QA2 Is there clear justification on aims of the research?		
QA3 The findings of the study are credible with supporting data?		
QA4 Does the study contribute to knowledge?		

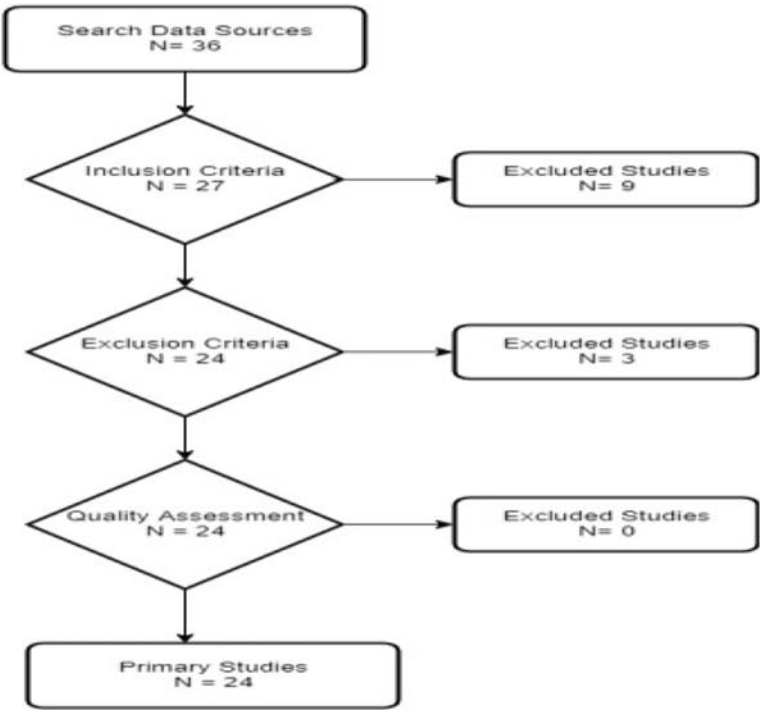

Fig. 2 Study selection process

In this research, we conducted a quality assessment to ensure that the study meets quality criteria. This is particularly important because we have also used conferences papers. If any of the papers that did not meet the criteria set in Table 3 above the papers were removed.

3.7 Study selection

The title and abstract of all the papers were read carefully where ever necessary since we have a small number of primary studies the whole paper was read. The papers were assessed against the inclusion, exclusion and quality assessment criteria. In total 36 papers were selected after assessing against the selection criteria 12 papers were removed. The papers have been removed for following reasons; the paper listed in multiple databases, the paper was not entirely written in English language or the paper does not report credible findings from which we can extract useful knowledge. Figure 2 provides an overview of the study selection process.

3.8 Data extraction and synthesis

In this step, we recorded the information from the primary studies. A data extraction form was created to record the relevant data. The following information was extracted from each of the primary studies.

- Context information used
- How context information is extracted and represented
- Types of adaptation
- Types of CAMLA developed

The extracted data was placed into a shared drive so that it can be easily assessable to all the authors. While the first author and second authors were responsible for reading papers and extracting data the third author checked a random sample of primary studies to verify data. The extracted data were summarised and grouped into tables. Finally, the data was analysed and results are presented in the next section.

Table 4 Papers retrieved per Database

Database	Date	Results
ACM Digital library	30/03/2019	1
IEEE Digital library	30/03/2019	8
Science Direct	30/03/2019	4
Springer Link	30/03/2019	3
Taylor and Francis	30/03/2019	6
Wiley Interscience	30/03/2019	1
Inderscience	30/03/2019	1

4 Reporting review results

This section provides an analysis of the data that was gathered. The research questions were answered using the data obtained and the discussion section provides a summary of our results. Although there was less number of papers as expected it is sufficient enough to build a substantial body of knowledge to guide researchers working in this field. In total 24 papers were selected that included there were 11 journal articles and 13 conference papers. Table 4 provides a summary of papers obtained per each database.Table 4Papers retrieved per Database

Database	Date	Results
ACM Digital library	30/03/2019	1
IEEE Digital library	30/03/2019	8
Science Direct	30/03/2019	4
Springer Link	30/03/2019	3
Taylor and Francis	30/03/2019	6
Wiley Interscience	30/03/2019	1
Inderscience	30/03/2019	1

RQ1. What context information is used in the development of CAMLA?

Context information is used to tailor learning activities to the individual needs of the learners. In this research, we found a total of eight different contexts that have been used in the development of 24 applications. The context information included; physical condition, time, learner, cognitive, learning style, location, device and people. In Table 5 we described each of the context used in the development. The statistics on context information used by different applications are given below in Fig. 3. From this data, we can reveal that learner, location, time and environment is most widely used in the development of CAMLA. In a prior research Zervas et al. (2011) studied the previous on work context modelling and identified eight contextual elements (learner profile, learning design, place, learner temporal information, people, time artefact and physical condition) the results of this questions reiterate that these contextual elements are used in the development of CAMLA. There is scope to explore more types of

Table 5 Details of context information

Context	Description
Physical condition	noise, temperature, lighting, weather, illumination
Time	time of the day, learning time, lesson time
Learner	preference, like, age, knowledge, interest, mood
Cognitive	attentiveness, load, attitude, manner
Learning style	learning activity, pedagogy
Location	situated place, zone, setting
Device	configuration, physical properties
People	peers, available learners

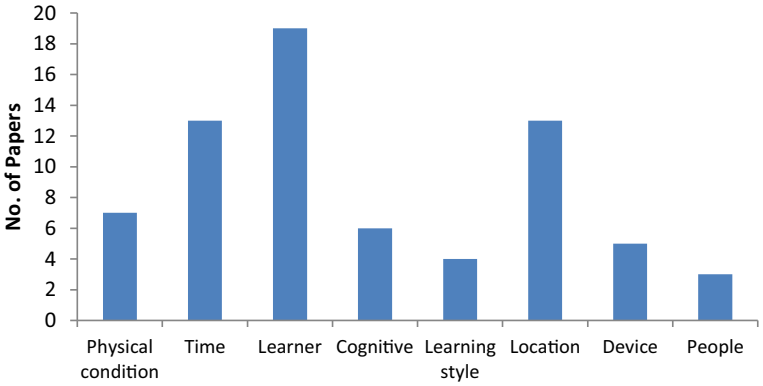

Fig. 3 Use of context information

context information such as social and cultural context they may be useful in the development of applications that support communication and interaction between learners.Table 5Details of context information

Context	Description
Physical condition	noise, temperature, lighting, weather, illumination
Time	time of the day, learning time, lesson time
Learner	preference, like, age, knowledge, interest, mood
Cognitive	attentiveness, load, attitude, manner
Learning style	learning activity, pedagogy
Location	situated place, zone, setting
Device	configuration, physical properties
People	peers, available learners

RQ2. How context information is extracted and represented?

The results of research question 2 revealed that the context sensing layer is responsible for capturing context data and different models that are used to manage context information.

For context sensing, there are two types of sensors being used, virtual sensors and physical sensors. Virtual sensors use service software to extract context information

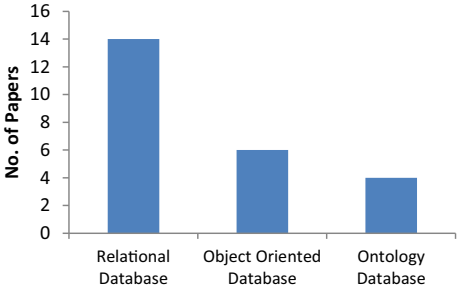

Fig. 4 Data models

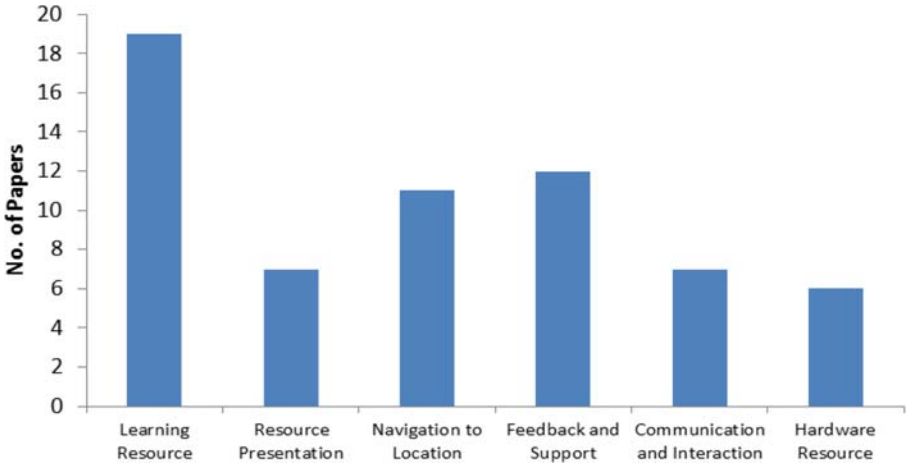

Fig. 5 Types of adaptation

from users' mobile phones. For example, user's location can be retrieved from location services, users available time can be retrieved from calendar services etc. Physical sensors also referred to hardware sensors are built into users mobile phones this includes environment sensors, tag sensors and gadget sensors. Data models with the store and manage context data our search revealed three types of storage mechanism used to store context data; relational, object oriented and ontology. Relational data is stored in tables with rows and columns. In object oriented context data is encapsulated in objects. Ontology representation of data and relations between the concepts, data, and entities. The relational database is the most common form of storage mechanism. Figure 4 provides statistics on different data models. (Curum et al. 2017; Baccari and Neji 2016; Morales et al. 2015) highlighted that presenting learning resource in mobile learning applications is a challenging task this is mainly due to limited bandwidth and limited resources available in mobile devices therefore further research is needed in context information modelling.

RQ3. What are different type's adaptations made on derived context?

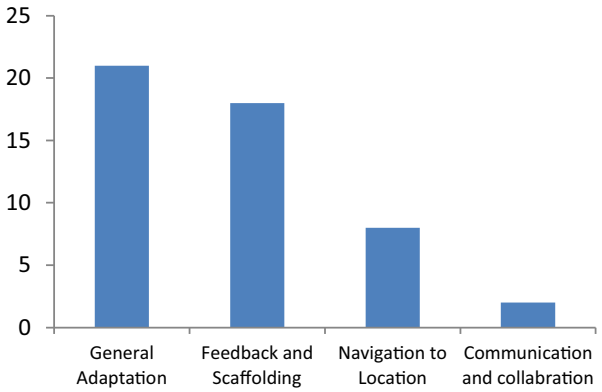

Fig. 6 Distribution of papers by application type

Context adaptation is presenting the most appropriate learning elements to the learner under different contexts. This is the core component of CAMLA.

The results of RQ3 revealed six different types of adaptation; learning resource, resource presentation, scaffolding, navigation, interaction and hardware resource. Learning resources—learning materials are selected and presented to learners. Resource presentation—this provides learning resource in appropriate format this may include mobile device capacity, network capacity or learner preference. Scaffolding—this provides hints and suggestions to assist in learning activities. Navigation—this supports learning activities through creating a learning path based on user location. Interaction—this assists in finding learning peers based on experience, location etc. this may also be useful to select required communication tools. Hardware Resource—this assists in utilising the hardware resource at the optimum level to support the learning activities. Figure 5 provides statistics on different types of adaptation in CAMLA. At the moment the research on CAMLA is in the infancy stage and there is a scope in developing algorithms to support adaptation. The current adaptation technique uses a basic rule-based or similarity-based algorithm techniques for adaptation.

RQ4. What are the different types of CAMLA developed?

Gomez et al. (2014) studied context aware mobile learning applications and classified them into four types; general adaptation, feedback and scaffolding, navigation to location and communication and interaction. We used the same classification for this question. Figure 6 shows the distribution of papers by classification. The applications are described below.

- General adaptation—automatic adaptation to learning activities based on contextual information. Adaptation to educational resources or learning activity is based on provided context information.
- Feedback and scaffolding—provide suggestions and hints based on provided contextual elements. Applications that were developed in this category were mainly used to support foreign language learning.
- Navigation to location—constructs a navigation path to support learning. Applications were developed that utilizes the location as the main context to support learning activities. These types of applications were useful to provide support for real time learning.
- Communication and interaction—selects appropriate communication and collaboration tool by exploiting learner's preference and needs.

The applications developed included;

General adaptation applications were developed that provide adaptation to educational materials based on context information. Curum et al. (2016) gathered context information from the device, learners and the surrounding environment to provide customized learning. Hashemi et al. (2012) designed a mobile learning application that asks the user to provide certain information that includes information such as the desired view, mood etc. and learning resources are provided based on this.

Navigation to location applications considers location as the main context. Hwang et al. (2009), developed a mobile learning application that provides the learning path for the users based on learners location on the university. Another application was developed by CMMCUL (Hwang et al. 2011) which uses RFID to detect the learners'

location and provide them with the learning material to find required objects during the learning process.

Feedback and Scaffolding applications were developed that mainly supported language learning. Paredes (2005) developed an application to support informal language learning. Al-Mekhlafi et al. (2009); Morales et al. (2015) developed an application to support Chinese language learning. Yin et al. (2010), Wang and Wei (2014), and Wang (2017) developed an application to support Japanese language learning. Nguyen et al. (2010); Chen and Li (2010), Liu et al. (2018) developed an application to support English language learning.

Communication and interaction applications were mainly developed to support interaction amongst peers. Economides (2008) developed collaborative learning applications based on learner's profile. Baccri and Neji (2016) developed a collaborative learning application that selects relevant resources, learning partners and learning activities based not only on the learner's needs but also on its current context of the learning environment.

5 Discussion

This section describes how this research is important for practice, the key findings and subsequent research that can be carried out.

The results provided a summary of key components of CAMLA that includes; (i) context information used, (ii) context extraction and representation, (iii) context adaptation and (iv) different types of CAMLA developed. The results are important as it provides substantial knowledge that can assist in the development of future CAMLA thus is easily transferable to practice. By examining the data obtained and answering the research questions we came to the following findings. The results of RQ1 revealed different types of context information used in the development of CAMLA, in total eight different context information were found; physical condition, time, learner, cognitive, learning style, location, device and people. The search revealed learner, location, time and physical condition most widely used in the development of CAMLA. There is room to further explore the context elements such as social and cultural context they may be useful for CAMLA that support communication and interaction amongst peers. The results of RQ2 revealed different ways in which context information is gathered and represented. Context information can be gathered by using sensors two of the most commonly used sensors are virtual sensor and physical sensor. The gathered context data are mostly represented as relational data. Due to limited resources in mobile devices further research is needed for context management and context modelling to develop efficient applications since mobile learning poses new challenges due to the limited bandwidth of wireless networks and the limited resource available on mobile devices.

The results of RQ3 revealed six different types of adaptation that can be made that includes adaptation to learning resource, resource presentation, feedback, navigation to location, interaction and hardware resource. The search results indicate that adaption to learning resource, navigation to locations and feedback and support are the most common forms of adaptation. There is scope for developing algorithms for efficient adaptation. The results of RQ4 provided

four different categories of applications; general adaptation, feedback and support, navigation to location and communication and interaction. The results indicated that current research activity is dominated by developing general adaptation, and feedback and scaffolding applications. General adaptation deals with automatic generation of learning activities. Feedback and scaffolding provide personalized hints at the right time. There were very few papers in the category communication and collaboration and navigation to location hence more research activity is expected in the future in developing these two types of applications.

The findings are important for subsequent research. Further work can be carried out to scientifically strengthen the field in the following ways.

- Context information—this research revealed eight different types of context, further research can be carried out to explore the social and cultural context, this type of context may be very useful to support the development of applications that supports communication and interaction among learners. Cultural context includes learners' cultural characteristics that are composed of beliefs, norms, assumptions, values, or sets of practice whereas social context includes interaction with the group and peers. It is important to be aware of the social and cultural context in developing learning environments for it to be effective (Economides 2008).
- Context Management—research may include investigating mechanisms to; (i) identify context changes that affect the relevance of context adaptation; and (ii) develop mechanisms to enable the ability to adjust context adaptation at runtime. Among the studied papers (Zhang et al. 2016; Gómez et al. 2014; Benlamri and Zhang 2014) declare context management as a future research area.
- Context Modeling—this is another area that can be explored currently since there is no appropriate data model proposed that can be used to efficiently manage context information in mobile learning applications. Context modelling include the development of new techniques and mechanisms to; (i) model context data; and (ii) identify a mechanism to integrate context data into adaptation engine.
- Framework—there is lack of guideline or framework for developing context aware mobile learning applications thus there is no homogeneity (standardization) in development of CAMLA. There should be a standardized method or process for context extraction, context representation and context adaptation. This may be useful in the following ways, (i) increases reliability because components have been rigorously tested, (ii) it reduces development cost mainly because of component reuse which leads to the shorter time to market and, (iii) reuse of knowledge will improve productivity and quality of applications.
- Context adaptation algorithms—research in this direction can be carried out to design different algorithms that support context adaptation in mobile learning environments. There are many types of algorithms needed to support adaptation efficiently. Research in this direction is currently in an infancy stage.

6 Limitation

In order to ensure the reliability of our results we planned and executed the SLR based on the guidelines proposed by Kitechneham (2007). Data was collected by first and second authors and it was independently reviewed by third authors. Since the SLR strictly conformed to the proposed guideline replicability of the results would not deviate significantly, there may be certain limitations of our study as described below.

In this study, we only included journal and conference papers and also limited the search based on selected venues only. This research omitted articles published in standalone journal and conferences, therefore, we can interpret the results as studies published in major journals and conferences.

The use of search string may have filtered some important papers in order to mitigate the threat an effective search string was designed changes were made to the search string and it was executed again to ensure that none of the qualifying results are missed out.

7 Conclusion

This study presents the results of the systematic literature review on context aware mobile learning application development. The SLR was useful to build a substantial body of knowledge to assist the researchers working in this field. Four research questions investigated the key components of CAMLA that included; context information used, context information extraction and representation, types of adaptation and applications developed. SLR was conducted using the guidelines proposed by Kitchenham and Charters (2007), The results provided useful insight into context information used in this research, we found a total of eight different context that has been used in the development of CAMLA that included; physical condition, time, learner, cognitive, learning style, location, device and people. Context sensing layer is responsible for capturing context data and data layer handles the storage and management of context data. For context sensing, there are two types of sensors being used virtual sensors and physical sensors. Data layer deals with storing and managing context data three types of storage mechanism was used to store context data; relational, object oriented and ontology. Six different types of adaptation were identified; learning resource, resource presentation, feedback and support, navigation to location, communication and interaction and hardware resource. Four types of applications are being developed; general adaptation, feedback and scaffolding, navigation to location and communication and interaction. Based on the findings further research can be carried out to explore different types of context, investigate the mechanism for context management, context modelling, establishing a framework to support the development of CAMLA and finally designing algorithms to support context adaptation. Future work is to extend SLR by providing regular updates that not only repeat SLR but adapt the iterations over the years according to lessons learned from previous iterations. Thereby, we can establish stable bodies of knowledge.

Appendix

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