Synthesis of a Framework of Design Guidelines for m-Learning Environments

A Study in a Tertiary Education Context in South Africa

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Keywords: Design and Development Strategy, Design Guidelines, Digital Devices, m-Learning Environment, Tertiary Education, Virtual Learning Environment.

Abstract: Smartphones and tablets are ubiquitous in educational contexts, where students on-the-move expect access to learning material via a range of digital devices in a mobile and transparent manner, whether on or off campus. A successful m-learning experience can be facilitated by a mobile learning environment which is efficient and effective, and that satisfies the users' versatile needs. An *ad hoc* design and development strategy that ignores design principles and guidelines, restricts the likelihood of successful m-learning experiences. This study was implemented in a tertiary education context and aimed to establish – from dual perspectives – a framework of design and development guidelines for m-learning environments. An initial set of themes and guidelines was synthesized from a comprehensive literature study. Secondly, the outcomes of a series of iterative evaluations of an m-learning application, *Mobile Learning Research* (*m-LR*) were used to generate new themes and guidelines. The quantitative and qualitative findings of heuristic evaluations by experts and questionnaire surveys administered to students, provided positive and negative feedback that was converted to a set of practical guidelines. Jointly, the initial theoretical guidelines and the subsequent empirical findings contributed to the synthesis of a comprehensive and cohesive set of design guidelines for m-learning environments.

1 INTRODUCTION

Smartphones and tablet devices offer ubiquitous m-learning opportunities for higher-education students who study while on-the-move (Cochrane and Bateman, 2010). Over and above educational aspects, the perceived usability and user experience (UX) of m-learning platforms depends to a large extent on underlying design and development factors (Oinas-Kukkonen and Kurkela, 2003). This study, which proposes a framework of design guidelines for the synthesis of m-learning environments, is a secondary outcome of the iterative development and evaluation of a real-world learning environment called *Mobile Learning Research* (*m-LR*) (Harpur, 2013, de Villiers and Harpur, 2013). A *first set* of design guidelines for m-learning was gleaned from the literature and used to generate the first version of *m-LR*. The purpose of this paper is not primarily to report on the evaluation and redesign of *m-LR* prototypes. However, the findings of the evaluations formed a vital part of the design process and the emergence of *a second set of guidelines*.

Ad hoc approaches that ignore design principles in the development of m-learning, may have unfortunate usability and UX implications that designers and developers of the end-product could regret. This study contributes to knowledge by synthesising a framework of design guidelines that incorporates theoretical guidelines based on acknowledged literature sources, as well as practical guidelines from the findings of empirical evaluation studies. Participants' responses identified problems in *m-LR* and also provided positive feedback. The composite set of guidelines, emerging from both theory and research, offers a rich broad-based collection of design guidelines that is transferable and adaptable to various mobile- and tablet-based learning situations. Through use and evaluation of *m-LR*, the theoretical guidelines were affirmed by use and new ones emerged.

Section 2 sets the context and outlines the background of this research. The research design is

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described in Section 3. Thereafter we view the guidelines from three lenses: their emergence; application; and evolution. Section 4 lists the initial guidelines that *emerged* from a literature review, while the impact of practically *applying* the guidelines, is reported in Section 5. Section 6 presents further guidelines that *evolved* from evaluations. The study is concluded in Section 7.

2 BACKGROUND

The primary researcher is a lecturer of undergraduate students taking Software Engineering at a private South African university. She observed that some students seemed demotivated by traditional face-to-face classroom education. In addition, the limited access of certain students to the Internet via PCs and laptops hindered effective communication and collaboration on group projects. However, the majority of students had smartphones and/or tablet devices and were proficient in the use of digital technology. They depended on these when they returned home and contributed to group projects from a distance, thus converting their mode of study to blended learning. This suggested that a technology-enhanced mobile learning solution might enrich their learning experience, therefore the researchers set out to custom-build an initial m-learning prototype, version *m-LR*$_1$, on a Moodle platform, a distributed digital learning environment, suited to m-learning requirements. Even though distributed digital learning environments such as Blackboard and Moodle provide support for anytime- and anywhere-learning, pertinent design issues include:

- The difficulty of integrating course material from different sources;
- The unwieldy size of digital learning systems;
- Maintenance pressures due to continual addition of learning content;
- A need to accommodate scalability and security requirements;
- Network problems; and
- Limitations posed by the delivery of large multimedia and course content (Li et al., 2008).

Guidelines were sought for producing and improving the prototype to optimise the effect of adaptations and to avoid an a*d hoc* design and development strategy. Despite an extensive literature study, no single appropriate design and development methodology was found.

A decision was therefore taken to synthesize a set of design guidelines in parallel with the development of the m-learning environment. Ethical clearance for the research was obtained from the institution where it was conducted and from the university where the primary researcher was enrolled for postgraduate studies.

3 RESEARCH DESIGN

The research paradigm used to generate *m-LR*, was design-based research. 'Design science' originated from the Nobel prize winner, Herbert Simon (Simon, 1981). It led in turn to 'design research', which investigates artificial phenomena and solves complex problems by creating and evaluating man-made products.

In the discipline of Information Systems, research of this nature is termed 'design science research' (DSR) (March and Smith, 1995, Peffers et al., 2007), and in the educational technology milieu, is called 'design-based research' (DBR) (Barab and Squire, 2004, Amiel and Reeves, 2008, Anderson and Shattuck, 2012). DBR is appropriate for pragmatic contextual research in complex domains, and is implemented by iterative cycles of empirical studies. It has dual outcomes in the form of (i) useful authentic products and (ii) theoretical contributions that are transferable to other environments. In this research, the practical outcome was *m-LR* and the theoretical outcome was the set of design guidelines, which are the contribution addressed by this paper.

3.1 Research Question

The following research question was thus posed:

What are appropriate guidelines to use for the design and development of m-learning environments?

The process of answering the question is shown in Figure 1, which depicts the iterative development and evaluation processes of *m-LR* versions: *m-LR*$_1$, *m-LR*$_2$, *m-LR*$_3$, *m-LR*$_4$, and a future final one, *m-LR*$_F$.

This research reflects on these four versions and four iterative studies: Evaluation Study 1, Evaluation Study 2, Evaluation Study 3 and Evaluation Study 4.

3.2 Research Methods

Evaluations and Participants

The research was conducted over two and a half years and entailed evaluations by two different methods amongst two kinds of participants.

First, heuristic evaluations (HE's) were undertaken, in which between three and five

experienced evaluators, so-called 'experts', study a system to identify problems and strengths (Nielsen and Molich, 1990, Nielsen, 1992). Different heuristic evaluators were hand-picked for each of the four studies. All of them were experts in HCI or in digital education or both, so-called 'double experts'. The numbers of heuristic evaluators in the studies were in line with Nielsen's recommendations.

Second, questionnaire surveys were conducted amongst end-users, i.e. using students as evaluators. In the first two evaluation studies, samples of experienced software engineering students were purposively selected to participate, while in the third and fourth studies, entire cohorts were used, i.e. the participants were a population, not a sample.

Furthermore, Evaluation Studies 1 to 3 were conducted on a suburban campus of the university, while Evaluation Study 4 was done on two different campuses of the institution – the suburban one, as well as a campus in an urban area, which was less affluent. This enriched the findings by administering questionnaires to two varying cohorts.

The use of these research methods aimed to achieve method triangulation (two different methods) and data triangulation (across two different campuses). The evaluations are described in detail in Section 5.1.

Evaluation Procedure and Tasks

The iterative approach provided sequential evaluations of the usability and user experience of four different versions of the m-learning environment.

Prior to conducting the evaluations, participants – both expert evaluators and students – completed a defined series of software engineering activities via mobile devices. This familiarised them holistically with the features of *m-LR*, enabling them to effectively evaluate versions of the *m-LR* platform. These activities included: secure login; exploration of specific software engineering course content; a brief review of a lesson, completion of a quiz associated with the lesson; entry of a blog comment; contribution to a forum discussion; a search for particular terms in a glossary; participation in a software engineering chat session; a contribution to a wiki topic; and the viewing of online media. This comprehensive exposure was crucial in helping them contribute meaningfully to the development of new guidelines. The resulting practical guidelines, which reflect findings of the evaluation processes, are presented in Section 6.

Research Instruments

The questionnaires were not adaptations of a standard instrument. Instead the evaluation criteria were custom-developed, based on five categories, namely: general interface criteria; pedagogical aspects; website specific criteria; factors specific to m-learning; and user experience (UX) criteria. A separate publication is in progress, focusing on the generation of these criteria.

Constructs in the questionnaires were based on these categories. There were evaluation statements using a 5-point Likert scale, as well as open-ended items for qualitative responses. The HE's by experts and questionnaire surveys amongst end-users thus provided both quantitative and qualitative data. The questionnaires and evaluation criteria are not included in an appendix, because they are too long.

The quantitative data analysis and the qualitative thematic analysis of free text identified usability and UX problems as well as highlighting positive factors. This led to a set of practical guidelines, specific to the design of m-learning environments.

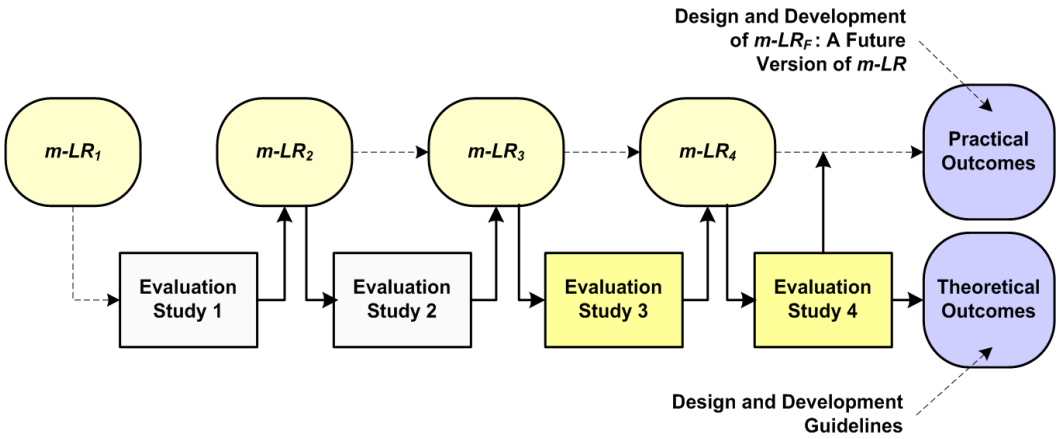

Figure 1: Development of *m-LR* through four versions and four evaluation studies.

3.3 Derivation of Design Guidelines

As previously mentioned, the guidelines emerged from two types of sources. Firstly, existing guidelines were garnered from pertinent literature and synthesized into an initial framework (Section 4), presented in Table 1, i.e. the literature served as secondary data. Secondly, empirical research was undertaken (Section 5) by evaluating versions of *m-LR* as described in Section 3.1 and illustrated in Figure 1. The findings of these evaluations (Section 6) were used as primary data to generate Table 3, which extends and completes the framework.

4 INITIAL GUIDELINES EMERGING FROM THE LITERATURE

Literature sources address various challenges within m-learning domains, including the issue of appropriate design guidelines for m-learning applications. The literature study underlying this study was comprehensive, being both broad and deep.

The work of many researchers contributed to the formulation of the initial collection of guidelines. Space constraints preclude detailed discussion of all the sources consulted, but we specifically mention contributions from certain acknowledged researchers such as:

- Botha, van Greunen and Herselman (2010): *mobile learning interactions viewed from an HCI standpoint*;
- Ebner (2009): *inclusion of Web 2.0 features such as microblogging in mobile learning*;
- Oinas-Kukkonen and Kurkela (2003): *developing successful mobile applications*; and
- Sharp, Rogers, and Preece (2007): *a focus on interaction design*.

The overall literature review resulted in the structured synthesis of an initial set of design and development guidelines, which are presented in Table 1. This table plays an important role in this paper, in that it is the first version of the framework of design guidelines, namely the contribution that emerged from theory. The initial framework comprises eight categories of guidelines.

Within each category, key terms are italicised to emphasise the contributions made by various authors. The contributing authors are cited in alignment in the third column.

Table 1: Design guidelines for m-learning environments – emerging from the literature.

	Design and Development Guidelines	Literature Sources
1 Strategy	▪ Provide *interactivity* via UCD	Göker and Myrhaug (2008)
	▪ Improve the environment by implementing *iterative design*	
	▪ *Involve experts* in contributing to the design	Bri, Garcia, Coll and Lloret (2009)
2 Mobile Specifications	▪ Provide *accessible information* to students whilst they are moving to and from locations, around campus, in the classroom, and between the outside world and the university	Oinas-Kukkonen and Kurkela (2003), Sharma and Kitchens (2004)
	▪ Focus more on *content and m-learning* than on technology	Landers (2002), Pinkwart, Hoppe, Milrad and Perez (2003)
	▪ *Link tasks* to course content	Parsons, Ryu and Cranshaw (2006)
	▪ Support *social networking* and learning, seamlessly	Landers (2002), Parsons, Ryu and Cranshaw (2006), Sharma and Kitchens (2004)
	▪ Include *mobile specifications* with accessibility via all devices	Low and O'Connell (2006)
	▪ Aim for compatibility with a *wide range of media*	Landers (2002), Parsons et al.(2006)
	▪ Incorporate *security* and *privacy* features	Naismith, Lonsdale, Vavoula and Sharples (2004), Pinkwart et al. (2003)
3 User-centricity	▪ Involve end users in guiding the *design of the interface*,	Sharp, Rogers, and Preece (2007)
	▪ Consider *users' understanding* of terminology and navigation	Oinas-Kukkonen and Kurkela (2003)
	▪ Incorporate *usefulness* from a user's perspective	
	▪ Allow *customisation* and *adaptability* for each user's preferences, needs and abilities	
	▪ Include features that enhance *motivation*	Botha, van Greunen and Herselman (2010)

Table 1: Design guidelines for m-learning environments – emerging from the literature (Cont.).

	Design and Development Guidelines	Literature Sources
4 Ease of Use	▪ Focus on *simplicity* and *flexibility*	Oinas-Kukkonen and Kurkela (2003), Sharma and Kitchens (2004)
	▪ Aim for easy *assimilation* on the part of the student	Bri et al. (2009)
	▪ Facilitate *availability* of important information	
	▪ Present only the *essential* and consistent *information*	Low and O'Connell (2006)
	▪ Make provision for *evaluation* of usability	
	▪ Implement fluent *navigation*	
5 Content	▪ Include self-contained '*chunks*' of educational material;	Low and O'Connell (2006), Sharma and Kitchens (2004)
	▪ Provide content in *accessible* and *compact formats*, presented in multiple ways	
	▪ Provide facilities that accommodate *communication* and *collaboration* within learning	Bri et al.(2009)
	▪ *Ground the content* in teaching and learning	Botha, van Greunen and Herselman (2010), Bri et al.(2009), Cheung (2009)
6 Context	▪ Take cognizance of *mobility levels*, usage mode, time and place of learning, budget, and network connectivity factors;	Botha et al. (2010), Oinas-Kukkonen and Kurkela (2003)
	▪ Plan for *in-situ learning* associated with new, individual and team skills with social interaction;	Parsons et al. (2006)
	▪ Incorporate *a selection of screen and keyboard/touch options*, operating systems, device types, network configurations, and student characteristics.	Botha et al. (2010)
7 VLEs	▪ Ensure that the environment reflects academic vision and offers relevant *curriculum content*, providing training and support for staff and students	Cheung (2009)
	▪ Resolve *copyright* and *intellectual property* issues	Levy (2003)
	▪ Rapidly provide value in a natural way via *mobile services*	Bri et al. (2009), Oinas-Kukkonen and Kurkela (2003)
	▪ Consider that *digital technology* has changed students' views of writing in the "old-fashioned" way. Current strategies differ from "pencil and paper" lessons	Lai, Yang, Ho and Chant (2007), Pinkwart et al. (2003)
	▪ Offer *uniform access* to a variety of information sources, e.g. websites, glossaries, reading material, relevant YouTube videos, other student opinions	Bri et al. (2009), Pinkwart et al. (2003)
8 Web 2.0 Tools	▪ *Extend* the student's *classroom* experience	Ebner (2009)
	▪ Include *Web 2.0 features* e.g. podcasts, blogs, microblogs, wikis, and social networking sites (SNSs)	Ebner (2009), Ebner and Schiefner (2008), Lockyer and Patterson (2008), Minocha and Thomas (2007), Safran (2008)
	▪ Emphasize the *planning* required for implementing social networking applications within an online educational program	Lockyer and Patterson (2008)
	▪ Facilitate *communication* and *collaboration* via synchronous technologies (chat rooms) and asynchronous interactivity (forums and e-mail)	Jones (2010), MacCallum and Kinshuk (2008), Minocha and Thomas (2007)

5 EMPIRICAL STUDIES

5.1 Evaluation Studies

The guidelines in Table 1 were used in generating four versions of a mobile learning environment: *m-LR*$_1$, *m-LR*$_2$, *m-LR*$_3$, and *m-LR*$_4$, with a view to a future version, *m-LR*$_F$. These versions can thus be considered applications of the guidelines.

Figure 1 in Section 3 showed the four sequential evaluation studies – Evaluation Studies 1, 2, 3, and 4 – that were respectively implemented on the four successive versions of *m-LR*. Participants in these studies were experts who served as heuristic evaluators and students who completed questionnaires. A brief description is now provided of each study, explaining its context and purpose. However, the findings reported in the next section, Section 6, focus exclusively on findings of the final two studies, Evaluation Study 3 and Evaluation

Study 4, which impacted strongly on the evolution of further guidelines.

Evaluation Study 1: As the study in 2010 that evaluated the usability of the first version of *m-LR*, a Moodle customised in an *ad hoc* manner, Study 1 uncovered usability challenges. Its purpose was to evaluate $m\text{-}LR_1$ running on the researcher's own Blackberry 9700 smartphone device, and to produce both quantitative and qualitative findings. Participants were three experts for an HE and ten students in a questionnaire survey, all drawn from a single campus. Subsequent changes to $m\text{-}LR_1$, included redesign of:

- Course content, providing information in chunks for viewing on mobile devices;
- Log-in features;
- Quantity of information per page;
- Formats of downloadable media and subject matter;
- Contents of the glossary.

Adjustments to the $m\text{-}LR_1$ version led to $m\text{-}LR_2$.

Evaluation Study 2: This small-scale evaluation of $m\text{-}LR_2$ in 2011, was a pilot study for the major Evaluation Study 3. Study 2 was implemented on a single campus with only four students (questionnaires) and one double expert (HE), As in Study 1, each used the same Blackberry 9700 smartphone for their evaluation. Study 2 primarily served to try out the research procedures, tasks, instruments and evaluation processes, but did lead to improvements in the:

- Privilege levels of the blog;
- Options offered by the glossary;
- Look-and-feel facets such as font styles, size and colour;
- Open-ended requirements for the quiz.

The refinements resulted in $m\text{-}LR_3$.

Evaluation Study 3: This study in 2011, was the largest up to that point. Five HE experts, with their own devices, and seventeen students from one campus, using Blackberry 9700 smartphones, evaluated $m\text{-}LR_3$ for usability and UX. Adjustments and extensions resulted in the next version of *m-LR*, namely $m\text{-}LR_4$. Feedback called for new functionalities or changes to:

- The help functionality;
- Built-in documentation;
- Links and navigation mechanisms;
- 'Breadcrumbs', and thus navigability;
- Compatibility of media such as video;
- The range of device types, which needed to be broadened;
- File size, aiming to reduce buffering issues;
- Layout of goals and objectives of learning units;
- Offline reading capability, required by users;
- Access to social networking applications

A growing need for storage and collaborative services via cloud technology such as Dropbox and Google Drive became apparent. It was suggested that the addition of these services would increase the appeal of *m-LR* whilst facilitating communication between teams of students doing collaborative projects.

Evaluation Study 4: This final, and largest, 2012 study used $m\text{-}LR_4$ as input. Its feedback engendered guidelines that, if applied, would produce a future improved version, $m\text{-}LR_F$. Five experts and 33 students from two different campuses completed evaluations, proposing modifications to the:

- Application design;
- Specifications, as participants required compatibility with several device types;
- The user experience, which could be enhanced by improving ease of use.

Despite the high number of participating evaluators, only a few problems were reported, indicating the success of the iterative evaluation and redesign process.

5.2 Aspects of *m-LR*

Figures 2 illustrates learning aspects of *m-LR* such as: topics and lessons; activities – chats, forums, glossaries, online self-assessment quizzes, resources

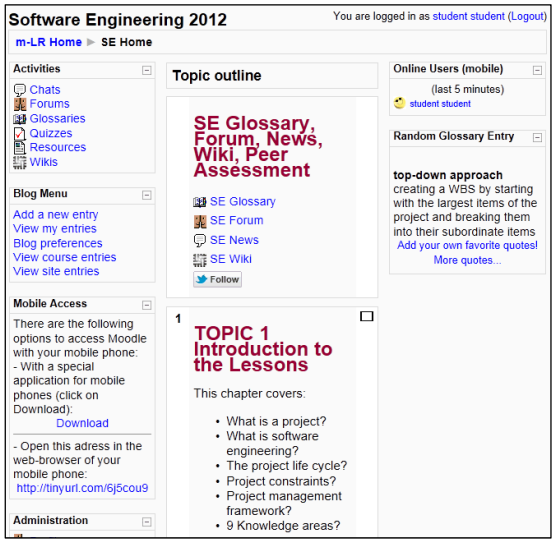

Figure 2: Homepage for the 2012 Software Engineering course.

(content and media), and wikis. These features provided team members with collaborative opportunities, extending the classroom experience to

incorporate Internet links to course related websites.

Figure 3 presents a view of a student response to a self-assessment quiz item, demonstrating immediate feedback.

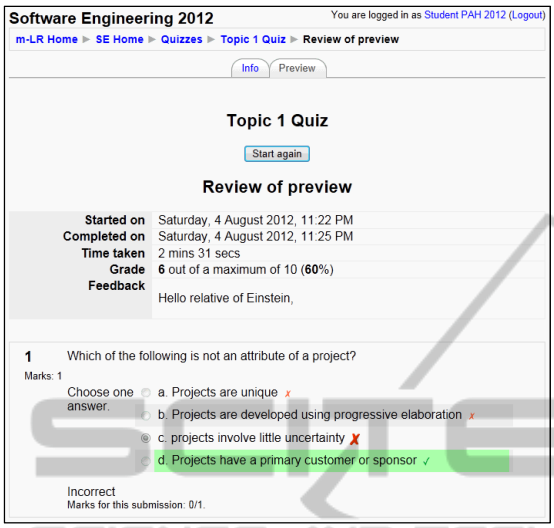

Figure 3: Self-assessment quiz with digital feedback.

Figure 4: Key software engineering terms stored conveniently in a 'mobile' glossary – easily accessible via mobile device.

A search for term 'project manager' in a software engineering glossary is shown in Figure 4, where 'Add a new entry' indicates how students participate in formulating the glossary.

5.3 Positive and Negative Feedback

Table 2 moves the overview away from the four studies in Figure 1 and focuses on Evaluation Studies 3 and 4, indicating the positive progress made as *m-LR* evolved.

Table 2: Positive and negative feedback leading to the synthesis of new guidelines.

	Positives	Negatives	New guidelines
Evaluation Study 3 (n=22)	74	87	25
Evaluation Study 4 (n=38)	132	90	18

In Evaluation Study 3, the number of negative comments (87) exceeded the positives (74). In Evaluation Study 4, there were more positive comments (132) than negatives (90). This occurrence, despite the fact that there were almost twice as many evaluators in Study 4, suggests that the adjustments made after Study 3 were effective.

In particular, qualitative analysis showed that the number of problems identified in the *Ease of Use* category, decreased from 33% of the negative feedback in Evaluation Study 3 to 26% of the negative feedback in Evaluation Study 4.

Furthermore, two additional categories are singled out, namely: *Strategy* and *Mobile Specifications*. For Evaluation Study 3 and Evaluation Study 4, the *Strategy* category contributed 14% and 22% respectively to the total number of problems. Problems reported in the Mobile Specifications theme increased from 7% (Evaluation Study 3) to 22% (Evaluation Study 4). The increase in reported problems in these two categories can be ascribed to three factors: a dynamically changing digital environment; greater technical acuity of the participants; and a more techno-savvy attitude to mobile technology design concepts.

As stated, the primary purpose of this paper is not to serve as an evaluation study but to use evaluation findings to derive generic design guidelines. *m-LR* provided a platform requiring evaluation, while the findings of the evaluations led, in turn, new guidelines that are presented in the next section.

6 EVOLUTION OF NEW GUIDELINES

An overview of four iterative evaluations was presented in Figure 1. Positive factors that emerged from these evaluations affirm the original guidelines, while yet other positive aspects, spontaneously articulated by participants, suggest implicit strengths that should be made explicit by new guidelines. Similarly, problems that emanated from the evaluations, suggest further required guidelines. If the resulting new guidelines, particularly those that come from qualitative findings, are consolidated into a framework along with the original eight synthesised from the literature, the result would be sixteen themes of guidelines.

These new aspects are now addressed in detail, as emergence of the original set of guidelines is reviewed, and the evolution of the additional sets, particularly from Studies 3 and 4, is set out.

6.1 Emergence of the Original Theoretical Guidelines

Table 1, which presented an initial framework of theoretical guidelines for the design and development of m-learning environments, comprised eight themes, namely: 1 *Strategy*; 2 *Mobile specifications*; 3 *User-centricity;* 4 *Ease of use*; 5 *Content*; 6 *Context;* 7 *Virtual learning* eight themes,

Table 3: Guidelines emerging from findings of Evaluation Studies 3 and 4.

Theme	Guidelines	Theme	Guidelines
9 Devices	▪ Use technology to enhance, rather than hinder, *learning experiences* ▪ Ensure *compatibility* with a range of devices ▪ Support *easy access* ▪ Consider the limitations of *input mechanisms* ▪ Consider *screen size* when incorporating features	13 Interactivity	▪ Enable 'on-the-fly' *communication* with classmates ▪ Support *visibility* of other online students ▪ Facilitate *collaboration* on group projects ▪ Allow *sharing* of information ▪ Include alternative forms of interactivity, designed to suit *user preferences*
10 Assessment	▪ Provide opportunities for *self-assessment* ▪ Provide *lecturer support* for the correction of errors in such self-assessment ▪ Include *multiple choice questions* ▪ Consider the possibility of *short-answer questions* ▪ Locate *quiz* options with associated course content ▪ Incorporate *rapid test feedback* to support students doing revision while on the move ▪ Provide links to online material to facilitate preparation of *coursework* assignments ▪ Align assessment exercises with *examination preparation*	14Visual Factors	▪ Provide a simple and appealing *layout* ▪ Design a *look and feel* that is user-centric ▪ Implement suitable *colour schemes* ▪ Make effective use of *white space* ▪ Where possible and appropriate, enhance the experience with suitable *graphic content*, *headings* and *font choices* ▪ Strengthen the visual experience, possibly including some *animation* ▪ When constructing a site, design for *logical* page *order* ▪ Create a *professional learning environment*
11 Efficiency	▪ Ensure *speedy loading* of site and pages ▪ Provide *immediate responses* for users accessing features of the application ▪ Achieve *fast navigation* between links ▪ Aim for *rapid content delivery*	15 Innovation	▪ Offer the user an environment which is perceived as *new and novel* ▪ Facilitate off-campus *mobile learning* ▪ Deliver course content in a *creative ~~and novel~~ digital manner*
12 Navigability	▪ Facilitate *easy and intuitive* navigation ▪ Ensure visibility of *links* ▪ Support *browsing* – anytime and anywhere	16 Satisfaction	▪ Create a match to user's view of *suitability* ▪ Embrace the user's sense of *excitement* ▪ Provide *consistency* with familiar applications and interfaces to avoid user frustration ▪ Focus on easy *readability* ▪ Establish an *easy-to-follow flow*, starting with an introduction and progressing logically to module sections ▪ Build a learning environment which offers *enjoyable user experiences* ▪ Ensure that *functionalities* operate correctly

namely: 1 *Strategy*; 2 *Mobile specifications*; 3 *User-centricity;* 4 *Ease of use*; 5 *Content*; 6 *Context;* 7 *Virtual learning environments*; and 8 *Web 2.0 tools*. These initial themes and guidelines were used in the development of the first version, *m-LR*$_1$, and also contributed, along with findings of the series of evaluations, to adjustments and improvements of subsequent versions of the mobile learning environment.

6.2 Guidelines from Evaluation Study 3

The evaluation of usability and UX of *m-LR*$_3$ in Study 3 by 22 participants produced positive and negative feedback, resulting in practical principles and guidelines that led to the development of version *m-LR*$_4$.

The positive results of the evaluation served two purposes. Firstly, they affirmed the utility of the initial framework of theoretical guidelines and, secondly, the positive response that emerged for aspects of *m-LR* that had been designed intuitively, showed the need to concretise and formalise certain implicit guidelines. Negative feedback and concerns indicated inadequacies in the design and highlighted the need for further guidelines. Thematic analysis of qualitative data, positive and negative, confirmed existing guidelines, while other evaluation findings were converted to five new categories of guidelines, namely: 9 *Devices*; 10 *Assessment*; 11 *Efficiency*; 12 *Navigability*; and 13 *Interactivity*, which are elaborated in Table 3.

6.3 Guidelines from Evaluation Study 4

The evaluation of *m-LR*$_4$ was a major study, with 38 participants, namely five experts and 33 students from cohorts on two campuses. Due to the improvements implemented to *m-LR*$_3$ after Study 3, the number of negative issues decreased, while positive feedback increased, as shown in Table 2. Moreover, negativity previously indicated by some initial themes namely: *Mobile Specifications*; *User-centricity*; and *Ease of Use* declined, probably due to the strength of the version *m-LR*$_4$, that had resulted from Evaluation Study 3.

Only three new categories of guidelines resulted from the findings of Evaluation Study 4, namely; 14 *Visual Factors*; 15 *Innovation*; and 16 *Satisfaction*.

Finally, suggestions emerged from Study 4 for improvements to *m-LR*$_4$ that would result in a future version *m-LR*$_F$.

6.4 Evolution of Guidelines and Extension to the Framework

The new categories of themes and design guidelines, introduced in Sections 6.2 and 6.3, are listed in Table 3. The original themes that re-emerged are not included, since they are already in Table 1. This table, which is the contribution that emerged from practical empirical research, continues the evolution of the framework of design guidelines.

6.5 Final Set of Guidelines

An integration of Tables 1 and 3 would constitute the final and comprehensive set of guidelines in sixteen categories for the design and development of mobile learning environments. Such a merged table of final guidelines, though valuable, would be repetitive and, for the sake of space, is explicitly omitted from this paper.

7 CONCLUSIONS

This study addressed the following research question:

> *Which guidelines should be included in a framework for the design and development of m-learning environments?*

An aggregation of the themes and guidelines in Tables 1 and 3, where theoretical sources from the literature and practical empirical findings, respectively, contributed to the synthesis of a final set of guidelines, demonstrate that the research question has been answered.

The goalposts moved over the duration of the studies, and the target audiences became more 'techno-savvy'! Although students were increasingly satisfied with the successive versions, the later feedback began to address sophisticated *refinements*. It appeared that the users were expecting similar functionality and features in a basic system designed by an academic, to what is encountered in commercial apps!

Rapid methods of evaluation, synthesis, adaptation and evolution will depend on a comprehensive and malleable set of design and development guidelines for *effectiveness*.

Moreover, students who are mobile and on-the-move expect fast and dynamic virtual learning environments which demonstrate *flexibility*. The evolution of the integrated multi-facetted set of guidelines is in line with these requirements.

The perspectives of a variety of evaluators (content and application developers, students, lecturers, administrators, e-learning experts) contributed to participative evaluation findings that led to iterations of redevelopment of a successful mobile learning application. The empirical findings of this study show that the varying expertise and idiosyncrasies of participants provided a broad spectrum of issues and positive contributions. A *design and development strategy* should accommodate the viewpoints from each of these user groups.

Due to the dynamic and rapidly evolving nature of mobile technology, the task of formulating a set of guidelines is unlikely to be complete. Hence the framework synthesized in Tables 1 and 3, begs *augmentation* over timelines and application within other tertiary education contexts. Moreover, it is likely that different device types will be brought to the classroom.

The application of the guidelines will evolve further as capabilities and affordances of new technologies are accommodated. Furthermore, it is acknowledged that the current framework is lengthy due to its comprehensive nature. Synthesis of the categories into a tighter framework could facilitate *practical application*. Finally in transferring the application of the guidelines to other mobile environments, they can be reduced and customized to the context and content.

Whereas literature sources may provide an initial foundational set of guidelines based on theoretical underpinnings, this study demonstrates that empirical findings based on participative *user-centric designs* can extend and enrich a framework of design guidelines.

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