A Qualitative Review of Empirical Mobile Usability Studies

Constantinos K. Coursaris
Michigan State University
coursari@msu.edu

Dan J. Kim
Michigan State University
dankim@msu.edu

ABSTRACT

The turn of this century marked an increased focus on mobile usability studies for research in the field of Human Computer Interaction. Such studies offer practitioners the needed insight to deliver usable mobile products and services adopted by consumers at increasing rates contributing to a $20 billion industry. Scholars also benefit by identifying new questions that need to be addressed, thereby enriching our understanding of this dynamic domain within HCI. A challenge for both of these groups exists in that many scholars define and operationalize usability differently.

This paper presents a roadmap for future usability research that consists of two parts. First, a framework is adapted for the taxonomy of empirical mobile usability studies. Second, results of the qualitative review of 45 empirical mobile usability studies include: i) the contextual factors studied; ii) the core and peripheral usability dimensions measured; and iii) key findings. Expected contributions of the completed research are also outlined.

Keywords

Mobile, usability, efficiency, effectiveness, satisfaction, mobile device, wireless, context, meta-analysis.

INTRODUCTION

Mobile devices are becoming increasingly popular, having already reached over one billion mobile subscribers. A recent forecast by the UMTS forum (2005) estimates that the global number of subscribers will be between 1.7 to 2.6 billion for mobile voice and 600 to 800 million for mobile data. As consumers' technology fears and adoption costs are reduced, mobile devices are approaching "mainstream" status around the developed world. Mobile devices propose increasing value to consumers found in "anytime, anywhere, and customized" connectivity, communication, and data services.

Although progress has been made in terms of technological innovations, there are obvious limitations and challenges for mobile device interfaces due to the characteristics of mobile devices (i.e., the size of small screens, low resolutions of the displays, non-traditional input methods, and navigational difficulties) (Nah Siau and Sheng 2005). Therefore, usability is a more important issue for mobile technology than for other areas, since many mobile applications remain difficult to use, lack flexibility and robustness.

Research Motivation & Objectives

Usability has been the focus of discussion (Venkatesh Ramesh and Massey 2003) and described by varying definitions (Nielsen 1993; Shackel 1991) in both academia and industry for a long time. Many of these definitions propose that the central theme of usability is to denote the ease with which people can employ a particular technology artifact in order to achieve a particular goal[1]. The turn of this century marked an increased focus on mobile usability studies for research in the field of Human Computer Interaction. Although a considerable volume of research on general usability exists, due to the novelty of mobile technology relatively few studies have been conducted on mobile usability. Even worse, only 41 percent of mobile usability papers are empirical in nature (Kjeldskov and Graham 2003). Moreover, there is no meta- analytical view on the usability dimensions considered in such mobile studies. Thus, this research aims to fill this gap and in doing so will also provide a roadmap for future mobile usability studies that will be of value to this relatively young research area. Specifically,

[1] Wikipedia, 2005. *Answers.com* 18 Feb. 2006. http://www.answers.com/topic/usability

this study addresses the following research question: *What are the key formation and evaluation dimensions of usability in mobile technology usability studies?*

To this end, this paper describes the qualitative review performed of 45 empirical mobile usability studies. First, the selection of the taxonomy used for the coding in this review is discussed. Then, the procedure followed for this qualitative review is described. Based on the literature review, a qualitative review framework for empirical mobile usability studies is presented next. The results emerging from this review regarding such studies are then presented, which include: i) the contextual factors studied; ii) the core dimensions defined and measured; iii) the peripheral dimensions explored; and iv) key findings. Finally, the paper discusses the expected contributions of the completed research.

Overview of Usability

Usability studies have their roots as early as the 1970's in the work of "software psychology". Over time, the focus of this body of research has shifted and most recently centred on the relevance of context of use for usability. The concept of *context of use* as it relates to usability emerged out of the work of several scholars (Bevan and Macleod 1994; Shami Leshed and Klein 2005; Thomas and Macredie 2002), who attempted to identify additional variables that may impact usability. Varied situational contexts will result in emerging usability factors, making traditional approaches to usability evaluation inappropriate. The significance of this area emerges from its importance in yielding a reasonable analysis during a usability study (Maguire 2001; Thimbleby Cairns and Jones 2001). Furthermore, during the evolution of HCI described earlier, the conceptualization of usability has varied extensively. The broad set of definitions and measurement models of usability complicate the generalizability of past studies at the level of the latent usability variable. Therefore, a usability study may be of limited value if it were not to be based on a standard definition and operationalization of usability. The next section looks at the key formative factors of usability explored in contextual usability studies.

Framework for Contextual Usability

The work of several scholars (Bevan et al. 1994; Shami et al. 2005; Thomas et al. 2002) that attempted to identify additional variables that may impact usability and subsequently adoption, led to the conceptual emergence of *context of use* (herein referred to as context) as it relates to usability, also referred to as contextual usability. Several frameworks encapsulating context have been proposed (Han Yun Kwahk and Hong 2001; Lee and Benbasat 2003; Sarker and Wells 2003; Tarasewich 2003; Yuan and Zheng 2005). While there may be other usability frameworks that attempt to capture the essence of context, the models cited here provide a representative set of work in this area. From these we adapted the framework proposed by Han et al. (2001), because it offers considerable detail for each dimension they identified. In their work they propose four contextual dimensions (i.e. user, activity, environment, product) as the principle components of any human-computer interaction, a perspective that has long been accepted (Shackel 1991). Two minor modifications are made here in terms of nomenclature. First, "Technology" replaces "Product", as this term helps conceive the system that a user may interact with as a greater set of components, instead of simply the device or application itself. One example of this is found in the case of mobile usability where the inclusion of the wireless network is likely in addition to the mobile device (i.e. the *product*) when studying usability of a mobile product or service. Second, "Task" replaces "Activity", as the former term appears more commonly in usability literature when describing the nature of users' interaction with the technology.

These four variables (i.e. user, task, environment, technology) will be used for the presentation of the review of previous empirical research that relates to the usability assessment of mobile applications and/or mobile devices. The benefit of using these variables for the literature review is found in both the structure it provides for the discussion to follow, as well as to help highlight any areas that are lacking investigation.

QUALITATIVE REVIEW

Procedure

This qualitative review began with the search for empirical mobile usability studies literature. To this end, we used multiple databases to minimize the chance of omitting relevant studies. We continued with cross-referencing the references of the retrieved studies. Hand searching of appropriate journals in this research included journals ranked among the top 10 in terms of perceived quality, as well as journals deemed relevant to the field of usability by the authors. Specific criteria were set for

the selection of articles sought in this literature review: i) a mobile technology was studied; ii) the study was empirical in nature; iii) the time frame for included studies was from 2000 onward. A conscious decision was made to not limit the reviewed literature to peer-reviewed journal articles, as it would significantly reduce the reviewed articles, given the relative infancy of the mobile usability field. The above procedure resulted in the identification of 45 empirical mobile usability studies.

Qualitative Review Framework of Empirical Mobile Usability Studies

On the basis of the discussion on contextual usability, along with the findings from the literature review of usability measurement, we present a framework that offers a qualitative review of empirical mobile usability studies. The framework is depicted in Figure 1 and contains three elements. First, the outer circle shows the contextual factors described earlier as impacting usability. Second, the inner circle shows the usability dimensions found to have been measured in the reviewed empirical mobile usability literature. Third, the box on the right shows a list of consequences being impacted by usability and studied in the reviewed literature.

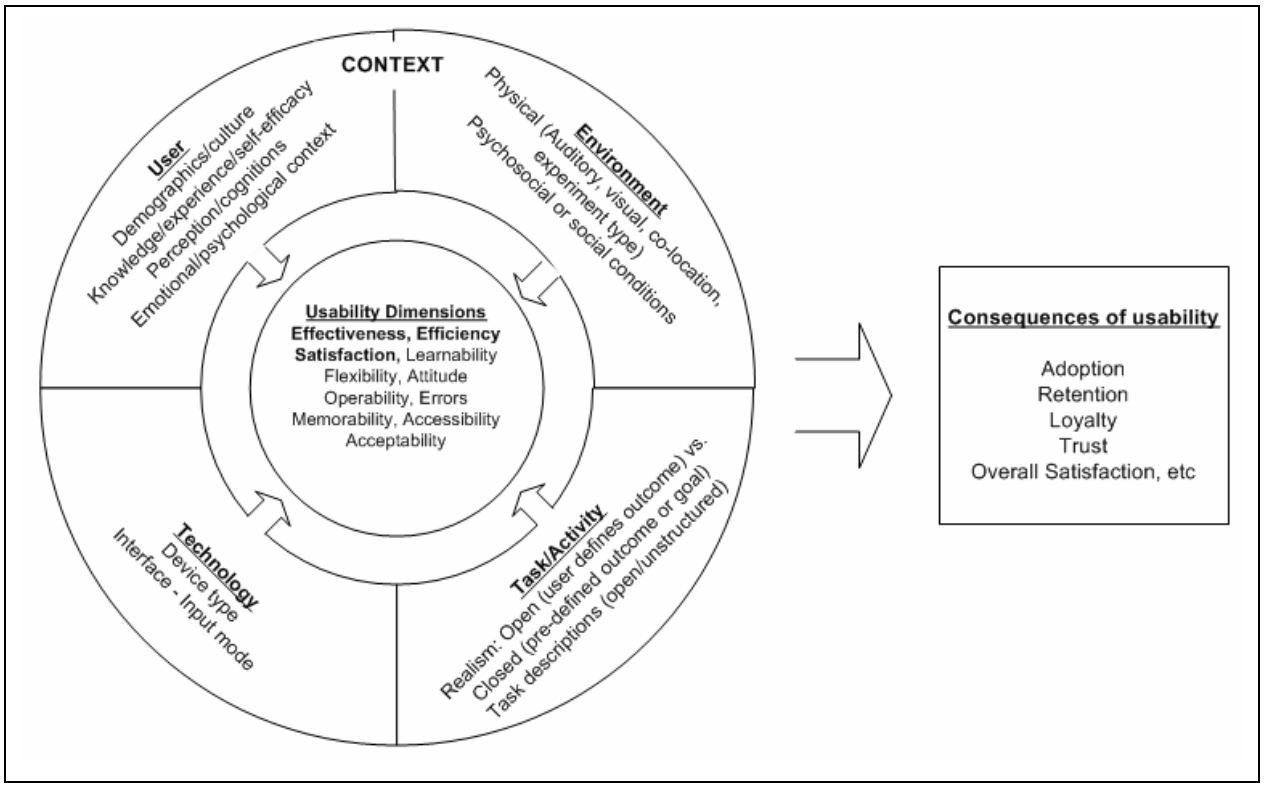

Figure 1. The Qualitative Review Framework of Empirical Mobile Usability Studies

While the use of an adapted perspective for context assisted in the classification of this qualitative review, it should be revisited. A next step for this research will be to define those factors based on the contextual dimensions studied in the reviewed literature. It would be of interest to compare that revised set of contextual factors found in empirical mobile usability studies with those of the general usability studies. Next, we turn our attention to the measured usability dimensions of the reviewed literature.

Usability Measurement Dimensions

The literature review of empirical research on mobile usability performed appears in Appendix A consisting of two sets of data. First, the cited research is described in terms of the context defined in the study and second, the dimensions measured and the relationships validated. The focus of this study is on the usability dimensions measured in these empirical mobile usability studies. Table 1 presents a summary of these measured dimensions, which include: Effectiveness, Errors, Efficiency, Satisfaction, Attitude, Flexibility, Learnability, Memorability, Operability, Accessibility, and Acceptability.

ORIGINAL LIST OF MEASURES			COLLAPSED LIST OF MEASURES		
MEASURES	**COUNT**	**%**	**MEASURES**	**COUNT**	**%**
ERRORS	23	51	EFFECTIVENESS	28	62
EFFICIENCY	15	33	EFFICIENCY	15	33
EFFECTIVENESS	5	11	SATISFACTION	9	20
ATTITUDE	5	11	LEARNABILITY	5	11
LEARNABILITY	5	11	ACCESSIBILITY	3	7
SATISFACTION	4	9	OPERABILITY	2	4
ACCESSIBILITY	3	7	MEMORABILITY	1	2
OPERABILITY	2	4	ACCEPTABILITY	1	2
MEMORABILITY	1	2	FLEXIBILITY	1	2
ACCEPTABILITY	1	2			
FLEXIBILITY	1	2			

Table 1. Frequency of usability measures used in the reviewed empirical mobile usability studies

From Table 1 it appears that the constructs of errors, efficiency, effectiveness, satisfaction, attitude, and learnability are most commonly measured in empirical mobile usability studies. All of these measures were defined in the work of Han et al. (2001) on the classification of performance and image/impression dimensions with slight variations. The measure of *errors* was defined by Nielsen (1993) as the "number of errors, ability to recover from errors, and existence of serious errors." Han et al. (2001) address *errors* through two measures: i) e*rror prevention* (i.e. "ability to prevent the user from making mistakes and errors"), and ii) *effectiveness* (i.e. "accuracy and completeness with which specified users achieved specified goals"). With respect to the reviewed literature, mobile usability studies measured the error rate, as opposed the error prevention, associated with the system. Hence, the *errors* measure found in this literature review may be collapsed with *effectiveness* (effectiveness offering a broader definition and operationalization). Similarly, attitude is defined as the "level of user satisfaction with the system" (Shackel 1984). Han et al. (2001) define *satisfaction* as "the degree to which a product is giving contentment or making the user satisfied." Hence, attitude (as defined in these usability studies) may be collapsed in the single measure of satisfaction. Upon review of the measures' relative appearance in the reviewed literature the core constructs for the measurement of usability appear to be:

- Efficiency: Degree to which the product is enabling the tasks to be performed in a quick, effective and economical manner or is hindering performance
- Effectiveness: Accuracy and completeness with which specified users achieved specified goals in particular environment
- Satisfaction: The degree to which a product is giving contentment or making the user satisfied

These three dimensions also reflect the ISO 9241 standard making a strong case for its use in related future studies. The use of this standard would allow for consistency with other studies in the measurement of efficiency, effectiveness, and satisfaction (Brereton 2005). Either all or at least one of the three constructs have been used in the work of most researchers cited in the literature review. The remaining measures identified in Table 1 reflect the peripheral dimensions measured in empirical mobile usability studies, while key findings are included in the Appendix.

Beyond the benefit of a standard view of usability, an important opportunity for future research arises from the data in Table 1. Accessibility appears to be one of the most underserved research areas. This observation may come as a surprise, given the growing popularity of accessibility research in less conventional (e.g. non-IS, non-peer-reviewed) publication outlets, and the increasing levels of legislative support and community interest. Further exploration of this construct, including its role with the remaining usability dimensions, is warranted.

CONCLUSIONS

This research-in-progress presents the basis of a continuing research, which aims to enhance our understanding of mobile usability considerations and measurement. Expected contributions of this study include the following:

- To our knowledge, this breakthrough meta-analytical research is the first to offer a holistic view of usability dimensions found in empirical mobile usability studies.
- The results of a future gap analysis between general usability and mobile usability studies will offer academics guidance for future research directions.
- The identification of a common measurement metric will support a future quantitative analysis (meta-analysis) of mobile usability studies. In turn, this could offer a unified view of empirical mobile usability studies.
- This study provides insights for practitioners regarding the aspects of the technology that may be considered during a usability evaluation of their mobile products and/or services.

REFERENCES

1. Andon, C. "USABILITY ANALYSIS OF WIRELESS TABLET COMPUTING IN AN ACADEMIC EMERGENCY DEPARTMENT," Oregon Health & Science University, 2004.

2. Bevan, N., and Macleod, M. "Usability measurement in context," *Behavior and Information Technology* (13) 1994, pp 132-145.

3. Bohnenberger, T., Jameson, A., Kruger, A. and Butz, A. "Location-Aware Shopping Assistance: Evaluation of a Decision-Theoretic Approach," Mobile HCI 2002, Springer-Verlag:Berlin, Pisa, Italy, 2002.

4. Brereton, E. "Don't neglect usability in the total cost of ownership," *Communications of the ACM* (47:7) 2005, pp 10-11.

5. Brewster, S. "Overcoming the Lack of Screen Space on Mobile Computers," *Personal and Ubiquitous Computing* (6) 2002, pp 188-205.

6. Brewster, S., and Murray, R. "Presenting Dynamic Information on Mobile Computers," *Personal and Ubiquitous Computing* (4) 2000, pp 209-212.

7. Bruijn, O.D., Spence, R., Chong, M. Y. "RSVP Browser: Web Browsing on Small Screen Devices," *Personal and Ubiquitous Computing* (6:4) 2002, pp 245-252.

8. Buyukkoten, O., Garcia-Molina, H. and Paepcke, A. "Seeing the whole in parts: Text summarization for web browsing on handheld devices," in: *Intl. World Wide Web Conf*, 2001.

9. Chan, S.S., Fang, X. and Brzezinski, J. "Usability for Mobile Commerce across Multiple Form Factors," *Journal of Electronic Commerce Research* (3:3) 2002.

10. Cheverst, K., Davies, N., Mitchell, K., Friday, A. and Efstratiou, C. "Developing a Context-aware Electronic Tourist Guide: Some Issues and Experiences," *In Proceedings of CHI2000*) 2000.

11. Chittaro, L., Dal Cin P. "Evaluating Interface Design Choices on WAP Phones: Navigation and Selection," *Personal and Ubiquitous Computing* (6:4) 2002, pp 237-244.

12. Chittaro, L.a.C., P.D. "Evaluating Interface Design Choices on WAP Phones: Single-choice List Selection and Navigation among Cards," Mobile HCI 2001, Lille, France, 2001.

13. Danesh, A., Inkpen, K., Lau, F., Shu, K. and Booth, K. "Geney: Designing a Collaborative Activity for the Palm Handheld Computer," CHI2001, Seattle, WA, USA, 2001.

14. Duda, S., Schiel, M., and Hess, J.M. "Mobile Usability," in: *Usability - Nutzerfreundliches Web-Design*, Springer-Verlag, Berlin, 2002, pp. 173-199.

15. Fithian, R., Iachello, G., Moghazy, J., Pousman, Z., and Stasko, J. "The design and evaluation of a mobile location-aware handheld event planner," the 5th International Symposium on Human-Computer Interaction with Mobile Devices and Services, Mobile HCI 2003, Udine, Italy, 2003.

16. Goldstein, M., Alsio, G. and Werdenhoff, J. "The Media Equation Does Not Always Apply: People are not Polite Towards Small Computers," *Personal and Ubiquitous Computing* (6) 2002, pp 87-96.

17. Han, S.H., Yun, M.H., Kwahk, J., and Hong, S.W. "Usability of Consumer Electronic Products," *International Journal of Industrial Ergonomics* (28:3-4) 2001, pp 143-151.

18. Hinckley, K., Pierce, J., Sinclair, M. and Horvitz, E. "Sensing Techniques for Mobile Interaction," UIST2000, San Diego, CA, USA, 2000.

19. James, C.L.R., K. M. "Text Input for Mobile Devices: Comparing Model Prediction to Actual Performance," *CHI*), 31 MARCH - 5 APRIL 2001.

20. Jones, M., Buchanan, G. and Thimbleby, H. "Sorting Out Searching on Small Screen Devices," Mobile HCI 2002, Springer-Verlag, Berlin, Pisa, Italy, 2002.

21. Juola, J.a.V., D. "First Time Usability Testing for Bluetooth-Enabled Devices," ITTC-FY2005-TR-35580-02, The University of Kansas.

22. Kaasinen, E. "User needs for location-aware mobile services," *Pers Ubiquit Comput* (7) 2003, pp 70-79.

23. Kaikkonen, A., Kallio, T., Kekäläinen, A., Kankainen, A., Cankar, A. "Usability Testing of Mobile Applications: A Comparison between Laboratory and Field Testing," *Journal of Usability studies* (1:1) 2005, pp 4-16.

24. Kallinen, K. "The Effects of Background Music on Using a Pocket Computer in a Cafeteria: Immersion, Emotional Responses, and Social Richness of Medium," in: *Conference on Human Factors in Computing Systems*, Vienna, Austria, 2004.

25. Khalifa, M.C., S. K. "Adoption of Mobile Commerce: Role of Exposure," *Proceedings of the 35th Hawaii International Conference on System Sciences*) 2002.

26. Kim, H., Kim, J., Lee, Y., Chae, M., and Choi, Y. "An Empirical Study of the Use Contexts and Usability Problems in Mobile Internet," The 35th Hawaii International Conference on System Sciences, 2002.

27. Kjeldskov, J., and Graham, C. "A Review of MobileHCI Research Methods," The 5th International Mobile HCI 2003 conference, Berlin, Springer-Verlag, Udine, Italy, 2003, pp. 317-335.

28. Lee, Y.E., and Benbasat, I. "A framework for the study of customer interface design for mobile commerce," *International Journal of Electronic Commerce* (46:12) 2003, pp 48-52.

29. Lehikoinen, J., and Salminen, I. "An Empirical and Theoretical Evaluation of BinScroll: A Rapid Selection Technique for Alphanumeric Lists," *Personal and Ubiquitous Computing* (6) 2002, pp 141-150.

30. Licoppe, C., and Heurtin, J.P. "Managing One's Availability to Telephone Communication through Mobile Phones: A French Case Study of the Development of Dynamics of Mobile Phone Use," *Personal and Ubiquitous Computing* (5) 2001, pp 99-108.

31. Lindroth, T., Nilsson, S. & Rasmussen, P. "Mobile Usability - Rigour meets relevance when usability goes mobile," IRIS24, Ulvik, Norway, 2001.

32. Ling, R. "We Release Them Little by Little: Maturation and Gender Identity as Seen in the Use of Mobile Telephony," *Personal and Ubiquitous Computing* (5) 2001, pp 123-136.

33. Maguire, M. "Methods to support human-centered design," *International Journal of Human-Computer Interaction* (55) 2001, pp 587-634.

34. Mao, E., Srite, M., Thatcher, J. B. Yaprak, O. "A Research Model for Mobile Phone Service Behaviors: Empirical Validation in the U. S and Turkey," *Journal of Global Information Technology Management* (8:4) 2005, p 7.

35. Nagata, S.F. "Multitasking and Interruptions during Mobile Web Tasks," Human Factors and Ergonomics Society 47th Annual Meeting, 2003.

36. Nah, F.F., Siau, K., and Sheng, H. "The Value of Mobile Applications: A Utility Company Study," *Communications of the ACM* (48:2) 2005, pp 85-90.

37. Nielsen, J. *Usability Engineering* AP Professional, New York, 1993.

38. Pagani, M. "Determinants of adoption of third generation mobile multimedia services," *Journal of Interactive Marketing* (18:3) 2004, p 46.

39. Palen, L., and Salzman, M. "Beyond the Handset: Designing for Wireless Communications Usability," *ACM Transactions on Human Computer Interaction* (9:2) 2002, pp 125-151.

40. Palen, L., Salzman, M. and Youngs, E. "Discovery and integration of Mobile Communications in Everyday Life," *Personal and Ubiquitous Computing* (5) 2001, pp 109-122.

41. Poupyrev, I., Maruyama, S. and Rekimoto, J. "Ambient Touch: Designing Tactile Interfaces for Handheld Devices," UIST2002, Paris, France, 2002.

42. Qiu, M.K., Zhang, K., and Huang, M. "An Empirical Study of Web Interface Design on Small Display Devices," IEEE/WIC/ACM International Conference on Web Intelligence (WI' 04), IEEE Computer Society, 2004, pp. 29-35.

43. Rodden, K., Milic-Frayling, N., Sommerer, R., & Blackwell, A. "Effective Web Searching on Mobile Devices," Proceedings of the 17th Annual Conference on Human-Computer Interaction, Bath, United Kingdom, 2003, pp. 281-296.

44. Ross, D.A., and Blasch, B.B. "Development of a wearable Computer Orientation System," *Personal and Ubiquitous Computing* (6) 2002, pp 49-63.

45. Sarker, S., and Wells, J. "Understanding mobile handheld device use and adoption," *Communications of the ACM* (46:12) 2003, pp 35-40.

46. Shackel, B. "Usability- Context, Framework, Design and Evaluation," in: *Human FActors for Informatics Usability,* B. Shackel and S. Richardson (eds.), Cambridge University Press, Cambridge, 1991, pp. 21-38.

47. Shami, N.S., Leshed, G., and Klein, D. "Context of use evaluation of peripheral displays," *INTERACT 2005* (LNCS#3585) 2005, pp 579-587.

48. Strom, G. "Mobile Devices as Props in Daily Role Playing," Mobile HCI 2001, Lille, France, 2001.

49. Tarasewich, P. "Designing mobile commerce applications," *Communications of the ACM* (46:12) 2003, pp 57-60.

50. Thimbleby, H., Cairns, P., and Jones, M. "Usability Analysis with Markov Models," *ACM Transactions on Computer-Human Interaction* (8:2) 2001, pp 69-73.

51. Thomas, P., and Macredie, R. "Introduction to the New Usability.," *ACM Transactions on Computer-Human Interaction,* (9:2) 2002, pp 69-73.

52. UMTS-Forum "Magic Mobile Future 2010-2020," UMTS Forum 2005, London, UK.

53. Venkatesh, V., Ramesh, V., and Massey, A.P. "Understanding Usability in Mobile Commerce," *Communications of the ACM* (46:1246) 2003, pp 53-56.

54. Waterson, S., Landay, J. A., Matthews, T. "In the lab and out in the wild: remote web usability testing for mobile devices," in: *Conference on Human Factors in Computing Systems*, Minneapolis, Minnesota, USA, 2002.

55. Wigdor, D., Balakrishnan, R. "TiltText: Using tilt for text input to mobile phones," *Proceedings of the 16th Annual ACM UIST Symposium on User Interface Software and Technology*) 2003, pp 81-90.

56. Yuan, Y., and Zheng, W. "Stationary Work Support to Mobile Work Support: A Theoretical Framework," International Conference on Mobile Business (ICMB 2005), Sidney, Australia, 2005, pp. 315-321.

APPENDIX A: Formations and Dimensions of Usability

Usability Studies	Formation of Usability				Research methodology* (Sample Size)	Key Usability Dimensions/ Constructs**	Other Variables	Key Findings
	User	Task/Activity	System/ Technology/Product	Environment				
(Mao 2005)	Culture (Turkey and USA)	N/A	Mobile phone	N/A	Survey (273)	N/A	Price, accessibility, efficacy, personal innovativeness, perceived usefulness, perceived ease of use, intention to use	**For USA sample:** PU →adoption. PEOU →usefulness efficacy→ ease of use, personal innovativeness→ PEOU **For the Turkish sample:** All above and PEOU→ adoption; price→adoption, personal innovativeness→usefulness, personal innovativeness→efficacy
(Pagani 2004)	Culture (Italy and USA)	N/A	mobile phone, PDA, i-pocket PC	Field	Interview (56) Focus groups (24 groups), phone questionnaires (1000)	N/A	Mobility, availability, functions, accessibility, EOU, bandwidth, cost, hardware and software functionalities, privacy Motivation, degree of service innovation, interest for service, preference, ranking of service	Usefulness was the most important factor in adoption, followed by ease of use, price, and speed of use PU → Adoption PEOU → Adoption Price → Adoption Speed → Adoption
(Chan 2002)	Novice	Checking & booking a flight, searching and buying a book, etc.	WAP-enabled mobile phones, PDA, & pocket PC	Lab	Device data	N/A	Information overload, depth of site structure, search, connection feedback and latency	Strong relationship between e-commerce and m-commerce
(Kaikkonen 2005)	N/A	Closed 10 tests	Mobile phone	Lab and field	Device data (40 users)	Errors, Learnability, Operability	Problems observed	The number of times of finding was observed in the two settings
(Rodden 2003)	experienced	12 closed tasks (web browsing, web search)	PDA	Lab	Experiment, questionnaire (24)	Efficiency (time)	N/A	Performance between tasks, and Interaction between browser and task
(Waterson 2002)	N/A	Closed	PDA	Lab, field	Observation, Device data, questionnaire (10)	Errors	N/A	This testing technique can more easily gather many of content related issues, but device-related issues are more difficult to capture.

(Lindroth 2001)	Expert interviews	Adding a person to the address book, scheduling lessons, creating a card.	PDA	Lab	Questionnaire, Device data (12)	Efficiency, Errors, Learnability, Memorability, Satisfaction	Weather, interaction situations	Users use the device in different ways in different situations. More satisfaction problems than efficiency and Learnability
(Nagata 2003)	experienced	Responded to the phone call, intercom message or IM notification,	PDA, desktop	Lab	Questionnaire, interview, Device data (8)	Efficiency, errors	Anticipation and origin of an interruption	Sig. difference between the ODA and desktop groups; origin→ Efficiency, anticipation→ Efficiency
(Kjeldskov et al. 2003)	N/A	Closed	PDA, EMS, mobile phones	Lab, field	Experiment, device data, Questionnaire, observation (48)	Errors, Efficiency	Performance, workload, situation	Seating at a table→errors, Amount of physical activity→workload
(Wigdor 2003)	N/A	Entered short phases of text	Mobile phones	Lab	Experiment, device data (10)	Efficiency, errors	Text entry interface	Sig. effects for the technique. Different efficiency increase for different users; error rates higher for TileText than for MultiTap
(Kim Kim Lee Chae and Choi 2002)	experienced	Open (put pocket diary into the web diary)	Mobile Internet phone	Field	Device data (37)	errors	Use contexts	Goal, hand, leg, auditory → usage; context→errors
Butts (20001)	Usage experience	Closed (enter five sentences using each input method	Mobile phone	Lab	Experiment, device data, observation (8)	Efficiency, error, Learnability	Text entry interface	Reliable differences in efficiency among different Text entry interfaces, no Learnability difference
(Chittaro 2002)	No previous experience	Closed (search and selection)	Mobile phone	Lab	Experiment, device data (40)	Efficiency, Operability	Screen interface	Sig. differences in Efficiency and, Operability among different Screen interface
(Bruijn 2002)	No previous experience	Closed (navigation to find the answers of questions.	Mobile phone	Lab	Experiment, device data (30)	Efficiency	Steps, browser	WAP is more efficient and costs sig. fewer steps than RSVP
(Buyukkoten 2001)	Computer experience, level of concentration	Closed (accomplish single-page info. search tasks using different methods)	Palm Pilot and mobile phone	Lab	Experiment (15)	Efficiency	Performance (User and System)	Combination of keywords and single-sentance summaries provides sig. improvements in efficiency.
(Andon 2004)	physicians	Open	Tablet PCs	Lab and field	Focus group, survey (9)	Errors	Weight, wireless infrastructure, technical support, security, reliability	Weight→acceptability
(Shami et al.)	Medical and dental students, and assessors	Clinical examination	PDA	N/A	Device data, questionnaires (43)	Effectiveness, efficiency, satisfaction	Form of assessing checklists (paper, electronic)	PDA checklist→efficiency; PDA checklist→effectiveness, PDA checklist→satisfaction

(Kim et al. 2002)	experience in using Mobile Internet, Age: 15-40 Average:23.1 Female: 57.8%	- Web diaries	N/A	Street, field study Noisy and Quiet Visual cues Public and alone	- Study (37) - Collecting and analyzing data - Comparing electronic and paper content	Errors	Goal (Utilitarian / Hedonic Use), Use in movement / static, Emotion, Hands Availability, Auditory Distraction	-Lack of appropriate content over internet → Errors - Use in movement / static + Good Emotion → Satisfaction - Goal → EOU - HA → EOU - UM → EOU - AD → EOU
(Palen and Salzman 2002)	Novice 12 female 7 male Age: 16-75	- Phone calls - Explore the functionalities of the phone	Wireless Telephone (N/A)	Field study Everyday life	- Study (19) - Observation - Interviews	Errors (software / hardware)	Network, Geographical terrain, Interior / exterior call, Building material, Call Traffic, Phone antenna, Weather, Ease Of Use, Perceived Usefulness	Other Variables → EOU Other Variables → PU Other Variables → Errors Errors → Satisfaction, Attitude (underutilization)
Fang (2003)	Adults Alumni Students Age: 20-50	- Evaluate characteristics of the devices - Mobile commerce tasks	N/A	N/A	- Study (101) - Questionnaire	N/A	Perceived Ease Of Use (PEO), Perceived Usefulness (PU), Perceived Playfulness (PP) Perceived Task Complexity (PTC), Perceived Security (PS)	PU, PS. PP. PEO affect intention* positively Mostly PU, PS, PP affect user intention* *intention to perform a task
(James 2001)	Novice and Experts	Text typing (multi-tap and T9)	Mobile phone	N/A	- Study (20) - Observation	Errors	Speed Complexity	Complexity → errors
(Juola 2004)	Undergraduate Students (engineering and psychology)	- Establish Bluetooth - Create calendar - Locate a document - Create a contact entry	Bluetooth devices, mobile phone	N/A	- Study (48) - Surveys - Observation (monitoring and recording)	Satisfaction Errors Attitude	Make the device work (MTDW), Intention of Adoption	Use → Satisfaction Satisfaction → Intention of Adoption MTDV → Errors, half satisfaction Bluetooth → favorable attitude to use
(Kaasinen 2003)	Age: 14-66 Very different experiences	- Follow instructions using a GPS system	Different GPS devices (PDA, mobile phones…)	Field and laboratory study	- Study (55) - Group interviews - Collecting data (device)	N/A	Location aware features	Location Aware features → enhance mobile services

(Kallinen 2004)	backgrounds 15 males 15 females Age:15-47, average =25.2	Read a story on a PDA, with and without listening music	PDA	Field Study (in a cafeteria) Noisy Public	Study (30)	User Satisfaction	Immersion, Positive/Negative Emotional Response, Perceived social richness, Surrounding Noise, Music, Attention, Time Of Use	No music → Attention affected by SN Music → Time of use longer Music → Immersion Music → Positive Emotional Response Music → User Satisfaction Music → Perceived social richness
(Khalifa 2002)	- Undergrad / Grad (50/50) - Students in second (and third) degree Age: 18-47	- Fill a questionnaire	N/A	N/A	- Study (202) - Surveys	- Attitude	Trial, Communication, Observation, Perceived Behavioral Control, Exposure to Mobile Commerce, Subjective Norms, Intention To Adopt	- Trial (mostly), and Communication → Exposure to Mobile Commerce - Subjective Norms → Intention To Adopt (ITA) - Attitude → ITA Behavioral Control → ITA
MacKenzie (2001)	Students	Text Typing	PC Concepts *KB-5640* numeric keypad	Lab study	- Study (20) - Observation - Data collection through computer	- Learnability - Error Rate	- Discovery phase (DP), Motor reflex acquisition phase (MRAP), Terminal Phase (TP)	DP → high Error Rate (ER) MRAP → average ER TP → Low ER Learnability → ER
(Duda Schiel and Hess 2002)	Gender (50 male, 50 female) Age: 29 (av.) Experienced of mobile phones	WAP services exploring	WAP phones:	N/A	-Study (36) (B to C service study) - Questionnaire - Observation - Interview	N/A	Utility, Usability, System in- and output (SIO), Feeling of control, Acceptance , Speed	In order of importance: Utility → Acceptance Usability → Acceptance SIO → Acceptance Feeling of control → Acceptance Speed → Acceptance
(Bohnenberger 2002)	novice	Shopping	PDA	Field	Experiment, questionnaire (20)	Effectiveness, efficiency	Adoption	PDA → less time, effort, cognitive effort and frustration
Brewster (2000) (Brewster and Murray 2000)	University students	Search trade information, sell shares	Palm V	Lab	Experiment (12)	Effectiveness, Efficiency	N/A	Audio presentation→efficiency, effectiveness
(Brewster 2002)	students and staff, novice of Palm III	Entering a series of five digit codes using the numeric keypad.	Palm III	Lab	Experiment (12, 16)	Effectiveness, efficiency	The amount of data, button size, sound type, workload	sonically-enhanced buttons →less workload, more frustration and performance, more data entry; small button→more workload, less data entry
(Cheverst 2000)	Experts, visitors	N/A	GUIDE prototype	Field	Interview, observation (60)	error	Flexibility, interface friendly	N/A

(Fithian Iachello Moghazy Pousman and Stasko 2003)	Age, experience with stylus and PDAs and with IM and SMS writing	Locate an individual and send a message, View event details and attendee locations, etc.	PDA/phone combination,	Field	Survey, interview, observation, questionnaire (9)	usefulness, appreciation, Learnability and performance measures	Ease of use.	Negative correlation between task completion time and participant's experience with stylus and PDAs and with IM and SMS writing
(Chittaro 2001)	Novice of WAP phone	Search and selection	WAP phone	Lab	Experiment (30), questionnaire	efficiency	user performance, perceived difficulty	N/A
(Danesh 2001)	Students in an elementary school	Transference of data, use album, drawing	Palm	Lab	Device data, observation (14)	error		N/A
(Goldstein 2002)	novice	Adding a visit card & make an appointment	PDAs or Smart phone	Lab	Experiment, questionnaire (25)	Attitude, Effectiveness	proximity between target and questioning source, Objective performance	N/A
(Poupyrev 2002)	All male	Scroll a text list	Palm	Lab	Experiment, questionnaire	N/A	user performance	Tactile feedback→efficiency
(Ross and Blasch 2002)	People with severe visual impairment	Cross three intersections	Wearable device	Field	Interview, device data (15)	Error, efficiency	Performance, Hesitations, Confusion Episodes, Preference	interface→ veering performance, less hesitation
(Ling 2001)	Culture - Youth - Parents	Use of Text messages	N/A	N/A	Questionnaires (2007 youth) Survey (1001 parents) Interviews (12)	N/A	N/A	Irrelevant → Social research. No link to Usability
(Palen 2001)	Novices (16-75)	Talk about their experience	mobile phones	Lab study	Interviews, voice mail diaries. Calling behavior data. (19)	N/A	Right Price, Business reason, Job-related reason, safety, security, social, special event, mobility, accessibility, net of safety/Proximity, freedom	- Right Price → Adoption - Business reason → Adoption - Job-related reason → Adoption - safety → Adoption - security → Adoption - social → Adoption - special event → Adoption - device → increase mobility - device → increase accessibility - device → increase safety/proximity - device → share resource - device → freedom

(Licoppe and Heurtin 2001)	(Culture) French users 55% men 45% woman	N/A	N/A	Lab study (for the 20 people)	- Questionnaire and face to face Interview (20) - Anonymous traffic database (1000)	N/A	Access, Joinability, Use Of a Mobile (UOM), Easy to Use, Sociological reasons	- Price → UOM - Ergonomics → UOM - Sociological reasons → UOM
(Qiu Zhang and Huang 2004)	27 graduate students, Mostly Novices with PDA	Web tasks	PDA	Lab study	Empirical Observation Interviews (27)	N/A	- Ease of Use - Zooming - Semantic Conversion -Presentation Optimization	Zooming → Ease of Use Semantic Conversion → Ease of Use
(Hinckley 2000)	2 woman 5 men 30-50 years old	- visual tracking (simulate a visually intensive real world task such as driving)	Palm-sized devices	Lab study	Sample (7)	Usability Errors	- Sensing Techniques (ST) - Design - Ease of Use	- Good Design → EU - ST → EU for certain tasks
(Strom 2001)	3 males 4 females	-N/A	Mobile phone, PDA, Walk / disc man, camera	Field study	Interviews Observation (7)	- Attitude	- Use - Social Attractiveness	- Use → less Social Attitude
(Jones 2002)	Volunteers (University students, experts)	- 3 scenarios - 3 tourist type task for each scenario	- PDA	Lab study	Observation Questionnaires (12)	- errors	- WAP interface - PDA interface - screen size (SS) - Ease of Use (EU) - (TC) Time Consuming - frustration (F)	- Small SS→ errors - PDA interface → EU - WAP I. < PDA I. - Small SS → TC - Small SS → F
(Lehikoinen and Salminen 2002)	Students Teachers Engineers	- Search tasks	Computer	Lab study	Sample (24)	- Errors	N/A	"BinScroll", a technique to navigate and search for words on mobile devices.

Note: * Research methodology: How (Observation, Interview, Focus group, Survey, Device data), and Where (Lab study, Field study)

** Key Usability Dimensions: Effectiveness, Efficiency, Satisfaction, Learnability, Flexibility, Attitude, Operability, Errors, Memorability, Accessibility, and Acceptability