Editorial: the inaugural issue (IJMLO)

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1 Introduction

It is an honour to have been invited to edit the International Journal of Mobile Learning and Organisation (IJMLO). It is also with pleasure to welcome all of you to the inaugural issue of the IJMLO. The IJMLO is a refereed, multidisciplinary journal for bridging the latest advances in mobile learning and organisation. It provides a global forum for presenting authoritative references, academic rigorous researches and case studies. The journal publishes well-written and academically validated manuscripts on both theoretical development and applied research.

With constant connectivity and the volume of information that new mobile devices can deliver, mobile learning will shape the new landscape for organisational training and lifelong learning as well as imprompt information gathering for problem-solving. The IJMLO intends to establish an effective communication channel among decision- and policy-makers in business, government agencies and academic and research institutions, which recognise the important role that mobile learning may play in organisations. Specifically, the IJMLO aims to be an outlet for creative, innovative concepts, as well as effective research methodologies and emerging technologies.
Although the *IJMLO* is devoted to the main area of mobile learning and organisation, it also expands its scope to broadly cover any issues overlapping or related to learning and organisation with mobile devices. The subject of coverage includes:

- globalisation of mobile learning
- lifelong learning for changing demographics
- assessment, authentication and security in mobile learning
- synchronous/asynchronous m-learning, m-coaching and m-training
- collaborative GDSS and mobile learning
- pedagogy and design methodology in mobile learning
- Learning Management Systems (LMS) and Learning Content Management System (LCMS)
- decomposability and modular design of course contents
- time modularisation, time management in mobile-learning design
- mobile life
- learning and knowledge creation in a mobile organisation
- virtual collaboration in the workplace
- virtual communities and universities
- value-based m-learning in commerce
- integrated mobile marketing communication
- knowledge and learning strategy in the mobile organisation
- methodologies for effective learning in the mobile organisation
- ubiquitous and pervasive learning
- emerging technologies for mobile learning and organisation
- managing sustainable change and learning in the m-organisation
- innovative case studies in the mobile organisation
- trust issues in mobile learning and organisation
- tools for mobile educational presentation and delivery
- mobile tools and devices for e-learning
- corporate universities and new approaches/models to mobile-learning content diffusion
- technologies and standards for developing tools for mobile learning
- mobile tools to enhance field study
- creating learning communities for mobile learning
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- efficacy and effect of mobile learning
- ethical and copyright issues in mobile learning
- cross-cultural issues in mobile learning
- problems and challenges in mobile learning and
- any other topics relevant to mobile learning and organisation.

2 Inside this issue

This inaugural issue of the IJMLO contains six papers related to mobile learning and organisation fields.

The first (Keynote) paper, ‘Developing Knowledge and Learning Strategies in Mobile Organisations’ by Jay Liebowitz, examines various considerations of developing knowledge and learning strategies in mobile organisations. He argues that part of the challenge for future mobile organisations is: how can they better communicate and collaborate among their employees, customers and stakeholders? The social network analysis is presented as a technique that can be used to identify and map these knowledge flows. He also states that as the world becomes more fluid, networked and complex, organisations will continue to be more mobile, agile, competitive and learning-oriented than ever before.

The second paper, ‘Studio-based learning via wireless notebooks: a case of a Java programming course’ by Miri Barak, Judson Harward and Steven Lerman, describes Studio-1.00, a project aimed at enhancing active learning techniques, interactive programming and the exploration of software development, through the use of mobile notebooks and electronic classrooms at the Massachusetts Institute of Technology (MIT). The results indicated that Studio-1.00 had a positive effect on students’ achievements, especially for the intermediate/low academic level students or those who had no or some prior knowledge in Java programming.

The third paper, ‘The mobile society: effects of global sourcing and network organisation’ by Milan Zeleny, explores the five stages of business focus evolution, with a special attention paid to the current, the fifth, stage of business evolution. He addresses that global sourcing is the key factor to attain global competitiveness and sustainability at the same time. It is becoming the interest of all network participants to maintain their relationships as competitive, sustainable and stable on a global scale. The focal point of the paper is that mobile knowledge and learning are brought forth by the underlying global forces of mobile business and society.

The fourth paper, ‘Array-based logic for realising inference engine in mobile applications’ by Reggie Davidrajuh, depicts a logic technology called array-based logic that guarantees applications developed by this technology which fulfil the three criteria: array-based logic operates on a linear (compact) space, the operations on it are faster (takes linear time) and it is also easy to use this tool. A case study is presented to show how easy it is to use array-based logic for realising inference engine in mobile applications.
The fifth paper, ‘Knowledge transformation for education in software engineering’ by Cat Kutay and Aybüke Aurum, examines the industrial SECI model of KM and how it is applied to the educational area, such as mobile learning. The authors further investigate Nonaka’s SECI model, how it applies to education and how the model suggests improvement to KM in education. Their results showed that the SECI model was an incomplete representation of KM in this context. Therefore, a further understanding of the technology, which supports each aspect of the model, would contribute to knowledge management and hence the constructive aspects of learning at universities as they move to mobile modes of learning.

The last paper, ‘Activity theory for designing’ mobile learning using by Lorna Uden, elaborates on activity theory as a social and cultural psychological theory that can be used to design a mobile-learning environment which involved a complexity of relationships. The author presents the use of activity theory as a framework to describe the components of activity system in the designing of context-aware mobile-learning application. A case study for the design of a mobile-learning application is described using activity theory. The article concludes with suggestions for further research.

Acknowledgements

To conclude, I would like to express my sincere gratitude to the contributing authors and to all the distinguished Editorial Board members for agreeing to serve on the board of the *IJMLO* and for reviewing the papers of this inaugural issue. I would like to take this opportunity to thank Dr. Mohammed A. Dorgham, Mr. Jim Corlett and Ms. Sue O’Marra of Inderscience Publishers for their support throughout the launching of this journal. Finally, to our readers around the world, I thank you very much for using this journal as your source of information, and hope you will find it helpful in your research endeavours.
Keynote paper: Developing knowledge and learning strategies in mobile organisations

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Abstract: As the world becomes more fluid, networked and complex, organisations will continue to be more mobile than ever before. A part of the challenge for future mobile organisations is on how can they better communicate and collaborate within their employees, customers and stakeholders. One technique that can help address this issue is social network analysis. Mobile organisations also need to develop new knowledge and learning strategies, especially as related to recognition and reward systems. The paper will discuss these various considerations.

Keywords: agility; knowledge-management; learning; recognition; rewards; social network analysis; strategic human capital.

Reference to this paper should be made as follows: Liebowitz, J. (2007) 'Developing knowledge and learning strategies in mobile organisations', Int. J. Mobile Learning and Organisation, Vol. 1, No. 1, pp.5–14.

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1 Introduction

Tomorrow’s organisations will need to be more mobile, agile, competitive and learning-oriented than ever before. Increasing competition at home and abroad has created a sense of urgency for organisations to be mobile and innovate at a quick pace. Creating knowledge suggests the need for improved knowledge flows internally within the organisation and externally to the customers and stakeholders. Leveraging knowledge through the connection and collaboration of others may lead to critical success factor in whether a mobile organisation is successful (Cavaleri and Seivert, 2005; Dalkir, 2005; Dawson, 2005; Stankosky, 2005).
One technique that is gaining prominence for determining knowledge flows in organisations to facilitate the communication, collaboration and innovation of others is called Social Network Analysis (SNA). SNA deals with mapping knowledge flows between actors, whether individuals, departments, companies, and so on (Zwijze-Koning and DeJong, 2005; Chan and Liebowitz, 2006). It is a powerful technique that has been used in many applications, ranging from education, business, international trade and government.

According to Cross and Parker (2004), network of informal relationships has a critical influence on work and innovation. Research shows that appropriate connectivity in well-managed networks within organisations can have a major impact on performance, learning and innovation. SNA is a way to understand better these informal relationships. SNA allows for a mapping of knowledge flows in organisations to identify key knowledge sources, sinks and relationships (links/ties) among actors/nodes (individuals/units) in an organisation.

SNA usually follows six key steps (Cross and Parker, 2004):

1. identify a strategically important group
2. assess meaningful and actionable relationships (e.g. relationships, which reveal collaboration in a network, information sharing potential of a network, rigidity in a network, well-being and supportiveness in a network, etc.)
3. visually analyse the results (typically done through SNA software like NetMiner, Inflow, UCINet-Netdraw, Pajek, etc.)
4. quantitatively analyse the results
5. create meaningful feedback sessions
6. assess progress and effectiveness (usually a follow-up, post-audit is conducted 6–9 months after the network analysis is first conducted).

In step 4, there are individual network and group measures that are frequently used in analysing the results. Individual network measures include various types of centrality. For example, in-degree centrality refers to the number of incoming ties a person has for a given relationship. Someone with a high in-degree centrality is a most sought after individual. Out-degree centrality is the number of outgoing ties a person has for a given relationship. Someone with a high out-degree centrality seeks advice or guidance from others and typically tries to communicate and collaborate with others. Betweenness centrality is the extent to which a particular person lies ‘between’ various other people in the network – those individuals with high betweenness centrality values could affect knowledge flows in networks if they were to leave. Closeness centrality is the extent to which a person lies at short distances to many other people in the network. Individuals are highly central with respect to closeness tend to hear information in advance than others (Cross and Parker, 2004).

Group measures such as density and cohesion are often used in SNA. Density is the number of individuals who have a given type of tie with each other, expressed as a percentage of the maximum possible. If each person were connected to every other person in the network, the density would be 100% or 1.0. Cohesion is the average of the shortest paths between every pair of people in the network. The average cohesion score
should be about two in groups, where managers are interested in employees leveraging each other’s expertise (Cross and Parker, 2004).

Geodesic distances between pairs of actors are the most commonly used measure of closeness. Geodesic distance is the minimum distance between actors. For example, I could send E-mail directly to Jim (path of length 1) or I could send my message for Jim to Kathryn (since Kathryn has Jim’s E-mail address) and ask Kathryn to forward it to Jim (path of length 2). I would choose to send directly to Jim, since the geodesic path would be lower and would often be the ‘optimal’ connection between two actors. Usually multi-dimensional scaling or component factor analysis are used to lay out the nodes.

There are different types of networks in organisations. Three of the major network types are the star, line and circle. Generally speaking, actors with more ties have more ‘power’ and greater opportunities because they have choices. In other words, there are alternate ways to satisfy the needs and be less dependent on the other individuals. There are also cliques and cutpoints. A clique is a subset of actors who are more closely tied with each other than the actors who are not part of the group. Cutpoints refer to the structure/network becoming divided into un-connected systems/networks if a node were removed.

Through SNA, types of individuals could be identified in the network. Central connectors refer to the most arrows pointing to them. These individuals could be the ‘power players’, ‘unsung heroes’ or ‘the bottlenecks’ depending on the situation. Boundary spanners provide critical links between two groups of people that are defined by functional affiliation, physical location or hierarchical level. Information brokers are indirect connections and play brokering roles that can hold the entire groups together. Peripheral specialists have one connection each and are not linked to each other (sometimes called ‘isolates’). Some people are ‘stuck’ (e.g. newcomers) on the periphery and others may ‘choose’ (e.g. experts) to be on the periphery (Cross and Parker, 2004). By applying SNA, social groups and positions in groups can be visualized by considering the strength of connections between individuals (proximity data). SNA and knowledge sharing/knowledge management techniques (e.g. online communities of practice, lessons learned/best practice systems, expertise locators and others) can enhance the organisational learning environment.

2  Social network analysis: a quick case study

SNA was recently applied by the author and colleagues (Liebowitz and Parsons, 2005) to examine employees’ communications within the IT Division of a major multinational financial institution. A knowledge taxonomy was developed using the following, as shown in Table 1.

The following key questions were asked:

- Is there much intra-departmental communication?
- Is there much inter-departmental communication?
- Is the organisation well-connected among employees?
- Is the organisation well-connected among the employees to the managers, directors and executives?
• Are the junior employees interacting with the senior employees?
• Are the directors and executives in the ‘power’ positions located centrally?
• Are the assigned experts the real experts?
• Are there correlations as to those employees sought based on the different types of knowledge?
• Are there more isolates, transmitters, receivers or carriers in the organisation?
• What can be learnt about the owners, sharers and interactions of those in the organisation regarding the different types of knowledge?
• How can communication and collaboration be improved?

Table 1  Knowledge taxonomy

<table>
<thead>
<tr>
<th>Types of knowledge</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Context knowledge</td>
<td>Knowledge of ‘what’ applications</td>
</tr>
<tr>
<td>Expert process knowledge</td>
<td>Knowledge of ‘how’ networks and systems work</td>
</tr>
<tr>
<td>General knowledge</td>
<td>Work-related knowledge of a general nature</td>
</tr>
<tr>
<td>Process knowledge</td>
<td>Knowledge of ‘how’ the business works</td>
</tr>
<tr>
<td>Relationship knowledge</td>
<td>Knowledge of ‘who’ has information</td>
</tr>
<tr>
<td>Strategic knowledge</td>
<td>Knowledge of ‘why’ business opportunities reduce cost, etc.</td>
</tr>
</tbody>
</table>

NetMiner 2.5 (www.netminer.com) was used as the SNA software for this application. In this organisation, there were 1,621 knowledge advice connections identified among the 698 employees. Figure 1 shows these connections among the employees. Of course, NetMiner allows the drill-down effect to see finer resolutions of employee interactions. Density and cohesion scores were low within all departments across all knowledge areas. Inter-departmental communication, such as employee communication within the knowledge areas, also yielded low density of communication. Some departments registered no communication with others across certain knowledge areas. Some departments played more central or powerful roles in communication within given knowledge areas. Whereas others, like the Strategic Planning Department, curiously exhibited lower centrality and power roles in the organisation. About 74% of reported advice communications were employee to employee. About 36 of 62 managers, directors and executives were named as sources of knowledge advice five or more times. There was a greater communication rate from employees to persons in management positions than from employees to designated experts. The communication rate from employee to employee was the highest. Junior employees have limited contact with senior employees. Executives and directors are not present or are relatively weak in most power or central positions in knowledge advice communications. Only a single executive and a director appear in central or power positions in Context, General and Relationship knowledge areas. Of the 1,621 knowledge connections, only 5% of those connections were to the experts. There seemed to be no evident correlation between knowledge type and employee attributes in central or power positions. In all knowledge areas, the greatest number of employees are isolates. Receivers are generally greater in number than transmitters in all knowledge areas. Carriers are the fewest in number in all knowledge areas.
areas. Owners of knowledge are fewer in number than those asking advice. Owners are mostly experienced employees, but the majority is not management.

**Figure 1** High-level view of employee communications

On the basis of the SNA analysis, this organisation is not communicating and collaborating well. Knowledge sharing has not quite permeated this culture, and as a result, creating knowledge and innovations have been hampered. Several recommendations can be made to improve communications and collaboration. Some of these include:

- use a portal with a central repository (include ‘cheat sheets’, PowerPoint briefing slides, minutes of meetings, key documents, etc.)
- apply a Google-type search engine within the portal for ease of search and retrieval
- develop an expertise locator system to make connections with people in the organisation (in order to know who to seek out for help)
- recognise and reward knowledge sharing in performance reviews (awards, money) to encourage and nurture a knowledge sharing culture
- develop a continuous learning culture through developing a lessons learnt/best practice system and capture the rationale why things do not work or why they succeed
- develop online communities of practice to improve a sense of belonging among the employees
break-down the functional silos and integrate across departments through cross-training, cross-functional teams, restructuring and mentoring programs

perform a task analysis of those persons in central or power positions to better analyse how to facilitate communication and collaboration in the organisation.

3 Knowledge strategies in mobile organisations

SNA can be applied for determining communication and collaboration patterns in organisations. A part of the reason for performing SNA is to identify the sources and sinks of knowledge and knowledge flows for stimulating knowledge creation and innovation. Without mapping these flows, an organisation may be creating functional silos and inhibiting knowledge sharing behaviour without fully realising the effects. As organisations become more mobile, resulting knowledge strategies need to emerge in order for the organisation to enhance its organisational learning capabilities.

In the same way that individuals have an IQ, organisations also have Organisational Intelligence (OI). OI, as defined by Liebowitz (2000), is the collection of all intelligences that contribute towards building a shared vision, renewal process and direction for the entity. A key part of OI is organisational learning and building systems and processes to encourage continuous learning. Mobile organisations also have an OI, and by the organisation being dispersed and distributed, developing a knowledge and learning strategy becomes even more challenging.

In order for an organisation to maximise its OI, a knowledge and learning strategy needs to exist. This strategy should consist of three main components: people, process and technology. The people aspect deal with how best to leverage knowledge internally and externally and harness the intellectual capital of the organisation. Culture is part of this ‘people’ equation, with embedded values, beliefs and trust. Process is another key component of a knowledge and learning strategy for a mobile organisation as it deals with embedding processes that foster knowledge creation and learning within the daily work activities of the employees. Technology is the other critical element in terms of creating a unified knowledge network, so that people can more easily communicate, collaborate and share their knowledge across the diverse organisation.

This knowledge and learning strategy should be typical of most organisations, whether mobile or not. However, what are the distinguishing characteristics of a mobile organisation that warrant a differentiation of such a strategy as compared to less mobile organisations?

1 A mobile organisation is usually geographically dispersed. This creates a stronger requirement for the technology piece of the knowledge and learning strategy to serve as the enabler and technological infrastructure for knowledge sharing. Instead of having isolated islands of knowledge, the intranet and web-based technologies can allow the bridges to be built across these islands. This is especially important in distributed organisations such as mobile ones.

2 Mobile organisations, due to their nature, need to be able to quickly adapt to change. They need to be flexible, adaptive and agile. Processes for ensuring some standardisation need to exist, but they should not be so structured and constraining that they inhibit the organisation from morphing into other shapes.
Mobile organisations have a more flexible workforce than more traditional organisations, and their employees are typically dispersed. This creates a different type of culture among its people, as the face-to-face contacts may be less frequent than in more traditional organisations. This awareness is important, when a knowledge and learning strategy is developed for the mobile organisation.

In terms of building this knowledge and learning strategy, ‘un-learning’ and ‘re-learning’ processes should be interwoven throughout the strategy. Some ways of doing things may not be the best approach, such as ‘we always did them this way’. Correcting either ‘bad habits’ through un-learning or re-learning techniques and processes to reinforce ideas should be included in the strategy. This really refers to the incorporation of ‘change management’ processes within the knowledge and learning strategy. Resistance to change or fear of the consequences due to change are typical in human nature. Change agents need to be designated as a part of the knowledge and learning strategy, and change management processes should be a part of the fabric of this strategy and mobile organisation. This goes back to building a continuous learning culture in the organisation.

**Developing a recognition and reward system for knowledge sharing in mobile organisations**

In order to help foster a culture of organisational learning that builds on what we know, how we translate on what we know to others, and what we hope to learn, several suggestions can be made regarding a mobile organisation’s recognition and reward system for perpetuating knowledge sharing and organisational learning. Moving to a performance-based culture may be an appropriate step for a mobile organisation to take. Even the US Government is moving towards a ‘pay-for-performance’ system per the Department of Homeland Security and Department of Defence. There are advantages and limitations of this approach. Certainly, a pay-for-performance system reinforces the notion of accountability, in terms of the employees being accountable for their actions and how these actions support the organisation’s mission. The downside of such a system is that this may create some unrest and uneasiness, and resistance to change may be strong. However, in spite of this initial resistance, a performance-based system for recognition and rewards may foster increased productivity among the organisation’s employees.

Also, the organisation may want to consider incorporating a ‘Learning and knowledge sharing proficiencies’ criterion within its ‘Performance evaluation and development plan’ form. This could help encourage and foster a knowledge sharing and continuous learning culture in the organisation. Table 2 shows some recommended knowledge sharing proficiencies, rated as ‘Exceeds expectations’, ‘Meets expectations’ and ‘Needs improvement’ (Liebowitz and Beckman, in press).
Table 2  Knowledge sharing proficiencies/competencies

- Communicates well with those within his/her department (intra-department communications)
- Communicates effectively with those in other departments (inter-department communications)
- Shares knowledge through various knowledge management mechanisms, such as mentoring, conference trip report discussions via brown bag lunches, storytelling (organisational narratives), lessons learned/best practice content contribution, online communities/threaded discussions, newsletter contributions, etc.) (knowledge contribution)
- Actively participates in cross-functional teams (collaboration)
- Regularly distributes articles of interest to other employees (knowledge dissemination)
- Shows value-added benefits from knowledge received from others and knowledge gained by others (knowledge value)
- Willing to be innovative, take risks and try new ideas (knowledge creation)

As a part of knowledge and learning strategy, people usually want to be recognised and rewarded for their individual achievement, as well as collective teamwork. There should be a proper balance between being recognised for teams as well as for individuals. Each of these areas should be accentuated, to promote knowledge sharing. An organisation could consider the following types of recognition (Liebowitz and Beckman, in press):

- Recognising the key contributors and users of the organisation’s intranet on a splash page on the organisation’s intranet and/or web site.
- Recognising (by name) in newsletters whose lessons or articles (and indicate which ones) were the most frequently accessed during the given month.
- Highlighting individuals who explain, via video or in textual story-mode, how the knowledge received from others has helped that individual in producing value-added benefits and perhaps not reinventing the wheel.
- At each monthly department staff and quarterly ‘all hands’ meetings, recognise those individuals who have exhibited strong learning and knowledge sharing skills.
- Institute a new set of awards and conduct an annual employee awards ceremony. Examples of such awards are:
  - ‘At a Boy’ or ‘At a Girl’ certificate awards for ‘going beyond the call of duty’ (individuals and teams).
  - ‘Significant Learning’ award: given to individuals who took calculated risks but resulted in projects that failed. These individuals then shared their knowledge to others on lessons learnt and how to avoid a similar problem. The value-added benefits of this ‘conveyed’ knowledge would be determined by the knowledge recipients on how it contributed to their awareness and project [Eli Lilly and Company has ‘Best Failures’ awards given at their annual global management meeting (at least at their 1997 Toronto meeting), and the awards were given to risk-takers who used the best available information at that time but whose efforts resulted in failure or bittersweet success].
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- ‘Best Knews’ award: given to individuals and/or teams whose contributed/shared lessons were most frequently accessed during the given month or whose interviews/discussions were most used by those accessing the intranet.
- ‘Not Invented Here, But I Did It Anyway’ award: individuals and/or team awards for taking a current process, product or service, and refining/reengineering it to be more effective and useful.
- ‘Special Achievement Award’: individual and team awards given for special recognition of playing a particular role on a project (e.g. in recognition of one’s contributions and support in implementing the XYZ system).
- ‘Celebrate the Success’ award: individuals and/or teams whose involvement resulted in tremendous success towards helping the organisation meet its strategic goals.
- ‘The Best Knowledge Sharers or Esprit de Corps’ award: individuals selected by all employees at the organisation as being the best sharers of knowledge in the organisation (the ‘voters’ must show evidence of this fact).
- ‘The Team Player’ award: individual awards given to the most productive and collaborative team players on cross-functional teams at the organisation.
- ‘The Mentoring’ award: given to an individual who was voted the best mentor by the mentees.

In terms of rewards, the organisation could consider using the following: bonuses, ‘paid days’, cash awards, paid conference trips for active knowledge sharing activity, gifts like i-Pods and PDAs for contributions to the KM efforts, and other types of rewards. If the organisation wants to take very bold steps, it can consider having ‘learning and knowledge sharing proficiencies’ be geared towards promotion in the organisation.

Finally, in order to build a learning and knowledge sharing culture for the organisation, staff roles should be re-engineered to better reflect and embed knowledge management activities into the daily working lives of the employees.

5 Summary

This paper has presented the need for mobile organisations to adjust to change quickly and in order to do so, these organisations must use knowledge sharing and apply knowledge flows to stimulate knowledge creation and innovation. Social network analysis is a technique that can be used to identify and map these knowledge flows so that communication and collaboration can be better facilitated among the employees, customers and stakeholders. In addition, organisations need to modify their recognition and reward systems as a part of their knowledge and learning strategies. The knowledge that is gained from the sharing process can then be leveraged and fed-back into the organisation as a part of its knowledge and learning strategy. This will better inform the knowledge and learning process, which will enable the mobile organisation to be more creative, produce more value-added benefits and stimulate a stronger sense of community among its dispersed workforce.
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Studio-based learning via wireless notebooks: a case of a Java programming course

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Abstract: This paper describes Studio-1.00, a project aimed at enhancing active learning techniques, interactive programming and the exploration of software development, by the use of mobile notebooks and electronic classrooms. We report on a study that investigated undergraduates’ in-class use of wireless notebooks and their learning gains. The study was conducted for three semesters, using qualitative and quantitative methodologies for data collection and interpretation. The results indicated that Studio-1.00 had a positive effect on students achievements, especially for the intermediate/low-academic level students or those who had little to no earlier knowledge of Java programming. The class observations revealed four main attributes that characterise studio-based learning: (a) hands-on, real-life problem-solving, (b) multi-interactions among learners and instructors, (c) knowledge sharing and (d) receiving immediate feedback. These attributes, which are suggested to enhance students learning gains, could not have been achieved without the in-class use of wireless notebooks.

Keywords: active learning; Java programming; studio-based learning; wireless notebooks.


Biographical notes: Dr Miri Barak is a Senior Researcher in the Department of Education in Technology and Science, Technion – Israel Institute of Technology. Her activities in the past 10 years have focused on developing, integrating and assessing science education curricula at the high school and higher education levels. Her research concerns theories of constructivist learning environments and applications of educational technologies for enhancing such environments. Her studies involve harnessing Information and Communication Technologies (ICT), with emphasis on emerging web capabilities, to foster science teaching and meaningful learning.
1 Introduction

The concept of m-learning covers a wide range of possibilities opened up by the convergence of new mobile technologies, wireless infrastructure and e-learning developments. M-learning is conceptualised as the acquisition of knowledge and skills by using mobile technology, anywhere, anytime (Geddes, 2004). It is considered as the point at which mobile computing and e-learning intersect to produce an anytime, anywhere learning experience (Harris, 2001).

Mobile technology is associated with any device that is designed to provide access to information in any location, or while on the move. Specifically, this includes, but not limited to: wireless notebooks, tablet computers, mobile phones and Personal Digital Assistants (PDA). One important field where mobile technology can make significant contributions is education. As learning has become more individualised and learner-centred, so too have the new digital technologies become increasingly personalised. The major advances in mobile-networked technology enable people to retrieve information and communicate regardless of their location and support situated and collaborative learning activities (Sharples, 2000).

The use of wireless notebook computers, as a part of the learning process, can enrich the academic experience in various ways. Their portability makes computer access more convenient for students and faculty, and when coupled with classroom setup for connectivity, it enhances onsite learning and classroom experiences (Driver, 2002). Usable in campus settings outside classroom or library contexts, notebooks offer students more opportunities to work on academic projects individually, to support group projects or simply to explore classwork with fellow students (Demb, Erickson and Hawkins-Wilding, 2004).

Chan and his colleagues (Chan et al., 2001) argue that the use of wireless notebooks has the potential to change the learning environment, and in particular, the classroom settings and activities. They suggest that connected classrooms, through computers, will change the organisational structure of schools and the definition of a class. The use of notebooks was found to have educational benefits such as increasing students motivation
and collaboration, strengthening connections between disciplines, improving students problem-solving skills and promoting academic achievement (Kiaer, Mutchler and Froyd, 1998; Stevenson, 1998; Mackinnon and Vibert, 2002; Siegle and Foster, 2002).

Innovative educational projects are evolving in response to the new opportunities that are becoming available by integrating advanced technologies (Barak and Dori, 2005; Barak, 2006). Similar to all computer-based teaching initiatives, a project that involves the use of wireless notebooks raises implementation issues related to the adoption of a new technology, the modification of a new curriculum and the reconfiguration of existing facilities. The question of how to increase the learning efficiency in m-learning is becoming more and more important. Indeed, there is an urgent need to find an effective way to use mobile technology in higher education. Thus, the development of a new curriculum, the adoption of a new teaching and learning format and the reconfiguration of facilities in a higher education course were the foci of this paper.

The dominant instructional method in science and engineering institutions is based on traditional lectures in large lecture halls, relatively small groups recitations and separate laboratories. On recognising the shortcomings of the traditional lecture-recitation-laboratory system, the faculty and staff of several universities have devoted attention for improving the traditional way of teaching and learning, by introducing the studio format (Wilson, 1994; Dori and Belcher, 2005).

The origin of the studio format was found in schools of architecture (Boyer and Mitgang, 1996). In general, it started as a model of human-problem engagement with no direct association to the use of technology or mobile devices. However, as the concept of Studio classes has evolved, it is now conceptualised as a mixture of student exercises, instructor coaching and laboratory work, which generally takes advantage of modern technology to deliver instructional materials (Pipes and Wilson, 1996; Roy, 1996; Cummings et al., 1999).

In this study, the studio format was introduced into a leading programming course: Introduction to Computers and Engineering Problem Solving, at the Massachusetts Institute of Technology (MIT). It is a part of a series of ongoing projects at the Center for Educational Computing Initiatives that examine the integration of new pedagogy and technology into higher education courses (Dori et al., 2003; Dori and Belcher, 2005). This paper describes the Studio-1.00 project and reports on a study that investigated undergraduate students’ in-class use of wireless notebooks, their attitudes about the new teaching format and their learning gains.

2 Studio-1.00: integrating mobile technology as part of the learning process

Studio-1.00 project focused on the development of a new curriculum and the reconfiguration of facilities for supporting the teaching of MIT’s subject 1.00: Introduction to Computation and Engineering Problem Solving, as a studio-based course rather than its traditional lecture-laboratory-recitation format. Studio-1.00 project aimed at enhancing active learning techniques, interactive programming and the exploration and discovery of software development methods and concepts, all facilitated by the use of mobile devices in an electronic classroom.

The course is taken by approximately a quarter of all MIT undergraduates. It serves students with a wide variety of interests and programming experience and draws students
from all schools and departments. Its goals are to introduce undergraduate students with programming and core concepts of software development, as well as, teach them to program in an interactive environment and use computation in solving scientific, engineering and management problems.

Until recently, the course instructors taught C and C++ languages, in a traditional teacher-centred lecture/recitation mode. As modern computation techniques have evolved with the rise of interactive, object-oriented computing, the instructors shifted to teaching Java together with applying the studio format, the new teaching approach.

In its new format, course 1.00 includes, three studio sessions per week, each 90 min long (30 min longer than in the earlier traditional format) and one small-group tutorial, 60 min long, consisting of about 12 students. The laboratory and part of the recitation work are integrated into the studio sessions, which include short lectures interchanging with short active learning exercise. The short lectures are given by the course lecturer, who presents new concepts and methods in Java programming, around 20 min long. The active learning units include authentic problem-solving activities, also around 20 min long. During the studio sessions, all the course instructors are present. This includes two lecturers and five-to-eight Teaching Assistants (TAs). During the active learning activities, they go around the students, and assist those who have difficulties.

As a part of the Studio-1.00 project, loaner notebooks were provided to all students who never owned one. The notebooks were equipped with wireless cards and with the Integrated Java Development Environment (IDE) system, which facilitated the creation, development and examination of Java applets and applications. The mobile notebooks were distributed for three main reasons:

1. providing students with an easy and convenient hands-on computing experience in a large lecture hall setting;
2. enabling immediate implementation of new programming concepts or procedures taught in class, and
3. providing students with immediate feedback (from both the IDE program and the instructors).

The wireless technology enabled students to access the course website or other Java resources on the web, read lecture summaries and other related information, and download pieces of Java code onto their notebooks, as a part of their problem-solving exercise. In fact, the wireless notebooks facilitated the implementation of the studio format in a large lecture hall setting by enabling the integration of lectures, hands-on exercise and immediate feedback.

3 Research objective and population

The objective of this study was to investigate undergraduate students’ in-class use of wireless notebooks and the effect of Studio-1.00 on students’ learning gains and attitudes. It was assumed that all students would gain knowledge in Java programming at the end of the semester, but the main questions were:

1. Who are the students that gain most knowledge in Java programming by learning in the studio classes?
2 What are the students’ pre- and post-attitudes towards Studio-1.00 learning components?

3 How do students use the wireless notebooks as part of their in-class learning process?

The research population was not randomly assigned; it consisted of 232 students from three consecutive semesters, who agreed to participate in the study by signing on a consent form. However, their demographics were very similar to those of the entire population. Most of the students were males (61%), and more than 60% majored in engineering. Only 7% were freshmen, 39% sophomores, 28% juniors and the rest seniors. About 32% had considerable earlier experience in programming, 38% had some earlier experience and the rest had no earlier experience. Students academic index scores ranged from 2.8 to 5.0 (Mean = 3.97, SD = 0.68).

4 Methodology

Studio-1.00 is a multi-faceted project that included the introduction of a new teaching/learning format, a curricular change and the integration of mobile technologies. The use of a single evaluation instrument or analysis technique cannot be expected to give a full picture of such a complex project. Therefore, both quantitative and qualitative analysis methodologies and tools were employed in an effort to understand students’ in-class use of wireless notebooks and the effect of Studio-1.00 on students’ learning gains.

With respect to the study’s quantitative part, no comparable course was found to serve as a control. The other programming courses at MIT, offers a different syllabus, focus on a different programming language and are taught by different instructors. It was therefore decided to use a pre-experimental design, that is, a one-group pre- and post-test design, for examining the relationship between students’ relative improvement scores and their attendance in the Studio-1.00 classes, dividing them by academic level, earlier-programming experience, gender, year of academic studies and major. These procedures were applied in an attempt to characterise the students who would be most likely to benefit from the new teaching format and the in-class use of notebooks.

The research tools included:

1 pre- and post-tests, for indicating students earlier and final knowledge in Java programming and examining their relative improvement;

2 pre- and post-attitude questionnaires, for indicating students perceptions about Studio-1.00 and the use of notebooks for educational purposes and;

3 class observations, for indicating students behaviour and interactions during the studio sessions.

The following describes in detail the research tools, their reliability, internal and external validity and their analysis procedure.

4.1 Pre-test

The pre-test was administered at the beginning of each semester, during the first studio session, aiming at examining students earlier/existing knowledge in programming. Since
the course syllabus is tightly packed, the instructors were pressed for time and since most of the students had little or no earlier programming experience, the pre-test was designed to take no more than 20 minutes and therefore included only three questions. Two questions required the students to explain, in their own words, concepts related to computer programming. In the third question, students were asked to choose the most efficient program of two, and explain their decision. The pre-test was designed and validated by the course instructors and educational researchers.

4.2 Post-test

The final examination of the course was used as the post-test for investigating students’ knowledge and understanding in Java programming. By using this, we could differentiate among students and learn in depth about their knowledge gain. The final examination was three hours long, which included five open-ended questions that required the developing of Java code segments, and eight true/false questions that probed students understanding of object-oriented programming. The examinations were designed and validated by the course lecturers and TAs.

4.3 Students relative improvement measure

In order to investigate students learning gains, the relative improvement measure <g> was calculated, which is the ratio of a students actual gain to his maximum possible gain, defined as follows according to Hake (1998):

\[
<g> = \frac{\%\text{Correct}_{\text{post-test}} \ - \ %\text{Correct}_{\text{pre-test}}}{100 - %\text{Correct}_{\text{pre-test}}}
\]

The relative improvement measure is on a 0.0 to 1.0 scale, with 0.0 indicating no improvement and 1.0 indicating maximum improvement.

4.4 Pre- and post-attitude questionnaires

A five-point Likert-type scale questionnaire (five-strongly agree to one-strongly disagree), was administered at the beginning and end of each semester for evaluating students’ attitudes towards Studio-1.00 teaching/learning format and the use of wireless notebooks. The questionnaires consisted of 12 statements: four related to in-class active learning, four to teamwork and four to the use of wireless notebooks (Appendix I). Five experts in science and computer education validated the questionnaires. Although the questionnaires items addressed different aspects of the studio-based learning, they all indicated students’ attitudes. Therefore, we report here on the Survey’s total internal consistency, Cronbach’s Coefficient Alpha, to be 0.84.

4.5 Class observations

Class observations were conducted for investigating students behaviour and interactions during the studio-based sessions. The observations focused on students interactions among themselves and with their instructors (lecturers and TAs). The students conversations served for investigating their learning process, and how they used,
explained and related to concepts newly taught in class. In each of the studio sessions, an educational researcher documented the students’ conversations and behaviour. Concurrently, the sessions were videotaped, using the video for maximising observational effectiveness and for minimising the researchers bias (Denzin and Lincoln, 2000). The data collected from both the research tools were compared for strengthening the research trustworthiness.

5 Findings

5.1 Characterising the students who gain the most by participating in the studio classes

In order to answer the first research question, that is, characterise students who gain the most knowledge in Java programming by learning in the studio classes, several statistical procedures were conducted.

1 The relationship between the students relative improvement in Java programming and their attendance in the Studio-1.00 classes was examined.

2 An ANOVA test was applied for examining differences among the following independent variables: academic level, earlier-programming experience, gender, year of academic studies and major course.

3 Scatter plots and regression lines were drawn for each independent variable.

Since MIT students tend to study on their own and some do not, or rarely, attend class, a class attendance sheet indicated students’ attendance percentage on a 0 (no attendance) to 100 (attending all studio classes) scale.

A linear regression analysis in which the students’ studio class attendance percentage was an independent variable, and their relative improvement score, \( g \), was a dependent variable, showed a significant relationship \( \beta = 0.31, p < 0.01 \). This result suggests that more the students attend the studio classes and exercise hands-on problem-solving with the use of wireless notebooks, the better they improve their knowledge in Java programming (Figure 1).

ANOVA analysis indicated a statistically significant difference among students from different academic level groups \( F = 5.20, p < 0.01 \). On comparison, the results showed that the high academic level students improved their Java knowledge significantly better (Mean = 0.77, SD = 0.18) compared to the intermediate and low academic level students (Mean = 0.71, SD = 0.22, Mean = 0.66, SD = 0.21, respectively). This result is not surprising, since the high academic level students are the most talented and bright learners. However, the regression lines in Figure 2 indicate that it is the intermediate and low academic level students who are most influenced by class attendance. The more the intermediate and low academic level students participate in the studio classes, and practice hands-on problem-solving via wireless notebooks, the higher is their improvement in Java programming.
Figure 1 Scatter plot and a regression line for the relationship between the students’ relative improvement score and their studio class attendance

Figure 2 Scatter plot and regression lines of the relationship between students relative improvement and their studio class attendance, based on academic level

Another statistically significant difference was found among students with different earlier-programming experience ($F = 3.41$, $p < 0.05$). The students with high earlier-programming experience showed significantly less improvement (Mean = 0.60,
Studio-based learning via wireless notebooks

SD = 0.27) when compared to students who had some experience or none at all (Mean = 0.71, SD = 0.21, Mean = 0.72, SD = 0.21, respectively). This suggests that the studio classes and the in-class use of wireless notebooks, at the maximum, promote students with some or no programming experience.

On the contrary, when compared to the earlier results, no statistically significant differences were found between gender, year of academic study and major courses. This means that the Studio learning approach via mobile notebooks, has the same positive affect on males as well as females, upper and lower-class students and science and engineering students.

5.2 Students’ attitudes towards the new teaching format and the use of wireless notebooks

On examining the students pre- and post-attitudes, we found an interesting pattern. While students’ attitudes towards active learning and teamwork, two major elements in the Studio-1.00 paradigm, decreased (statistically significant); their attitudes towards the use of wireless notebooks increased, though non-significantly (Table 1).

<table>
<thead>
<tr>
<th>Studio-1.00 learning components</th>
<th>Pre-attitudes Mean ± SD (on a 1–5 scale)</th>
<th>Post-attitudes Mean ± SD (on a 1–5 scale)</th>
<th>t</th>
<th>p&lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teamwork</td>
<td>3.83 ± 0.69</td>
<td>3.42 ± 0.68</td>
<td>-3.47</td>
<td>0.01</td>
</tr>
<tr>
<td>Active learning</td>
<td>3.74 ± 0.67</td>
<td>3.45 ± 0.70</td>
<td>-3.46</td>
<td>0.01</td>
</tr>
<tr>
<td>Use of notebooks</td>
<td>3.89 ± 0.69</td>
<td>4.04 ± 0.56</td>
<td>1.64</td>
<td>NS</td>
</tr>
</tbody>
</table>

The results presented in Table 1 indicate that students have high attitudes towards the use of wireless notebooks, before, as well as after using them as a part of their learning process. The students felt that the use of wireless notebooks helped them to understand programming better and encouraged teamwork and interactions among themselves. Most of the students found learning with a wireless notebook to be enjoyable and only a few wrote that it made them anxious.

The decrease in students’ attitudes towards in-class active learning and teamwork can be explained by the fact that the studio format is a non-traditional, non-familiar teaching/learning approach that required students to be actively engaged in the learning process, solve complex problems and interact with their classmates. Some students did not feel comfortable with being active in class. Several asserted that they prefer the traditional way of learning – having the instructor give a lecture and sitting as passive listeners.

Further analysis found no statistically significant correlation (Spearman test) between the students attitude towards the use of notebooks and their relative improvement in Java programming knowledge. This means that even low achieving students asserted high attitudes towards in-class use of the notebooks. On the contrary, a statistically significant correlation was found between students’ attitudes towards the use of notebooks and their attitudes towards active learning and teamwork (r = 0.34, p < 0.01 and r = 0.42, p < 0.001, respectively). These results suggest that students who find the use of notebooks most helpful are those who appreciated active learning and teamwork.
5.3 Students use of the wireless notebooks as a part of their in-class learning process

The transcription and analysis of the class observations indicated that the studio classes and the use of mobile technology, i.e. wireless notebooks, had four main attributes that contributed to students academic achievements and Java understanding:

1. hands-on, real-life problem-solving,
2. multi-interactions among learners and instructors,
3. knowledge sharing, and
4. receiving an immediate feedback, computerised (the IDE system), as well as human (peers and instructors).

The data collected from the observations is vast and cannot be fully presented in this paper. However, one typical example was chosen to reflect the students’ use of the notebooks and their in-class learning process. In the following, LR is the course lecturer, TA1 and TA2 are two of the five TAs who were present in the class, and ST1, ST2 and ST3 are students who were engaged in conversation, while attempting to solve a programming problem. The square brackets denote the participants behaviour; curly brackets denote the researchers comments, and bold words denote the newly taught concepts.

LR The French originally defined the meter to be 1/40,000,000 of polar circumference of the earth. A kilometre is 1/40,000 of the polar circumference. Using that fact and whatever you want to cut and paste from the NauticalMile Class, create the code to calculate how many kilometres are there in a nautical mile and print it to the Java Console. {Presenting students with a hands-on, real-life problem}

ST1 [Looks at the lecture handouts and talks to himself] Emm… I do not understand how to begin… {General confusion} [Raises his hand and calls a TA].

TA1 Hi, can I help you? {Immediate help and feedback}

ST1 I do not understand from where to begin. What should I do now? How can I find this NauticalMile Class the lecturer was talking about? {Seeking for help}

TA1 Oh, that is not a problem. Open your notebook and use the IDE program for creating and storing your programs. But, first you need to create a folder for your Java files, like this [the TA shows the student how to do certain operations on his notebook]. I click on File, then Open, and Class… like this [the TA points to the notebook screen]. {Immediate help and feedback}

ST2 [Sits next to ST1, and listens to TA1’s explanations] Can you also show me on my notebook?… We learned about Classes, and how to develop Java programs last session … and today we learned on how to use the IDE, but I do not understand the concepts or how to start a new Class. {Sharing knowledge}

ST1 Remember the example the lecturer gave last session about Antenna as a Class and many Antennas as an example for Objects. Look at Lecture 1, which is on page 8. {Sharing knowledge, peer interactions}
TA1 Well, a **Class** is a programmer-defined data type. They are patterns from which **Objects** are made. It will be much easier for you to understand once you practice. [looks at ST2’s notebook and shows him the procedure to open a new Class] Oh, and do not forget that first you need to create a new project. Try doing it yourself. [watches how ST2 operates his computer]. Now, if you both hit on the Finish button, you will be all set. {immediate feedback and help} {hands-on problem solving}

TA1 went to help another student. ST1 and ST2 opened a new Class, named it Kilometre, and started to write lines of code, using the IDE program on their notebooks, but both seem quite uncertain.

ST2 [addresses ST1] Emm… I am not sure. I started writing public class Kilometre but I am not sure. [Reads once again the lectures handouts].
The lecturer said that the polar circumference of earth is 24859.82 miles.
From what I am reading, we can also use **int** and convert it to **double** as we learned in the first lecture [shows ST1 Lecture 1 notes].
Can you look over here? [pointing at his notebook] I hope I did it right. {Seeking help and feedback}

ST3 [sits a row behind ST1 and ST2, overhears their conversation]. I have some experience in programming…. You need to remember defining variables as **double** or your numbers will be represented incorrectly. By the way, my name is ST3. {Sharing knowledge}

ST1 [shows ST2 his screen]:

```java
public class Kilometre {
    public static void main (String[] args) {
        double circum = 24859.82 * 5280; …I hope this is correct.
    }
}
```

ST2 [Responding to ST1]: It seems OK.

[Responding to ST3]: Hi, I am ST2 and this is ST1. We are both freshmen in civil engineering. [Continues to read the lectures handouts].

ST1, ST2 and ST3 are working on their lines of code individually. From time to time, they show each other their work by exchanging notebooks.

TA2 Hi there, is every thing OK?

ST3 I think we are OK. We ended our program:

```java
System.out.println("Kilometres in a statute mile =" + kmPerMile);
```

ST1 Well… actually I have a problem. I have a similar program but when I compile I receive a **syntax error**. [Shows TA2 his notebook screen]. {Seeking guidance}

TA2 Let me see. [Checking ST1s program] Oh, you forgot the semicolon at the end of this line. Fix this and try again. Overall, you have done a good job. {Immediate feedback}

While trying to solve a problem, students face technical as well as conceptual difficulties, they seek help, and later ask for instructors or peers feedback. The course instructors provided students with three important learning components: technical assistance, conceptual support and immediate feedback. Though the studio-based learning was designed for self/individual learning, spontaneous teams were formed among the students, resulting in information sharing. The students helped each other, while verbally expressing ideas and talking about newly introduced concepts such as class, object, double, int and syntax error.
Implementing curriculum reforms and integrating educational technologies are major challenges for higher education institutions. Nowadays, educators are using a variety of learning technologies to enhance learning in their classes and to achieve their teaching goals (Barak and Rafaeli, 2004; Dori, Barak and Adir, 2003). Similarly, Studio-1.00 attempted at exploiting mobile technologies to support innovative teaching and learning.

Geddes (2004) indicated four major advantages that can be gained from m-learning to a greater degree, or more easily than any other learning methods. The advantages are:

1. **Access** – the opportunity to access information where earlier it would have been impossible.
2. **Context** – providing context through problem-solving activities in simulated authentic environments.
3. **Collaboration** – enhancing learning through social interactions.
4. **Appeal** – attracting students attention and promoting their motivation.

The Studio-1.00 teaching and learning format via wireless notebooks does indeed demonstrate the four m-learning advantages. The wireless notebooks enabled the integration of the studio format in a regular lecture hall with no need for specially designed computer laboratories. The instructors and students were able to enjoy all the advantages of using computers as cognitive tools in a regular classroom setting.

The technology works best when it meshes with the other components of the learning environment and meets a specific educational need that has not been met (or poorly met) by more conventional media. Studio-1.00 via wireless notebooks allowed the instructors to develop a technology-based curriculum, free of concerns regarding the classroom settings and the number of students registered. The use of mobile notebooks facilitated the following attributes of the studio format:

1. **Hands-on problem-solving and exploration by learning.**
2. **Immediate feedback from both software (the designated program) and humans (the course instructors).**
3. **The concretisation of abstract concepts by enabling visualisation and simulation applications.**
4. **Individual learning, together with collaborative work, when applicable.**

It is well-established among educators that for students to learn, they have to construct knowledge rather than passively absorbing it (Tobin and Tippins, 1993). Accordingly, our study indicated that Studio-1.00 had a positive effect on students learning achievements, especially for the intermediate and low academic level students and those who had no or some earlier knowledge in Java programming. In fact, the hands-on active learning and real-world problem-solving cannot take place without the use of mobile technology.

In the affective domain, students asserted highly positive attitudes towards the use of wireless notebooks. They felt that the use of wireless notebooks helped them to understand programming better and encouraged interactions among themselves. On the contrary, the students’ asserted intermediate attitudes towards active learning and
teamwork. Similar results were also found in other higher education studies (Huba and Freed, 2000; Dori, and Belcher, 2005). It seems that students have difficulties in changing conventional learning patterns and in accepting new teaching/learning formats, especially if other courses are taught within a traditional, teacher-centred paradigm.

The world of mobile and wireless computing is evolving fast. However, research on the educational use of mobile devices is still in its infancy. In order to fully leverage the mobile learning, educators need to rethink about their teaching strategies and reinvent their curriculum. The shifts to mobile learning are not likely to occur dramatically or in isolation. Instead, they may augment, complement, coexist with and transform current paradigms over an evolutionary cycle (Singh, 2003). Indeed, a shift from lectures to studio-based instruction, and a shift from individual/self-tutoring to collaborative studio-based learning, via mobile devices, may be an important trend in the way learning is perceived and knowledge is constructed.

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References


Notes

1The academic index is a numerical score on a scale of 1.0-to-5.0, used as an element in the evaluation of applicants for admission to MIT. It is the rating of class rank in secondary school and an average of mathematics, science and humanities scores in the Standardised Achievement Tests (SAT1 and SAT2).
Appendix I

Course 1.00/1.001 questionnaire

As a part of our effort to improve the learning experience in Course 1.00/1.001, we are asking you to complete this questionnaire. The questionnaire is for research purpose only, all data collected will be treated in a confidential manner and the results will be reported in the aggregate, so information cannot be connected to individuals. Your response will not have any effect on your grade and will not be seen by the instructors and TAs. Your participation is voluntary and you may skip any question that you do not wish to answer.

Please indicate how strongly you agree or disagree with each of the following statements:

<table>
<thead>
<tr>
<th>Learning with notebook computers makes me anxious</th>
<th>Strongly agree</th>
<th>Agree</th>
<th>Non decisive</th>
<th>Strongly disagree</th>
<th>Comments, explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>The use of notebooks helps me understand programming better</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning with notebooks encourages teamwork</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Learning with notebook computers is enjoyable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active learning promotes my understanding of the learning material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I enjoy interacting with my friends while solving problems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I feel uncomfortable to participate in active learning sessions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I like the challenge of solving problems as a part of class activities</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>I prefer being a passive listener during the lesson</td>
<td></td>
<td></td>
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<tr>
<td>I like learning in teams</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I prefer working alone while solving problems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working in a team promotes my learning</td>
<td></td>
<td></td>
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</table>
The mobile society: effects of global sourcing and network organisation

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Abstract: The notion of a mobile society needs to be rooted in the newly emerging forms of business and organisation of the global economy. In this paper we explore the five stages of business focus evolution over the past 50 years, with a special attention paid to the current, the fifth stage. From the given and fixed processes, through their re-engineering and extension to networks, we have moved up to their disaggregation and distribution. This is a remarkable journey in search of competitive advantage and its main acceleration is beginning now. The future of business and entrepreneurship is more remarkable than its recent past. We focus on global sourcing as the main driver of attaining global competitiveness and sustainability. It is becoming the interest of all network participants that their relationships are competitive, sustainable and stable on a global scale. The main point of this paper is that mobile knowledge and learning are brought forth by the underlying global forces of mobile business and society.

Keywords: global sourcing; mobile business; mobile knowledge; mobile networks; mobile society; modular corporation; offshoring; outsourcing; sustainable advantage; virtual subsidiary.


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Websites: www.bnet.fordham.edu/zeleny/ and www.mzeleny.cz
1 Introduction

All societies of the past were ‘mobile’ to a certain degree and within their referential contexts. What is so new and challenging about the newly emerging mobility? There are several characteristics of the new notion of mobility worthy of listing:

1 For the first time, the emerging human mobility is massive and realised on a truly global scale.

2 Business and entrepreneurship have become the main drivers of societal change and its dynamics.

3 Mobility has expanded from merely physical objects to ideas, information, knowledge, wisdom and digitised coordination. One can be and act anywhere without being physically present.

4 Networks are the new frontier of business organisation and management.

5 Outsourcing or global sourcing brings new stability to these networks.

6 Knowledge and coordination function are mobile and can be outsourced.

7 The engendered new web of global business relations is generating larger stability and weakening the destabilising influences of traditional politics, religion and national interests.

We could continue along these lines, but the main point has been made: the new mobility is quite unprecedented and it will take some vigorous learning to understand and master all it can offer.

In the past, politicians dreamt of national separation, isolation and state ‘fortresses’ in order to escape the turbulence of the surrounding world. Now it is the politically isolated islands – the pockets of discontinuity in the increasingly connected world – that are the sources of global instability and threats. This new world of business is certainly not about ‘Winning’, but about cooperating so that all participants can win. Nations that do business together are less likely to fight. Business alliances are stronger than political alliances. Global sourcing, leading to globally shared information, resources and wealth, contributes to global peace.

In order to participate in shaping the future, we should understand how and why we got to this stage and how have the notions of mobility, networks and global sourcing emerged. Such understanding and awareness will make our work much less uncertain and our actions more self-confident.

In the past 50 years, the world of business has moved through five evolutionary stages, moving along at an ever-accelerating rate of succession. The current, the fifth stage, brings forth the era of networks, characterised by disaggregated corporation and distributed process.

Once the stable networks and alliances are in place, the issue becomes what is to be propagated over such networks? are they goods, information, knowledge, wisdom …? The sixth and subsequent stages are already assuming their contours and taking shapes ….
1.1 Process organisation and its evolution

The five evolutionary stages include:

1. **Final-product orientation**, where the process is given and final-product improvement is the primary focus

2. **Process-operations orientation**, where process improvement comes into focus and Total Quality Management (TQM) emerges

3. **Integrated-process orientation**, where the focus shifts from continuous improvement to discontinuous redesign and from operations to overall process architecture – Business Process Reengineering (BPR) emerges

4. **Extended-process orientation**, when the internal process becomes embedded and integrated in the extended network – supply and demand chain management emerges; and finally

5. **Distributed-process orientation**. Only in the fifth stage, the currently emerging paradigm, both customers and suppliers become global sources, driving the search for competitive advantage.

The last two stages start an ever-accelerating process of **global sourcing** (outsourcing, offshoring, homeshoring, etc.) as the main driver of global change (Agrawal and Farrell, 2003; Sen, 2006).

1.2 Evolution of management systems

After World War II, the earlier paradigm of product-oriented mass production (linear assembly lines, organisational hierarchies of command, product quality control and mass consumption) had reached its peak.

Soon afterwards, the Deming-Juran process quality teachings spearheaded a new quality orientation (later referred to as TQM) and propelled Japan directly to the post-war **process focus** (process quality control, just-in-time, continuous improvement). The US responded by a painful and prolonged product-to-process transformation, ultimately leveling the playing field again by the mid 1980s.

At the end of the 1980s, BPR focused on the radical redesign of the production process through the reintegration of task, labor and knowledge (Zeleny, 2005). As a result, lean, flexible and streamlined production processes were created, capable of fast-response and internet-based integration necessary for the upcoming phase of **supply chains** – business-to-business (B2B) – and **demand chains** – business-to-customer (B2C) orientation.

In all three described stages, the competitive advantage was derived almost exclusively from the **internal resources** of the firm. At the end of the 1980s, the most radical fourth shift has occurred: the competitive advantage became increasingly derived from the **external resources** of the firm – through the **extended networks of suppliers and customers**.

In Figure 1 we display the basic scheme of production and service delivery process. This scheme has remained unchanged and unchallenged for centuries of the engineering and economic descriptions of business management. What has been changing is the evolving **focus of management** on different parts and components of the basic scheme.
Although the scheme \[\text{inputs} \rightarrow \text{process} \rightarrow \text{outputs}\] remains unchallenged, there are some indications in the emerging fifth stage that it will also undergo a major restructuring in the future. It will become disaggregated and distributed, subjected to non-linear modularity and thus bringing forth entirely new ways of making things and delivering services.

In view of Figure 1, the managerial focus first shifted from product to the internal process. It has become clear that improving quality of the process leads to a better-quality product, but not vice versa. Improving the process was first carried out by continuous improvement, concentrating on improving the operations (circles). Then the emphasis shifted from operations to process relations (arrows), that is, to discontinuous improvement through redesigning the process architecture, reengineering of the process. In all these efforts, the corporate focus was rooted in developing the internal sources of competitive advantage, knowledge, innovation and productivity.

Only in the last two paradigmatic shifts were the internal processes expanded into the extended process – including supplier networks and alliances as well as customer self-service, mass customisation and disintermediation – as the main, increasingly external, sources of competitive advantage. Such a shift changed the very notion of competitive advantage, the sources of knowledge and the concept of the firm itself.

The subsequent process of global sourcing brings forth and fosters a new set of relationships with customers and suppliers. The firm starts disaggregating its production processes, transferring, leasing or selling selected pieces off to a higher-added value operator/coordinator.

Any firm can be only as good as is the network of which it is a part. Consequently, the firm will disaggregate and become a network. No firm is an island.

Users of the newly emerging networks have to become ‘mobile at work’. The main business location is no longer the main work environment. An effective collaboration between employees, vendors and customers has become the cornerstone of business success. Secure wireless LANs and effective IP telephony to improve employee collaboration; wireless connections to network resources allow virtual meetings and projects to be completed on the spot. Technology fully supports the emerging trends.
The mobility and the emergence of the Mobile society are implied by the shift towards the external sourcing, disaggregation of the production process and the need for global coordination. Specific global coordination techniques are described, for example, in Rabelo, Pereira-Klen and Klen (2004).

1.3 Summary of the five stages

1 Final-product orientation. The final product is a primary focus, the production process is considered secondary. Its operations and their sequences are technologically fixed or ‘given’. Product quality is ‘inspected in’, mostly at the end of the process. Statistical quality control, inventory control, cost minimisation, mass production, assembly lines, work specialisation, hierarchies of command, mass consumption, statistical mass markets and forecasting are among the defining characteristics of this stage.

2 Process-operations orientation. It is the high-quality process that assures the high-quality product, but not vice versa. The main focus is on the improvement of process operations. Quality of the process was understood as the quality of its operations. Powerful new concepts of Total Quality Management, Continuous Improvement (Kaizen) and Just-In-Time systems have characterised this stage. Although the operations are being improved, the process architecture and structural sequencing are kept intact and remain technologically ‘given’.

3 Integrated-process orientation. The focus of attention shifts from operations (circles) to linkages (arrows) – thus changing the process architecture itself. The reengineering of the process, re-integrating individual components into effective, more autonomous and even self-manageable wholes, has characterised this stage. The production process became a business process and therefore subject to qualitative redesign and reengineering (BPR). Discontinuous improvement and process innovation replaced the piecemeal continuous improvement. Traditional vertical hierarchies of command have flattened out into more horizontal, process-oriented networks. Mass customisation, disintermediation, knowledge management and autonomous teams have started emerging.

4 Extended-process orientation. In this current stage, networks of suppliers and communities of customers have extended the internal process into a functional and competitive whole. Both internal and external sources of knowledge and competitiveness form new core competencies. Supply and demand chains management have emerged. Intranets and extranets have provided a communication medium for B2B and B2C exchanges. Quality has become bundled together with cost, speed and reliability.

5 Distributed-process orientation. The emerging stage represents the most radical business refocusing so far. Through the global sourcing, sections and components of the internal process are being outsourced to external providers and contractors in search of the highest added value contribution. Long-term alliances are formed and companies are transforming themselves into networks. Network cooperation is replacing corporate competition: ‘coopetition’ emerges. Globally distributed process brings forth new forms of organisation, coordination and modular integration.
It is necessary to note that the incessant and accelerating paradigm shifting is carried on by the best global players only. The majority of companies (and educational and training institutions) are still in the first, i.e. post-war stage of final product orientation and even the early process orientation has been eluding them. That is how rapid the management evolution has become: the best world-class companies are already in the fifth stage. For those still in the First stage there is little chance of bridging such a rapidly opening chasm, and virtually no way of ‘catching up’.

2 Distributed process and global sourcing

The fifth stage is underlying the move towards the Mobile Society. Global sourcing is propagating the search for the maximum added value worldwide.

The difference between the fourth and the fifth stages is that the extended process involves only the coordination of supply/demand chains, i.e. the flow of external inputs (from suppliers) and outputs (to customers) – the flow of ‘things’, parts and products, to sustain the internal process. The internal process remains intact, being a captive of the firm. In the fifth stage, the internal process is being deconstructed and its pieces transferred to external providers and contractors, to be coordinated and managed externally. In its later stages even the knowledge and coordination is being transferred.

Outsourcing contractors, such as Genpact, Accenture and IBM Services, split the workflow of an entire department, such as HR, IT or Finance; then they reengineer all processes and administer programmes, acting as virtual subsidiaries. The work is dispersed among global networks, producing mobile networks and modular corporation. The process towards such a disaggregated form of corporation allows companies to boost productivity and deliver better products, cheaper and faster.

Typically, outsourced processes include contract manufacturing, testing and design, just-in-time shipping, purchasing, after-sales repairs, training, payroll, billing, call centres, market research, financial analysis, bill collection, etc. Virtually all and any process components can be outsourced. For example, Procter & Gamble has outsourced everything – from IT infrastructure, HR and office management – from Cincinnati to Moscow.

Production process has moved from being fixed and ‘given’, through internal reengineering, to extended coordination. Now it is becoming modular, purposefully disaggregated, physically dispersed and flexibly re-arranged in myriads of variations.

The global sourcing is a reflection of the search for the highest added value on a global scale. Every operation and every string of operations must be adding value. To serve the global customer means that also the highest possible added value must be identified and exploited. Only then can the firm deliver the best quality at the lowest cost and the greatest speed – the necessary condition for sustainable competitive advantage. Short-term competitive smugness, as the recent case of Ford Co. clearly demonstrates, is not sufficient anymore. The key phrase is long-term sustainable advantage (e.g. Sahay, Mohan and Maini, 2004).

2.1 Smiling curve

The outsourcing phenomenon is the best captured by Stan Shih’s ‘Smiling Curve’ (Figure 2). Both external sides of the extended process (R&D and After-sales service) are
claiming larger and larger portion of the added value, both upstream and downstream of the value chain. The value-added ‘smile’ is getting broader and deeper – pointing to new business opportunities and new outsourcing arrangements (Bartlett and Ghoshal, 2000).

**Figure 2** Stan Shih’s smiling curve

The lowest added value is increasingly focused on the internal process, around the centre of the extended process. That is why these sections of the internal process are the best candidates for outsourcing. The low added-value activities are being outsourced – creating new business opportunities for developing economies, while high added value activities are being retained and strengthened – mandating a new business orientation for established companies.

The outsourcing of low-added value activities allows not just reengineering, but also the *new redefinition* of business and its internal processes. That is the true benefit of outsourcing. Business is being redefined according to added-value maximisation, new business forms and practices emerge, powerful innovations flow in from the outsourced networks.

*Outsourced activities produce more stable networks.* Whenever a firm outsources its low added-value activities, the outsourcee firms become long-term providers and suppliers of parts, assembly or sales, often indistinguishable from the company itself. The company itself becomes a network. Cooperation and alliances replace competition and competitive bidding along the entire value chain (Zeleny, 2005).

Similarly on the demand side: *outsourcing to customers* becomes an increasingly effective strategy as self-service, do-it-yourself, disintermediation and mass customisation bring more and more customers into longer-term relationships with the company (Prahalad and Ramaswamy, 2000). More and more of lower added-value activities are outsourced directly to customers who are becoming much more effective in performing them (automated teller machines, hypermarkets, self-serve technology). More in Zeleny (1997, 2001).
As a result, larger firms are transforming into networks of outsourced resources and smaller firms are becoming – through increasingly serving as outsourcees – parts of these same networks. These networks are then further interconnected into partnerships, alliances and contracting arrangements, often even across competing networks. Cooperation complements competition and transforms it into the modern ‘coopetition’.

A network replaces the firm as a unit of competition. Adaptability and flexibility, continuous reshaping and optimisation of networks are now more important to corporate success than operational performance. Strategy for agility and marketplace differentiation is more important than cost reduction and execution – effectiveness drives efficiency. It is more important to do the right things than just doing things right.

2.2 New forms of business

As the resources are being outsourced (offshored), new forms of doing business are being insourced (inshored). Both the outsourcer and the outsourcee benefit.

Some of the new forms are showing strong emergence rates during the fifth stage:

1. **Mass customisation.** Total responsiveness to the customer through individualisation and ‘fit to measure’ products and services. *First sell, then produce.* Let the customer co-design the product. Eliminate tradeoffs because the global customer wants it all: highest quality, lowest cost and greatest speed.

2. **Disintermediation.** Eliminate the middleman: provide the most direct path from the producer to the customer. Unnecessary, non-value-adding links of dealers, agents, wholesalers, retailers, warehouses, etc. are being reexamined or eliminated.

3. **Self-service and Do-it-yourself.** Customers are becoming most effective in performing certain services or completing suitable production processes. Self-service now affects all sectors of the economy as well as many traditional business functions. Customer is being integrated into the production process.

4. **Work at home.** Now called *homeshoring*, utilising SoHo (Small office/Home office). Home is now becoming a very effective location for distributed product and service delivery, source of new productivity and the main driver of the search for productivity. (JetBlue has 1,400 reservation agents working from home.)

5. **Menu-based delivery.** The customer pays only for what he wants, not for unwanted packages, bundles, fixed fees and other ‘creative’ rip-offs. Assorted Pay per View, Pay per Song and Pay per Program innovations are now being expanded into Pay per Time (on the phone, computer, online), Pay per Module, Pay per Page and Prepaid cards for everything. Digitisation technology allows these forms to propagate rapidly.

6. **Co-location.** Suppliers do not just deliver parts, they deliver *functional* parts, i.e. they install and test them directly at customer’s plant or locality. Co-location is going to expand from manufacturing to services, tying up with the increasing work at home.

Outsourcing does not just export jobs; it imports innovation, knowledge and productivity. It adds value and the workers must move to higher added-value activities.
3 What is added value?

The increased mobility, both real and virtual, is the result of the search for the best portfolio of added-value activities. *The global search for the added value is at the core of the Mobile Society.*

Added value is becoming the most effective measure of business. Minimising cost, maximising speed, maximising quality, etc., all these performance measures are ineffective if no value is being added.

Essentially, *added value is the measure of human knowledge* embodied in the coordination of the production or service delivery processes: all other inputs can be purchased, internally or externally, and in themselves do not add value. However, also knowledge, measured by added value, has become mobile, ‘hitting the road’ in search of its highest appreciation.

The value of information is intangible, unless it is translated into knowledge and thus into measurable action (Zeleny, 1987, 2006).

Knowledge is measured by the value our *coordination* of effort, action and process adds to materials, technology, energy, services, information, time and other inputs used or consumed in the process. Coordination of globally distributed supplier and customer networks is the most sought after function, skill and knowledge of the future. Coordination knowledge is becoming the highest added value activity. *Knowledge is measured by added value*; see also Zeleny (2005).

In any business (and human) transaction, value has to be *added to both* participants or sides: the provider and the customer. Adding value is what makes the transaction satisfactory and sustainable.

There are two kinds of value to be created: *value for the business* and *value for the customer*. Both parties must benefit: the business — in order to make it; the customer — in order to buy it. In the global age it is precisely this business-customer *value coopetition* that is emerging as the hardest and the busiest battleground.

In Figure 3 we explain the process of creating new value.

**Figure 3** Adding value

![Diagram](image-url)
First, the customer pays for the service or product: the *Price paid*. The producer subtracts the *Cost*, covering all direct and indirect materials and services purchased. The difference is the *added value* for the business. This added value can also be interpreted as the *value of knowledge* engaged in producing the service or product. In order to pay wages and salaries, the production process and its coordination must generate sufficient added value. Added value is the only true source of corporate wages, salaries and profits.

If the added value does not cover the wages and salaries, then these must be correspondingly lowered. If no value is being added, then the value of knowledge is zero and no payment should be attributed to it. The business must add enough value in order to cover at least its workers and managers, their salaries and wages. If even more value has been created, then *profits* can be realised, up to the price received.

The customer, of course, must be ready and willing to pay more for the service/product than he actually paid. The *maximum price* the customer would be willing to pay must exceed the price the producer has asked for. The difference is the added value for *customer*.

If there is no value for customer – when the maximum price is lower than the price to be paid – then the customer should not buy the service or product. In a competitive market, the customer pays only for the value received, i.e. for the value for the customer (Jackson, 2004).

3.1 Global customer

The customer is changing from the relatively uninformed, unsophisticated and unskilled local customer of the past to his new embodiment: The *Global Customer*.

Market dominance is steadily shifting from producers to customers and consumers. The emergence of the *global customer* mandates that a globally effective management system must emerge as well. Global customers want things cheaper, better and faster, year after year, with no end in sight. In fact, they want it all: *Free, Perfect and Now*.

Without paying sufficient attention to customers, a company would be doomed to keep delivering *either* low cost *or* high quality *or* high speed, but never all the requisite dimensions together. Yet, what is needed in the global economy is to deliver *all*: low cost *and* high quality *and* high speed. The need for a shift from Strategy *OR* to Strategy *AND* is undisputable:

<table>
<thead>
<tr>
<th>Global Producer</th>
<th>Global Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Cost</td>
</tr>
<tr>
<td>OR Quality</td>
<td>AND Quality</td>
</tr>
<tr>
<td>OR Speed</td>
<td>AND Speed</td>
</tr>
<tr>
<td>OR Reliability</td>
<td>AND Reliability</td>
</tr>
<tr>
<td>OR ...</td>
<td>AND …</td>
</tr>
</tbody>
</table>

4 Conclusion

The mobile society is here to stay. Global sourcing is its main driver and the necessary collaboration and communication technology effectively supports the outsourcing trends. Disaggregated processes lead to modular corporations, being continually assembled,
operated and disassembled according to the rapidly changing needs and preferences of global customers and the never-ending search for higher added value.

References


Array-based logic for realising inference engine in mobile applications

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Abstract: Mobile and wireless devices suffer from technological limitations such as limited battery life and limited memory size. Hence, the use of technologies for mobile applications is confined to those technologies that are faster and take small footprint in memory. Firstly, this paper presents a survey of technologies that can be used for realisation of inference engine, satisfying the qualities mentioned above. Secondly, this paper introduces a Scandinavian invention called array-based logic that enables realisation of inference engines for decision-making which are compact and fast. Finally, a case study is presented to show how easy it is to use array-based logic for realising inference engine in mobile applications.

Keywords: array-based logic; logic modelling; mobile ad hoc network; mobile applications.


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1 Introduction

Mobile devices have become indispensable tools these days. Since mobile devices have limited resources, the research and application of technologies in these areas are confined to those technologies that are:

- Faster: in order to save battery life and to accommodate synchronous (blocking) communication.
This paper introduces a logic technology called array-based logic for realising inference engines in mobile applications. Section 2 presents a literature review of technologies that can be used for realisation of inference engines. Section 3 introduces array-based logic.

As mentioned earlier, among other issues, battery life and memory size are critical issues in mobile devices. Battery life and memory size are the two dependent variables of independent variables like processing time and program code size, respectively. Thus, if array-based logic minimises processing time, it also implies that the usage of array-based logic saves battery life. Similarly, if array-based logic minimises program code size, it also means that the usage of array-based logic demands less memory. The case study given in Section 4 proves minimisation of the two independent variables, processing time and program code size; implication is that battery life is increased and less memory is needed.

The case study talks about developing an inference engine for evaluating a Mobile Host (MH) as the call manager in Mobile Ad hoc wireless NETwork (MANET). This is a simple problem dealing with a small set of logic variables. Since the size of this problem is small, it is true that many logic technologies could be used to solve this problem, and the usage of array-based logic will not make any considerable difference. The benefits of array-based logic will be apparent when large and complex problems with many logic variables are considered. However, the case study is intentionally made small to give emphasis also to the modelling and simulation approach behind array-based logic; this modelling and simulation approach is unique and is based on the ‘theory of connection’ (e.g. Davidrajuh, 2000).

2 Literature review

The aim of logic in industrial applications is to develop a formal method for modelling problems so that decisions can be made out of the models and it can be made automatically, for example, by an inference engine. In order to create models, a language is needed with which sentences can be created in such a way that forms the logical structure of the model.

2.1 Propositional logic

The first language that can be used for logic modelling is the language of propositional logic. It is based on propositions or declarative sentences, which can be argued as being true or false; thus, propositional logic is concerned with the validation of an argument consisting of a set of propositions that are split up into a number of premises and conclusions. The Boolean logical variables describe the facts in the premises, and the premises themselves describe the system when combined together (Davidrajuh, 2000; Huth and Ryan, 2000).
2.1.1 Formal language

In propositional logic, symbols are used to compress a large set of English declarative statements into a compact logic model. Suppose a logic model consists of a set of premises $\phi_1, \phi_2, \ldots, \phi_n$ and a conclusion $\varphi$, then the logic model is expressed by the sequent:

$$\phi_1, \phi_2, \ldots, \phi_n \vdash \varphi$$

By applying proof rules on these premises, the validity of the conclusion is found (Huth and Ryan, 2000).

2.1.2 Mathematical reasoning approach

By the use of propositional logic, modelling a logic system can be done exactly like modelling a physical system (Bjørke, 2000). First, the fundamental logic variables (also called primitive logic elements) are identified and each logic variable is assigned an axis; thus the logic variables span the whole universe of discourse (total space), see Figure 1a. Then the logic variables are connected into premises, thus creating a subspace of the total space, see Figure 1b. Finally, the premises are combined to form the logic system, connecting subspaces spanned by the premises. There are some differences between the space span by the physical systems and logical systems; logical spaces are always linear and discrete.

Figure 1  Configuration space spanned by the logic variables

Let us say that a logic system consists of three primitive logic variables, Temperature (with domain values 'low', 'high'), Alarm ('off', 'on'), and Power ('off', 'on').

The space spanned by the primitive logic variables Power, Alarm and Temperature  

The subspace spanned by the combination  

$$\left[ (\text{Temp is 'low'} \text{ AND (Alarm is 'off') OR (Power is 'on')}) \Rightarrow (\text{Power is 'on'}) \right] \text{ AND } \left( [\text{Alarm is 'on'} \text{ OR (Power is 'off')}] \Rightarrow (\text{Power is 'off'}) \right)$$

By connection spaces that do not satisfy the constraints are removed, leaving a smaller space that represents the feasible solution (Figure 1); this is after Lagrange, who in analytical mechanics developed the free variational method. Thus Lagrange developed
the mathematical foundation for basic procedures of logic modelling, and it was Pierce who applied these procedures (constraint satisfaction) to logical problems (Møller, 1995).

2.1.3 Advantages and disadvantages of propositional logic

This logic representation is useful in providing formal proofs as it offers clarity. Logic systems modelled with propositional logic is well defined and easily understood (Kusiak, 1997). Also, a Cartesian axis is assigned to each logic variable in the system by the mathematical approach for modelling logic systems, generating subspaces spanning all possible states of all the variables and hence providing a complete representation. However, there are two serious shortcomings of propositional logic that disqualify itself as the technology for realising inference engine:

1. **Exponential growth**: Though propositional logic offers complete systems, the representation is huge; this means, the resulting space of $2^M$ subspaces for $M$ Boolean logic variables. This exponential growth (also known as combinatorial explosion) of the subspaces with increasing number of variables makes the modelling and simulation slower. Thus, propositional logic is not suitable for realising the inference engine.

2. **Lack of quantifiers**: Though propositional logic uses simple Boolean connectives like negation (‘not’), conjunction (‘and’), disjunction (‘or’), if-then (‘direct implication’), it lacks quantifiers like ‘all’, ‘among’, ‘only’, ‘at least one’, etc. This limitation is restored in predicate logic.

2.2 Predicate logic

This is much like propositional logic, but with its quantifiers it is possible to express all arguments occurring in natural language. In other words, precise symbolic logic model equivalent to a set of English language statements is possible.

2.2.1 Formal language

A predicate logic formula has three entities: variables, functions that describe relationships between variables and terms that are expressions consisting of constants, variables and functions. Because of the power of predicate logic, the language is much more complex than that of propositional logic; interested reader is referred to Huth and Ryan (2000).

2.2.2 Mathematical reasoning approach

In the mathematical approach for modelling, predicate logic systems is similar to that of propositional logic systems; a Cartesian axis is assigned to each logic variable in the system, generating subspaces spanning all possible states of all the variables and hence providing a complete representation making a huge representation if large number of logic variables are involved. Thus, advantages and disadvantages of predicate logic are similar to that of propositional logic.
2.3 Production rules

Production rules are in effect subsets of predicate calculus with an added prescriptive component indicating how the information in the rules is to be used in reasoning. A production rule has the following form (Kusiak, 1997):

\[
\text{IF (condition)} \quad \text{THEN (conclusion)}
\]

2.3.1 Mathematical reasoning approach

The basic reasoning approach employed for production rule is searching: starting with a set of facts and look for those rules in which the IF clause matches the facts; if such rules are found (‘hit’), then proceed to the THEN clause. This reasoning is known as ‘forward reasoning’. In ‘backward-reasoning’, searching starts with a set of desired goals and to look for those rules in which the THEN clause (conclusion) matches the goals. Figure 2 shows an example with six rules, using forward reasoning (or bottom-up search). As shown in Figure 2, it is usual to use AND/OR tree to illustrate the inference process.

**Figure 2**  Forward reasoning inference process
2.3.2 Advantages and disadvantages of production rules

The main advantage is that the simple rules are easy to understand, modify and extend. However, there are some shortcomings: In production rules, a logic system is evaluated with a couple of ‘if-then’ statements, taking a linguistic view than a mathematical approach. This means, for $M$ multi-valued logic variables with $N$ values $N^M$ ‘if-then’ statements are needed to span all combinations of the variables; missing any of these statements may cause unexpected results. For a large system of many logic variables, it is impossible to write so many if-then statements to take care of all possible combinations of variables; thus creating a complete model is not easy and prone to errors. In addition to this shortcoming, there is another serious problem: the reasoning approach based on searching is slow.

2.4 Fuzzy logic

In relation to classic logic, fuzzy logic, in a narrow sense, can be considered as an extension and generalisation of classic multi-valued logic (Klir and Yuan, 1995). Fuzzy logic is a promising technology to realise inference engines and is used in diverse industrial applications. For a detailed study about fuzzy logic, see Adcock (1993), Tsoukalas and Uhrig (1997) and Yager and Zadeh (1991).

2.4.1 Formal language

Fuzzy logic is a methodology for expressing operational laws of a system in linguistic terms, instead of mathematical equations. Systems that are too complex to model accurately using mathematics can be easily modelled using fuzzy logic’s linguistic terms. These linguistic terms are most often expressed in the form of logical implications, such as fuzzy if-then rules. For example, a fuzzy if-then rule (or simply a fuzzy rule) looks like:

\[
\text{IF delivery\_time is LATE} \\
\text{THEN supplier\_preference is LOW}
\]

The terms LATE and LOW are actually sets that define ranges of values known as membership functions. By choosing a range of values instead of a single discrete value to define the input parameter ‘delivery\_time’, we can compute the output value ‘supplier\_preference’ more precisely.

2.4.2 Inference mechanism

Inference mechanism in fuzzy logic is based on fuzzy rules that connect input and output parameters (fuzzy rule base) and the membership functions for input and output parameters. To create an inference engine, first the membership functions for input and output parameters are developed; both a range of values and a degree of membership define membership functions.

Inference mechanism in fuzzy logic is implemented in three phases (see Figure 3):
Figure 3  The three phases of inference mechanism in fuzzy logic

- **Phase 1**: fuzzification phase (converting crisp input value into fuzzy value)
- **Phase 2**: inference phase (computing fuzzy output value by the fuzzy rules base)
- **Phase 3**: defuzzification phase (converting fuzzy output value into crisp value)

2.4.3 **Advantages and disadvantages of fuzzy logic**

Fuzzy logic offers fast inference and compact executable code that can be downloaded into micro-controllers for embedded applications. Fuzzy logic is also easy to learn and use. However, it has some limitations too.

1. Fuzzy logic has limited tuning; if one wanted to change the pattern the output parameters that are computed from the input parameters, then in addition to changes in the fuzzy rule base the membership functions of the input and output parameters must be changed too.

2. Fuzzy logic does not guarantee completeness; it is up to the designer to include all the fuzzy rules connecting all possible combinations between the input and output parameters.

3. There is difficulty in generating fuzzy rule base. The fuzzy rules generated for an application must be consistent; they must properly adhere to the process dynamics with no contradictions between rules. Generating the antecedent (the IF part) of a fuzzy rule is easy; but generating the consequent of a fuzzy rule (the THEN part) is not easy as it demands deep understanding of the process dynamics (Davidrajuh, 2000).

2.5 **Array-based logic**

The previous subsections state that a complete representation of $M$ multi-valued logic variables with a domain of $N$ values contains $M^N$ subspaces. This exponential growth of the subspaces with increasing number of variables makes the modelling and simulation slower. Array-based logic developed by G.L. Møller avoids this exponential problem by compressing $N^M$ subspaces into $M \times N$ linear representation (Møller, 1995). Array-based logic also provides mechanisms for operations to operate on the compressed representation in linear time.

2.5.1 **Formal language**

In addition to Boolean variables and multi-valued variables, array-based logic allows also quantitative (e.g. intervals) to be treated as logic variables. There are three types of variables in array-based logic: the nominal logic variables (Boolean and multi-valued),
ordinal logic variables (e.g. coordinate is [2, 2], [4, 2] or [3, 3]) and intervals (e.g. cost is between 50 and 100).

Structured Array-Based Logic (SABL) is a formal language of array-based logic for modelling, logic programming and implementation of logic systems; interested reader is referred to Davidrajuh (2000).

2.5.2 Inference mechanism

The inference mechanism used in array-based logic is geometry or topology of connections between fundamental components of a system. A system consists of three fundamental components: elements, connections and sources. Elements carry all the physical properties of the system; thus, elements are the fundamental building blocks of a system. Connections reflect how elements in a system influence each other; thus, connections represent the structure of a system. Finally, sources reflect the influence between a system and its environment. Sources are the environment’s influence on a system.

The inference mechanism consists of three phases; see Davidrajuh (2000) for details:

- **Phase 1**: identifying the primitive system
- **Phase 2**: making the connected system
- **Phase 3**: applying the sources and solving the connected system.

2.6 Summary

Table 1 presents the summary of the literature review. It reveals that array-based logic satisfies all requirements on the qualities for realising an inference engine (such as high processing speed and compact size) for mobile applications. However, this does not mean that array-based logic is the only or the best option for realisation of every inference engines. On the contrary, the type of the inference engine or the modelling problem under scrutiny determines the technology for realisation. For example, if the model could be best expressed by a set of English statement that approximately describes the dynamics of the system, then fuzzy logic is perhaps the best technology for the realisation of the system.

Table 1

<table>
<thead>
<tr>
<th>Technology</th>
<th>Property (relation)</th>
<th>Inference mechanism</th>
<th>Inference cycle time</th>
<th>Complete system</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propositional logic</td>
<td>Boolean truth values</td>
<td>Modus, ponus, etc.</td>
<td>Slow</td>
<td>Yes</td>
<td>Not compact</td>
</tr>
<tr>
<td>Predicate logic</td>
<td>Any predicate</td>
<td>Same as propositional</td>
<td>Slow</td>
<td>Yes</td>
<td>Not compact</td>
</tr>
<tr>
<td>Production rules</td>
<td>IF-THEN</td>
<td>Searching</td>
<td>Slow</td>
<td>No</td>
<td>Not compact</td>
</tr>
<tr>
<td>Fuzzy logic</td>
<td>Fuzzy rules</td>
<td>Membership functions and fuzzy rule base</td>
<td>Fast</td>
<td>No</td>
<td>Compact</td>
</tr>
<tr>
<td>Array-based logic</td>
<td>Any predicate</td>
<td>Geometry</td>
<td>Fast</td>
<td>Yes</td>
<td>Compact</td>
</tr>
</tbody>
</table>
3 Structured array-based logic

Array-based logic guarantees complete solutions (explained later), compact code, as well as fast computation (for real-time applications). Array-based logic was written in APL language; APL is a primitive symbolic language that is hard to learn and use. Davidrajuh (2000) ported array-based logic to MATLAB environment with some additional functions, and named it ‘structured array-based logic’.

SABL toolbox consists of two types of functions:
1. propositional logic functions and
2. array-based logic functions.

Propositional logic functions are for basic mathematical treatment of the logic system after Lagrange and Pierce. Though the configuration spaces will be large (exponential growth with increasing number of variables). By using the propositional logic functions, it will be complete; that is, the configuration space includes all possible combinations of the logic variables. Array-based logic functions are enhanced logic functions for modelling and simulation of logic systems using a compression technology that provides compact representation of configuration space and faster simulation, without losing completeness. The following subsections present these two types of logic functions.

3.1 Propositional logic functions

All the logic variables (primitive elements) that are used in a system are to be declared first; it is the function element that is used for declaration. Relevant to the function element is the function assign; this function changes the values of a logic variable.

For example, declaration of a multi-valued logic variable ‘Colour’ with a domain of three values ‘red’, ‘green’ and ‘blue’:

\[
\text{Colour} = \text{element}('n',\{\text{red}, \text{green}, \text{blue}\},\{\text{green}\}, \text{\textquote{\textquote{Colour}}});
\]

The first argument ‘\textquote{n}’ indicates that the variable is multi-valued (or Boolean). The second group of input argument are values (of domain), the third group is the default values selected at the time of declaration (in this example, default value is ‘green’), and the final input argument is the label or name of the variable. After declaring a logic variable, values of the variable could be changed with the function assign:

\[
\text{ColourRED} = \text{assign}('\textquote{red}', \text{\textquote{Colour}});
\]

**Definition 1.** Basic operations. A logic system can be built by applying the following four basic operations on variables: disjunction (V), direct-implication ($\geq$), nand and converse-implication. These four operations are known as the Klein four group. Other logic operations can be derived from these four basic operations. The functions for these four operations are, disjunct, dimp, nand and cimp, respectively.

\[
\text{e.g. if Premise1} = (\text{ColourRED} \geq \text{AlarmON}) \text{ then Premise1 is declared as:}
\text{(Premise1} = \text{dimp(ColourRED, AlarmON));}
\]

**Definition 2.** Colligation. If the same variable occurs more than once in a premise or in a combination of premises, then duplicate axes will be found in the configuration space.
The process of removing superfluous axes without losing any information is called Colligation. The function that performs colligation is fuse.

\[
\text{e.g. if System} = \text{disjunct(Premise1, Premise2), where} \\
\text{Premise1} = \text{dimp(ColourRED, AlarmON) and} \\
\text{Premise2} = \text{dimp(ColourGREEN, AlarmOFF)}
\]

Then, the system contains two copies of logic variables, Colour and Alarm (or mathematically, two axes each for Colour and Alarm). Duplicates of Colour and Alarm must be removed (or the axes are fused together):

\[
\text{System} = \text{fuse(System)};
\]

### 3.2 Array-based logic functions

The following definitions present the main functions for array-based logic.

**Definition 3.** Compressed representation. Compressed representation is to keep the relation (premises, subsystems or system; see Figure 2) to a minimal size without losing any information. The function used for compression is compress.

In compressed form, functions like join, deduct, etc. make use of the compressed (compact) representation for faster computation. The function join connects premises together via the common variables they possess; the resulting relation (subsystem, or system) will be in compressed form. Compression technique is similar to the Karnaugh map (K-map) reduction done in digital electronics.

**Definition 4.** Intervals as logic variables. Array-based logic facilitates intervals to be treated as logic variables too. An interval variable may contain many intervals, each of which may be true or false.

To declare an interval, the function interval is used. e.g.:

\[
\text{LowerInterval} = \text{interval(‘ge’, 85, ‘lt’, 98)}
\]

This means, the LowerInterval is greater than or equal to 85, and less than 98.

An interval variable is created using the function element. e.g.:

\[
\text{InputPrice} = \text{element(‘i’, \{LowerInterval, UpperInterval\}, ‘Input Price’)}
\]

where the first argument ‘i’ indicates that the variable to be created is an interval variable, and the final argument is a label of the variable.

**Definition 5.** Deducing conclusions. Deduction (or inference) is to draw conclusion from a connected system. Deduction is performed by the function deduct, which makes the OR – projection of all the axes complementary to the variables concerned, on the axes of the variables.

The final definition is about the state of a system.

**Definition 6.** State of a system. The state of a system is the information required of the system to uniquely determine an output for an input to the system. The output is a vector of output variables, which is computed from the input vector of variables and the system (see Figure 4), using the function state.
Allowing quantitative variables to be treated as logic variables facilitates numerous advantages in modelling large logic systems. Use of propositional and array-based logic functions will become clear in Section 4 where a case study is done on mobile platform. See Davidrajuh (2000) for more elaborate explanation of the logic functions.

4 Case study

Section 3 proved that array-based logic provides fast computation and compact code. In this section, a case study is provided to show whether it is also easy to develop (program) an inference engine. Case study deals with an inference engine that is to be used to evaluate a MH as the call manager; the call manager is to manage MHs in a specified area in MANET. MANET is a mobile network where any mobile device (mobile phones, personal digital assistants, etc.) located inside a specified area can act as the call manager. Selecting a call manager is an important problem and is discussed widely in literature; see for example Yan et al. (2004).

4.1 The best MH

Yan et al. (2004) proposes an algebraic equation for selection of the best MH as the call manager in a specified area in MANET. The equation computes the total cost of a MH that is under evaluation. After calculating the total costs of all the MHs, the one with the minimal cost is selected as the call manager in the specified area. The equation is:

\[
c_i = (w_1 \times d_i) + (w_2 \times s_i) + (w_3 \times p_i)
\]

where \(d\) is the distance between the MH to the centre of the specified area, \(s\) is the average speed of the MH and \(p\) is power cost; \(w_1, w_2\) and \(w_3\) are coefficients (weighting factors). Thus, the equation calculates total cost of an MH in terms of its distance from the centre, its speed and its battery power. In summary, using the equation proposed by
the Yan et al. (2004) demands the calculation of total cost of all the MHs in the specified area so that the best MH (the one with minimal cost) can be selected as the call manager. Since, calculating total costs of all the MHs in the area to find the best MH takes time, this paper proposes selection of an optimal MH (rather than the best MH) as the call manager. If an MH under evaluation satisfies the selection criteria, then it is selected as the call manager and the selection process is terminated; this means the selection process does not evaluate all the MH in that area.

4.2 The optimal MH

This paper proposes a selection process that uses a logical equation rather than an algebraic equation. The logical equation is based on Yan et al. (2004) in the sense that the logical approach uses distance, speed and power as input parameters for the selection process. In the logical approach, first the primitive logic variables (elements) are identified. Then these variables are grouped into premises using the logic operators like disjunct, dimp, etc. Finally, the premises are joined to make the complete system.

It is assumed that the inference engine receives information from MHs in the specified area about their distance from the area centre, their speed and about their power capacities (Figure 5). For brevity, how the information is sent to the inference engine is not discussed here.

Figure 5 The inputs and outputs of the inference engine

The selection is based on three data (Figure 5): distance of MH from the centre of the area, speed of the MH and the power cost of the MH. To make decisions based on the data, the inference engine needs three set points (one for each input). These set points are fine-tuned to make the selection process agile; suppose all MHs fail in the selection process, then the set points are relaxed a little to make some MHs pass the selection process.

Figure 6 shows the logic variables and the premises that make up the complete system. The first three premises deal with the input values. The input (numeric) values for distance, speed and power cost are used to assign values to some auxiliary logic variables. In effect, the first three premises are about converting interval variables into
nominal (Boolean or multi-valued) variables. Premises 4 and 5 uses the auxiliary logic variables to compute the conclusion.

Figure 6  Logic model of the inference engine

4.3 Premises 1–3: dealing with the input values

Premises 1–3 deal with the input values named as inputDistance, inputSpeed and inputPower. Premises 1–3 are to convert the input numerical values into auxiliary logic variables named distance, speed and power, respectively.

4.3.1 Dealing with inputDistance

If the distance is greater than the set point for distance, then the distance is ‘long’. If the distance is less than or equal to the set point for distance, then the distance is ‘short’. To formulate this logic statement, two logic variables are needed: a multi-valued logic variable ‘distance’ with the domain values of ‘long’ and ‘short’ and an interval logic variable ‘InputDistance’ with two intervals, one interval between minimum possible distance to set point and the other interval between set point to maximum possible distance.

To declare the logic variable distance:

\[
\text{distance} = \text{element}(\mathcal{D}, \{\text{short}, \text{long}\}, \{} , \text{distance});
\]

Before declaring the interval variable InputDistance, a value should be assigned to the set point for distance. It is assumed that the given value for set point is 2 km, the minimum possible value for distance is 0 km and the maximum possible value is 5 km.

\[
\text{DistanceSetPoint} = 2; \text{MinDistance} = 0; \text{MaxDistance} = 5;
\]

To declare two intervals, the lower interval and the upper interval:

\[
\text{LowerInterval} = \text{interval}(\ge, \text{MinDistance}, \le, \text{DistanceSetPoint});
\]

\[
\text{UpperInterval} = \text{interval}(\gt, \text{DistanceSetPoint}, \le, \text{MaxDistance});
\]

Declaraing the interval variable InputDistance:
InputDistance = element('i', \{LowerInterval, UpperInterval\}, ‘InputDistance’);

Finally, declaring the Premise 1: (DistanceIsFair) if and only if (FairDistanceRange)

\[ \text{ShortDistanceRange} = \text{assign}(\text{InputDistance}, \text{LowerInterval}); \]
\[ \text{DistanceIsShort} = \text{assign}(\text{distance}, \{‘short’\}); \]
\[ \text{Premise 1} = \text{bimp}(<\text{ShortDistanceRange}, \text{DistanceIsShort}>); \]

4.3.2 **Dealing with speed**

If the speed is between the minimum possible speed and the first set point for speed, then
the speed is ‘slow’. If the speed is between the first and second set points, then the speed
is ‘moderate’. On the other hand, if the speed is between the second set point and the
maximum speed, then the speed of the MH is ‘fast’. To formulate this logic statement,
again two logic variables are needed: a multi-valued logic variable ‘speed’ with the
domain values of ‘slow’, ‘moderate’ and ‘fast’, and an interval logic variable
‘InputSpeed’ with three intervals. The first interval (LowerInterval) is between the
minimum possible speed and set point-1, the second interval (MiddleInterval) is between
the set points and the third interval (UpperInterval) is between set point-2 and anticipated
maximum speed.

Formulating the Premise 2 that deals with the inputSpeed is very similar to Premise 1
for inputDistance. The only difference is that speed has three intervals whereas distance
has two intervals. For brevity, detailed formulations are not shown here.

4.3.3 **Dealing with power cost**

Premise 3 for power is formulated very similar to that of Premise 1.

4.4 **Premises 4 and 5: accepting or rejecting a MH**

The auxiliary logic variables distance, speed and cost are used to compute Premise 4.
Premise 4 is about the conditions for accepting MH as the call manager. A MH should be
selected if and only if all three inputs values are within the acceptable regions, like
distance is ‘short’, speed is ‘moderate’ or ‘fast and power is ‘moderate’ or ‘superior’.

First the logic variable Conclusion is declared:

\[ \text{Conclusion} = \text{element}(‘n’, \{‘reject’, ‘select’\}, \{\}, ‘Conclusion’); \]

Now the acceptable conditions:

\[ \text{AcptDIS} = \text{assign}(\text{distance}, \{‘short’\}); \]
\[ \text{AcptSPE} = \text{assign}(\text{speed}, \{‘moderate’, ‘fast’\}); \]
\[ \text{AcptPOW} = \text{assign}(\text{power}, \{‘moderate’, ‘superior’\}); \]
\[ \text{AcptCondition} = \text{conjunct}(\text{AcptDIS}, \text{AcptSPE}, \text{AcptPOW}); \]

For these acceptable inputs, the conclusion is ‘select’:

\[ \text{Action} = \text{assign}(\text{Conclusion}, \{‘select’\}); \]
Finally, the Premise 4 is for accepting a MH (selecting a MH): Conclusion is ‘select’ if and only if \([(\text{distance is ‘short’}) \land (\text{speed is ‘moderate’/’fast’) \land (\text{power is ‘moderate’/’superior’})]\):

\[\text{Premise 4} = \text{bimp}(\text{AcptCondition, Action});\]

4.4.1 Premise 5: rejecting a MH

A MH should be rejected if any one of the following conditions is met: distance is ‘long’, speed is ‘slow’ or power is ‘inferior’.

The conditions for rejection:

\[\text{RejtDIS} = \text{assign}(\text{distance}, \{\text{‘long’}\});\]
\[\text{RejtSPE} = \text{assign}(\text{speed}, \{\text{‘slow’}\});\]
\[\text{RejtPOW} = \text{assign}(\text{power}, \{\text{‘inferior’}\});\]
\[\text{RejtCondition} = \text{disjunct}(\text{RejtDIS}, \text{RejtSPE}, \text{RejtPOW});\]

For these inputs, conclusion is ‘reject’:

\[\text{Action} = \text{assign}(\text{Conclusion}, \{\text{‘reject’}\});\]

Finally, Premise 5 for rejecting a MH: (Conclusion is ‘reject’) if and only if (distance is ‘long’ OR speed is ‘slow’ OR power is ‘inferior’):

\[\text{Premise5} = \text{bimp}(\text{RejtCondition, Action});\]

4.4.2 The connected system

The system is the combination of the five premises. That is,

\[\text{System} = \text{join}(\text{Premise 1, Premise 2, Premise 3, Premise 4, Premise 5});\]

When the five premises are joined using the function join, it removes duplicate variables in the connected system and leaves the connected system in compressed form; the three auxiliary variables (distance, speed and power) are only to help compute the conclusion from the input numeric values and thus in the final system. Thus they must be removed.

\[\text{Inputs} = [\text{InputDistance InputSpeed InputPower}];\]
\[\text{SYSTEM}_F = \text{deduct}(\text{[Inputs Conclusion], System});\]

The final system (SYSTEM_F) is compact and complete. This is the core of the inference engine. Because it operates in linear time, the decision made by the inference engine is also fast.

4.4.3 Simulations on the connected system

Some sample input values are input to the inference engine:

\[\text{InputDIS} = \text{assign}(\text{InputDistance, 1});\]
\[\text{InputSPE} = \text{assign}(\text{InputSpeed, 4});\]
\[\text{InputPOW} = \text{assign}(\text{InputPower, 8.2});\]
Making a source vector of sample inputs:

\[ \text{TestInputVector} = [\text{InputDIS \ InputSPE \ InputPOW}] \]

Applying the source (vector of sample inputs) to the system, the outputs are generated:

\[ \text{output} = \text{state(TestInputVector, SYSTEM_F)} \]

Using the print system, the output is echoed on the screen:

\[ \text{print(output)} \]

The output of the system (printed on the screen) is:

**Conclusion**: select

This means, for the given input values and for the given set points, the MH is selected as the call manager.

5 Managerial implications

The most difficult aspect of developing applications for the mobile platform is that the applications must satisfy at least three basic criteria: they must be memory friendly (compact code); they must run fast (take minimal execution time, for example, to save battery); and the tools for development must facilitate fast and easy development. This paper presents a logic technology called array-based logic that guarantees applications developed by this technology fulfill the three criteria; array-based logic operates on a linear (compact) space thus the code size is small; the operations on it are faster (takes linear time); and it is also easy to use this tool.

This paper also presents a structured language of array-based logic called SABL, which is a toolbox of functions written in MATLAB language. This toolbox can be used for modelling and simulation of logic programs as shown in the case study; the case study deals with developing an inference engine for selection of a mobile device as the call manager in MANET. The case study is intentionally kept small just to give emphasis to the modelling and simulation approach behind array-based logic; this approach is unique and is based on the theory of connection.

Reference


Knowledge transformation for education in software engineering

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Abstract: The use of Knowledge Management (KM) is increasingly relevant to education for the management of information and knowledge resources. It is important that educational organisations adapt to mobile learning using existing established frameworks for evaluation. In particular, strategies for KM within the university context need to be understood. This article examines the industrial Socialisation Externalisation Combination and Internalisation (SECI) model of KM and how it is applied to the educational domain. The purpose of this investigation is to analyse the KM supported by different technologies within a SECI framework, in the Software Engineering (SE) programme within a university, and how this may support learning. Results indicated that the SECI model was an incomplete representation of KM in this context. An increased understanding of the technology that supports each aspect of the model would contribute to KM and thus constructive aspects of learning at universities as they move to mobile modes of learning.

Keywords: empirical; knowledge management; mobile learning.


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1 Introduction

As a central element in organisational continuity and growth in today’s competitive
global market, Knowledge Management (KM) has been highlighted as an important
factor that enhances executive decision-making and enables companies to prosper in the
economic environment. The concept of KM reflects the transformation currently
occurring in many organisations. The advent of the 21st century has seen a greater need
for organisations to become more dynamic, tempered by their ability to build upon
successive experiences to improve business processes. Today, almost 80% of the world’s
largest organisations have implemented KM solutions (Lawton, 2001). There is concern
that ‘what knowledge to manage is a significant challenge’ (Housel and Bell, 2001).
Perhaps, an even greater challenge is how knowledge can be managed, given the
complexity of business environments and demands they place upon individuals.

KM is vital in the private sector, and researches into KM practices have found that
KM can lead to improvements in the educational sector as well (Aurum, Parker and Cox,
2004). Potential benefits include better decision-making capabilities for academics,
reduced development cycles for curriculum development, improved academic and
administrative services as well as reduced costs (Kidwell, Vander Linder and Johnson,
2000; ISKME, 2003). Already the management of knowledge is regarded as a main
source of competitive advantage for organisations (Andersen, 1996; Nonaka and
Takeuchi, 1995; ISKME, 2003; Barreto and D’Eredita, 2004).

For educational institutions, KM provides a framework for understanding how to
access new educational developments such as mobile learning projects, improve
educational outcomes, organise their efforts and share resources. In educational research
there have been suggested approaches for students to gain the most out of the tertiary
education. Some of these approaches are supported by KM practices, which should be in
place. In transferring learning and teaching to the mobile environment with the new
technology, it is imperative that established frameworks be used to evaluate these new
processes. For example, an environment that encourages students to learn from each
other’s work, including graduates from previous years, and become more and more
qualified as time progresses is considered advantageous in constructivist educational
theory (Savery and Duffy, 1995) and is part of the KM model of practice (Nonaka and
Takeuchi, 1995). However, this knowledge socialisation process has to be modified by
the need to assess students as individuals, and reduce plagiarism.

As the market for knowledge workers increases, it is appropriate that universities
employ these strategies in their educational endeavours. In 1999, International Data
Corporation’s analyst Gerry Murray forecast that in 2003 an average of 40% of the
workforce from the Fortune 500 companies would be knowledge workers, increased from
20% in 1999 (Murray, 1999). Brown and Duguid (2000) point out the profound changes
in competition in the environment that have made educational institutions think and behave like businesses. Mobile learning is itself one such change; in the past decade many institutions have turned to a new paradigm of education, i.e. online distance education, which uses computers and telecommunication technologies (Na Ubon and Kimble, 2002).

This research uses the Socialisation Externalisation Combination and Internalisation (SECI) model, developed by Nonaka and Takeuchi (1995), to assess the KM practice of an educational institution. SECI is often used to assess the existing support for KM in an organisation, as this model can successfully explain the transition process of KM for individuals in the organisation. This study has two objectives. Firstly, it examines the components of the SECI model of KM as used through technology in education. Then, it investigates how their implementation through technology influences the success of KM practices in an educational context, thus assessing the model in this context. A case study was used to explore KM in education, in particularly for the Software Engineering (SE) programme in University of New South Wales (UNSW). This programme is at present on campus, but is developing online components and has a student population that already accesses mobile resources, such as Personal Digital Assistances (PDAs).

In this study a detailed questionnaire was developed and used to gain an understanding of the current KM uses of technology within the SE degree. While learning takes many forms at the university, some aspects of learning, such as developing a Community of Practice (Wenger, McDermott and Snyder, 2002) and Constructivist Learning, can be supported by KM practices.

The remainder of the paper is outlined as follows. Some of the related work for this study is presented in Section 2. Section 3 presents the case study. The research methodology is described in Section 4. Section 5 introduces the results, which are then further discussed in Section 6. Finally, validity issues are discussed in Section 7 and concluded in Section 8.

2 Literature review

KM is seen as integral to idea creation and improvement, executive decision-making and organisational improvement. It involves transforming information and intellectual assets into enduring value (Kidwell, Vander Linder and Johnson, 2000). It connects people with the knowledge they need to take action, when they need it. In the corporate sector, managing knowledge is considered important in achieving breakthrough competitive advantage. Effective KM programmes identify and leverage the know-how embedded in work processes, with a focus on how it will be applied.

The objective of this section is to provide background on KM. General KM concepts are first introduced to provide a basic understanding of the area in Sections 2.1 and 2.2. Finally, key KM models are discussed in Section 2.3.

2.1 Paradoxical nature of knowledge

The definition of ‘knowledge’ is one that has attracted a significant amount of conjecture (Davenport and Prusak, 1997). Knowledge has been defined as an ‘understanding, awareness, or familiarity acquired through study, investigation, observation or experience over time’ (Borg, Gall and Gall, 1993). It has also been conceived as ‘justified personal
belief that increases an individual’s capability to take effective action’ (Alavi and Leidner, 1999). From the work of Polanyi (1966) emerged a widely accepted classification strategy, categorising knowledge as either tacit or explicit. Tacit knowledge cannot be easily codified, remains highly personal and is difficult to communicate with others (Nonaka, and Takeuchi, 1995). In contrast, explicit knowledge can be formally expressed, is systematic in its application and can be readily processed (Nonaka and Takeuchi, 1995).

In educational theory, often knowledge is distinguished as either action-centred (procedural) or non-action-centred (declarative) (Bruning, 1999). In many cases, it is assumed that procedural knowledge is implicit, while declarative knowledge is explicit. However, the links are more complex. For instance, in learning a procedural skill the process may be accessed through explicit description while some aspects may remain implicit in how processes are conducted in that environment, and will only be learnt through working in different environments, or socialising the knowledge.

Hence, any management of knowledge in education or organisations must be able to handle the transition from explicit knowledge to implicit and from implicit to explicit. At the same time, any explicit knowledge must be combined with other explicit knowledge and some implicit knowledge must be able to be absorbed from your peers implicitly.

2.2 Defining knowledge management

As a result of confusion surrounding the definition of knowledge, the concept of KM is often perceived to be equally as mystifying. A multitude of researchers have associated KM with the management of intellectual assets, the procurement of competitive advantage, the refinement of business processes as well as improvements in quality. KM has been articulated as the ‘capacity of individuals to know’ (Gladstone, 2000), as well as the transfer of tacit to explicit knowledge (Aurum et al., 2003).

A problem emerging from the definition of knowledge is that KM has been ‘myopically interpreted as simply information management’ (Von Kroch, Ichijo and Nonaka, 2000). Although the two concepts may superficially appear similar, information management is concerned with the users of information rather than also incorporating the views of its creators (Gladstone, 2000). When we manage the information, we also want to manage our understanding of the information, or our knowledge. Knowledge is the full utilisation of information and data, coupled with the potential of people’s skills, competencies, ideas, intuitions, commitments and motivations. KM is the collection of processes that govern the creation, dissemination and utilisation of knowledge.

It is argued that, in contrast to information management, KM addresses beliefs, commitment, action and meaning (Nonaka and Takeuchi, 1995). It is this distinction between information and knowledge that makes KM so difficult to analyse, quantify and plan. For we are dealing with the information which resides inside people’s head or is assumed in enacting a company process, as much as that which resides as information on paper or on computer.

The performance of KM may also be assessed in terms of either personalisation strategies, for tacit knowledge, or codification strategies, for explicit knowledge (Hansen, Nohria and Tierney, 1999). An effective KM strategy requires the utilisation of both explicit and tacit (or implicit) knowledge, promotion of knowledge creation and sharing at all levels and availability of appropriate technology (Anderson, 1996; Leonard, 1998).
The cynicism surrounding the introduction of new KM strategies in organisations can partly be attributed to the development of expensive Information Technology (IT) systems that have failed in their attempts to foster knowledge creation and transfer in organisations. Hence, technology can no longer be regarded as a universal panacea for KM.

2.3 Knowledge management models

Over the past few years various KM models have been constructed to provide organisations with a template of how knowledge is transferred, and how it can be best managed (Andersen, 1996; de Jager, 1999; KMAT, 2000; Nonaka and Takeuchi, 1995).

One of the most well-known KM models is Arthur Andersen’s Organisational KM Model (Andersen, 1996). The Knowledge Management Assessment Tool (KMAT) was originally designed as a benchmarking tool to assist organisations in assessing how well they meet certain criteria for performing KM (de Jager, 1999). This model comprises seven processes: create, identify, collect, adapt, organise, apply and share. The model suggests that each person in an organisation undergoes these processes naturally. Four knowledge enablers that facilitate the workings of the KM process are identified: leadership, measurement, culture and technology (Holsapple and Joshi, 1999). This model essentially implies that leadership, technology, culture and measurement must be addressed considering the KM process for organisations, in order to determine the most appropriate means for managing organisational knowledge. This model is the most commonly adopted by organisations within an educational context due to the knowledge enablers described earlier (Kitagawa and Arai, 2001; Aurum, Parker and Cox, 2004).

Another well-known model is the SECI model developed by Nonaka and Takeuchi (1995), which has emerged from a study of Japanese organisations and has been accepted as an important contribution to understanding the creation of different types of knowledge. The SECI model is built around the processes needed to transfer implicit to explicit knowledge and back again, as well as extending implicit and explicit knowledge in their own domains. The SECI model is a theory-based model put together from various situations in operational work (Figure 1). Nonaka and Takeuchi (1995), also present a spiral model (Figure 2), detailing the movement between tacit to explicit knowledge. This process is one that is termed ‘knowledge conversion’, and encompasses epistemological and ontological dimensions. The vertical axis is representative of the manner in which knowledge conversion occurs, from tacit to explicit, through the model components (Nonaka and Takeuchi, 1995). The horizontal axis is representative of the ontological dimension of this model, illustrating the distinction between knowledge created by individuals and knowledge that is distributed and accessible to a wider network within an organisation and between organisations (Nonaka and Takeuchi, 1995).

The components of the SECI model are defined as (Nonaka and Konno, 1998) are:

1. **Socialisation**: the conversion of tacit knowledge through interaction between individuals. One important point to note here is that an individual can acquire tacit knowledge without language.

2. **Externalisation**: the expression of tacit knowledge and its translation into comprehensible forms that can be understood by others.
Combination: the conversion of explicit knowledge into more complex sets of explicit knowledge. In this stage, the key issues are communication and diffusion processes and the systemisation of knowledge.

Internalisation: internalising newly created knowledge by the conversion of explicit knowledge into the community’s tacit knowledge. This requires the individual to identify the knowledge relevant for one’s self within the organisational or community knowledge.

Figure 1  Representation of SECI model


Figure 2  Knowledge levels in SECI model

Various software systems have been developed using the SECI, in particular for educational organisations. For example, research into a virtual organisational learning model based on SECI illustrates how a transactional memory system supports inter-organisational KM (Lin and Lin, 2001). A transactional memory system is composed of three components: knowledge map, social network and mnemonic function. Lin and Hseuh (2003), have used this model to look at supporting communities of practice within learning institutions.

2.4 Constructivist learning

When analysing KM in the SE programme, we consider how technology affects the learning assuming a constructivist approach in the programme design. The constructivism approach used in the programme is the encouragement of the integration of new ideas with prior knowledge in order to make sense of, or reconcile, a discrepancy, curiosity or perplexity. Learners construct their own meaning for different phenomena (Vygotsky, 1978). Constructivist can take a cognitive or social approach to learning, and in this programme a social approach was used. In this view, social interactions play a fundamental role in the development of cognition (Bruner, 1960; Cobb, 1994; Savery and Duffy, 1995; Taylor, 1998).

Therefore, the processes of KM, as supported by the technology used in the programme delivery, are crucial to the learning process as envisaged in the programme design. The details of how students learnt, or how the domain knowledge was handled, are not in the scope of this study. What is important is that the learning process involved socialisation for learning, internalisation of external knowledge and externalisation of individual knowledge for the group. Also combination was involved in the student’s construction of knowledge. Hence the SECI model provided a suitable categorisation of the technology to analyse the effect on providing a suitable learning environment.

2.5 Contribution to mobile learning

Learning at tertiary (and secondary) level is moving to flexible and mobile mode. However, we need to effectively evaluate such programmes against existing instructional techniques and outcomes (Ahmad and Wegner, 2003). Studies such as the Palm Education Pioneers Programme (2002) have been initiated to evaluate mobile learning projects. This study used questionnaires of staff and students involved with no control group. Other studies (summaries in Finn and Vandenham, 2004) have used similar approaches and tend to ignore the negative effects of mobility and technology for learning. All these studies have small samples and performed by researchers with educational but few analytical skills. While some of these problems are repeated in this study, such as small sample size, an increased number of such studies would benefit the area. As this study attempts to provide a benchmark against which future versions of the programme in flexible mode is evaluated, subsequent studies of the programme will be relevant.

The introduction of distance and mobile learning systems use technology to enable the separate functioning of the learner from the teacher and the learner from the learning group, yet maintain the integrity of the education process. With technology being introduced at a rapid pace, often driven by the student’s familiarity with the technology as a communication device, it is imperative that educational institutions establish a
framework for assessing these technologies and their effects on the learning. For instance, the use of chat channels for group meetings can be hampered by flaming and bulletin boards due to the lack of synchronicity (Kutay, Ho and Whale, 1999).

### 3 Case study

SE is a discipline that is taught and managed differently in each educational institution around the world. At UNSW, SE is taught collaboratively by the Schools of Computer Science and Engineering (CSE) and Information Systems, Technology and Management (SISTM). This programme consists of three components:

1. compulsory core courses (taught by CSE and SISTM)
2. SE workshops (where the workshops are conducted by CSE and SISTM together) and
3. a number of electives (http://www.cse.unsw.edu.au/seng/).

The programme takes a project-based learning approach and hence utilises flexible learning technologies in terms of online support where available. Increased support of mobile learning is aimed for. However, before we change the learning environment we aim to understand how the technology supports learning in the existing programme.

This programme has been examined previously using the APQC model (Andersen, 1996) for the impact of the components of KM on the success of KM practices on education (Aurum, Parker and Kox, 2004). In this study we used the SECI model to investigate KM in an educational context.

### 4 Methodology

Although the SECI model appears to fit quite well with the approach to learning and information transfer of that period, it is unclear if the model is applicable for the current education system. The SECI model is not always adaptable to the personal activity for KM or the environment for personal knowledge handling, and others have extended it (Wierzbicki and Nakamori, 2005). For this study it was noted that the focus on supporting Communities of Practice (Wenger, McDermott and Snyder, 2002) within learning institutions suggests that the SECI model could be used to assess the requirements of such a KM system (Smits and de Moor, 2004). However, a review of KM literature identified an absence of empirical data to support the cognitive SECI model proposed by Nonaka and Takeuchi (1995).

This is an empirical research that aims to use the SECI model in analysing KM in an educational context whilst also testing the theory behind this model in relation to the overall KM in the programme.

#### 4.1 Research design

In an effort to look at how the SECI model may help understand and assist KM in programme coordination, the following research questions have been investigated within the case study:
RQ1
1. Does the level of use of each type of transformation of knowledge, i.e. socialisation, externalisation, combination and internalisation, have any effect on the level of KM?
2. Is the SECI model applicable in an educational context, and does the significance of the model components vary between years or across gender?

RQ2
1. What are the current KM practices within educational organisations?
2. Which procedures are being utilised effectively by students and which can be improved?

The research was carried out by surveying students in the UNSW SE workshop.

4.2 Development of the questionnaire

The existing literature on technology for enabling KM includes many tools and enablers applicable to the education domain. These were analysed according to the construct definitions developed by Nonaka and Takeuchi (1995) in SECI model. This provided us with the technology focus for the questions under each construct. The construction of the questionnaire began by breaking down the four constructs of the SECI model into the main KM tools and enablers available to students (See Figure 3). The questionnaire was constructed with questions relating to each construct. Questions on KM were selected from the KMAT questionnaire. Some questions were in the negative to avoid distortion of responses. A seven choice response scale was used.

Figure 3  Questionnaire constructs

The Questionnaire was designed in five sections. The first four sections had questions covering the benefits, the level of communication and the potential knowledge increases through each of the four constructs.
The final section consisted of questions used to verify the level of KM generally within the educational context were selected from KMAT questions on the basis of their being appropriate to the education domain, and the questions reworded to fit the context. The KM questions were selected from questions relating to (a) Knowledge Sharing Culture, (b) Critical Success Factors for KM, (c) KM Infrastructure and (d) Knowledge Networking levels.

4.2.1 Pilot study
A pilot study was run in two stages. Firstly an informed pre-subject phase was conducted with five subjects who were aware of the study’s objectives and were asked to assess (a) the clarity of questions, and (b) the adequacy of the question to obtain useful data. Also any misunderstandings and ambiguities were noted for alteration.

The second phase was an uninformed pre-subject phase where ten volunteers were sought from students doing workshop courses. These students were asked to review the structure and clarity of the questionnaire. Also the responses were analysed for reliability. The reliability of the questionnaire was examined for its freedom from random error in the form of consistency of individual respondents to the same question and internal consistency in each section to verify the questions are all measuring the same underlying attribute.

In the second reliability test the section on internalisation and combination failed. Also, the general KM measures showed a Cronbach's alpha score just below the recommended value of 0.7 (Lin and Hsueh, 2003). However since these were adapted from a previously tested instrument, it was assumed the lack of knowledge about KM concepts may be the problem, and unavoidable in this context.

For internalisation and combination, the questions which had no correlation to the overall construct were removed. These related to the reading of journals and textbook as knowledge resources for internalisation. In the combination section part of the difficulty in developing questions was the lack of clarity in the definition of this construct. Combination relates to the connecting various elements of explicit knowledge. The question which were non-correlating and were therefore removed, related to the level of use of online discussion boards and emails to lecturer for discussing ideas.

4.3 Data collection procedure
The students surveyed were from all years of the programme, and included students studying purely SE and some combining it with other degrees. The data was collected from the 19 different SE laboratories through asking for volunteers, and questionnaires were distributed in classes. The resultant response rate is shown below in Table 1. The high return was due to the persistence in chasing up responses. However two returns were deleted due to no questions answered on KM attributes. For regression analysis these form large data sets, except in the analysis for variance for gender.

The students who answered zero for Socialisation questions were students who had not completed the industry experience component hence were unable to comment on the majority of questions relating to this aspect of the SECI model within the programme. Also they may not have attended the consortiums, BBQ and other social activities which were the latter one third of the questions. Their lack of answers related more to their lack of experience in this aspect, rather than any judgement on the possible value of the
Socialisation attribute. The Externalisation zero was assumed to be similar in cause and hence included in the analysis as missing data under that attribute, rather than as a zero value for that attribute.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Questionnaires completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaires distributed</td>
<td>150</td>
</tr>
<tr>
<td>Questionnaires useable</td>
<td>91</td>
</tr>
<tr>
<td>Female</td>
<td>20</td>
</tr>
<tr>
<td>Male</td>
<td>71</td>
</tr>
<tr>
<td>Questionnaires missing data</td>
<td>34</td>
</tr>
<tr>
<td>Socialisation (33) or externalisation (1)</td>
<td></td>
</tr>
<tr>
<td>Female with missing</td>
<td>10</td>
</tr>
<tr>
<td>Male with missing</td>
<td>24</td>
</tr>
</tbody>
</table>

5 Data analysis

In this section we analyse the data and discuss these results in the light of the hypotheses above. In analysing RQ1, this section examines the relationship between KM and its potential predictors: socialisation, externalisation, combination and internalisation, finding the robust correlation value of each construct. Correlation was used as the relationship between KM and the predictors was shown to be close to linear (see Kutay and Aurum (2005) repeated in Figure 4).

In analysing RQ1 (ii) we consider the effect of non constant variance in KM and its predictors between groups defined by year, gender, and country of birth.

Analysis of RQ2 was done using questions about activities or technology which was not yet introduced or used greatly in the programme, and students were asked for the value of such changes. Also the variation between the predictor distributions raise some issues relating to RQ2 (i) and the relative significance of each predictor in the KM practice in the programme.

5.1 Variation between predictors

In this section we look at RQ2 and the significance of each predictors within the programme practice. Each predictor is the average of the score for all questions on that component. There was different number of questions (after spurious questions removed) for each area, as shown in Table 2.

The results showed greater spread in Internalisation although there were more questions in this area, hence averaged over more data values. The highest mean was for Combination which suggests this was the component which students felt was best handled in the learning environment (the Socialisation and Externalisation data had the zero values removed). The scale used in the questionnaire was from one to eight, hence four was average. This suggests that the components were considered to be not very useful for learning, except Combination which was better utilised. This is illustrated in Figure 5. However, in this interpretation, the overall KM approach was under-utilised as well.
Figure 4  Scatterplots of socialisation, externalisation, combination and internalisation predictors (x axis) against knowledge management (y axis) showing individual regression lines.

Table 2  Component features from questionnaire

<table>
<thead>
<tr>
<th>Component</th>
<th>No. of questions</th>
<th>Mean</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socialisation</td>
<td>15</td>
<td>2.86</td>
<td>0.099</td>
</tr>
<tr>
<td>Externalisation</td>
<td>10</td>
<td>3.14</td>
<td>0.086</td>
</tr>
<tr>
<td>Combination</td>
<td>8</td>
<td>4.07</td>
<td>0.089</td>
</tr>
<tr>
<td>Internalisation</td>
<td>12</td>
<td>3.62</td>
<td>0.078</td>
</tr>
<tr>
<td>Knowledge management</td>
<td>8</td>
<td>3.26</td>
<td>0.087</td>
</tr>
</tbody>
</table>
The response to hypothesis RQ2 (i) is therefore that KM and its predictors are under utilised in the course, except Combination factors. This may due to University level teaching concentrating on the overriding concepts and abstractions as the most valued aspect of the teaching and learning which utilises the process of Combination as defined in the SECI model.

5.2 Correlation between predictors and knowledge management

In this section we look at RQ1. The correlation coefficients were obtained between the level of KM and each of its potential predictors in the form of socialisation, externalisation, combination and internalisation. The results are shown in Table 3.

The results show mild correlation between KM and externalisation and internalisation values. The Spearman correlation analysis was used, as this is a non-parametric analysis that is not susceptible to non-normal distributions and outlier effects. Also Spearman examines the ranked order rather than assuming a linear association.

Table 3 Values for Spearman correlation analysis

<table>
<thead>
<tr>
<th>Knowledge management</th>
<th>Correlation coefficient</th>
<th>Significance (two-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socialisation</td>
<td>0.148</td>
<td>0.161</td>
</tr>
<tr>
<td>Externalisation</td>
<td>0.270</td>
<td>0.010</td>
</tr>
<tr>
<td>Internalisation</td>
<td>0.294</td>
<td>0.001</td>
</tr>
<tr>
<td>Combination</td>
<td>0.083</td>
<td>0.434</td>
</tr>
</tbody>
</table>
This analysis was done ignoring the missing values for socialisation and externalisation. Socialisation was more effected by these outliers, as there were many missing values and only 58 complete responses used in this analysis. Also the majority of outliers were outliers in terms of the socialisation distribution. This would suggest there was less understanding in this context of the effect of socialisation aspects on the overall KM in the programme.

In relation to RQ1 this suggests that at least externalisation and internalisation aspects of the programme are partially effective in providing KM support for students in this context. Socialisation, where it is used, is also mildly effective.

We also looked at the correlation between predictors, as it was often hard when designing the questionnaire to distinguish learning technology in terms of which aspect they supported. However, as seen in Table 4 there is only partial correlation between the predictors; hence they may be considered separate, although related aspect of possible KM affects.

Table 4  Spearman’s correlation values between predictors. Significant correlations (>0.05) highlighted

<table>
<thead>
<tr>
<th>Socialisation</th>
<th>Externalisation</th>
<th>Combination</th>
<th>Internalisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socialisation</td>
<td>1.00</td>
<td>0.467</td>
<td>0.296</td>
</tr>
<tr>
<td>Externalisation</td>
<td>0.467</td>
<td>1.00</td>
<td>0.497</td>
</tr>
<tr>
<td>Combination</td>
<td>-0.090</td>
<td>-0.005</td>
<td>1.00</td>
</tr>
<tr>
<td>Internalisation</td>
<td>0.296</td>
<td>0.497</td>
<td>0.052</td>
</tr>
</tbody>
</table>

The correlation between externalisation and socialisation may be due to the similarity in their implementation through technology. For instance, the aspects of the learning environment that reflect external aspect of KM are also social activities or involve communication with others, even if not concurrently. These are aspects that are highly enjoyable to students, and hence may acquire higher credit for the effect on KM for that value.

There is also correlation between internalisation and externalisation constructs. Internalisation constructs were quite distinct and very social activities, except for Lectures that were similar to the externalisation aspect, Lecture Notes.

The correlation between socialisation and internalisation effects was mildly significant. In this case the internalisation activities were often social, as in group work, so the distinction may not have been clear to students. Whether or not it would be useful to present KM or learning models to students as separate factors is worth investigation.

5.3 Contribution to knowledge management by predictors

To investigate RQ1 further, we ran a linear regression with the significant predictor for KM. Table 3 indicates that there is a strong correlation between these predictors, externalisation and internationalisation. Hence, they may not each have an independent correlation with KM. We then did a robust (i.e. resilient to non-normality) multiple regression relating all predictors to KM, shown in Table 5. We included all predictors and did a stepwise analysis. The zero values for socialisation and externalisation were included.
This suggests that externalisation is the only factor that is an independent predictor of KM. While the correlation table showed that all the predictors are correlated with the variation in KM across the population, this variation does not explain a large proportion of the variation in KM in a robust linear regression model. Hence we did not find the SECI model to be either necessary or sufficient to explain KM in an educational organisation.

**Table 5** Effect of significant predictors on KM variation using stepwise robust multiple regression

<table>
<thead>
<tr>
<th>KM-dependent</th>
<th>Coefficient</th>
<th>Standard error</th>
<th>t</th>
<th>p &gt; t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Externalisation</td>
<td>0.30</td>
<td>0.10</td>
<td>3.05</td>
<td>0.003</td>
</tr>
<tr>
<td>Constant</td>
<td>2.32</td>
<td>0.30</td>
<td>7.68</td>
<td>0.000</td>
</tr>
</tbody>
</table>

To further analyse the effect of the predictors on the level of KM we looked at an analysis of variation in relation to other factors gathered in the questionnaire. In the following sections we look at a median analysis of the effect of year, gender and country of birth on KM and its predictors, relating to RQ1(2).

### 5.4 Level analysis for year

The aim of this analysis is to verify if the effect of different years has confounded the data and reduced the correlation between internalisation, socialisation and combination in terms of overall KM. This section examines hypotheses RQ1(2) further and examines possible areas where KM is not well supported (RQ2).

The median value for each variable was assessed for the groups by year and these were found mostly to be insignificant. However, externalisation showed greatly reduced level and range in year 2 (Table 6).

**Table 6** Median by year

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socialisation</td>
<td>2.67</td>
<td>2.94</td>
<td>3.13</td>
<td>2.70</td>
</tr>
<tr>
<td>Externalisation</td>
<td>3.15</td>
<td><strong>2.75</strong></td>
<td><strong>3.30</strong></td>
<td>3.15</td>
</tr>
<tr>
<td>Combination</td>
<td>4.07</td>
<td>4.00</td>
<td>4.13</td>
<td>4.38</td>
</tr>
<tr>
<td>Internalisation</td>
<td>3.71</td>
<td>3.25</td>
<td>3.67</td>
<td>3.50</td>
</tr>
<tr>
<td>Knowledge management</td>
<td><strong>2.75</strong></td>
<td>3.13</td>
<td>3.50</td>
<td><strong>3.07</strong></td>
</tr>
</tbody>
</table>

The most significant difference in levels is externalisation from year 2 to 3. The greatest variation in perception of the level of KM existing in the programme was found to be between first-year and third-year students.

In response to RQ2(1) assuming the KM facilities are equal across years, it is worth noting that socialisation and combination predictors and KM effects are less in year 1
compared to later years. This would suggest that universities do impart skills in this area, although in varying amounts across the years.

In response to RQ1(2), it is found that year is not a greatly compounding factor in the failure of the model although variation across years was effecting the correlation of socialisation and combination with KM. Also further analysis looking at gender and country of birth effects showed no significant results (Kutay and Aurum, 2005).

5.5 Knowledge management predictor activities which are underutilised in the programme

Some of the questions in the questionnaire included questions relating to the predictive factors, which were about activities or technology that was not yet introduced or used greatly in the programme, and students were asked if they felt these ‘would increase my knowledge’ or similar comment. This information is used to look at RQ2.

For these questions the respondent rated highly the following activities under each predictor. This would suggest that students feel these should be encouraged in the programme to assist their KM. Also any effect of gender and birth country on these perceptions is included in Table 7.

Table 7  Factors that were perceived as leading to a higher level of knowledge management which are not utilised well in degree

<table>
<thead>
<tr>
<th>Socialisation</th>
<th>Consortium with industry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Social activities such as BBQ’s and picnics with lecturers and other students</td>
</tr>
<tr>
<td></td>
<td>Industrial training (at present only 60 days)</td>
</tr>
<tr>
<td></td>
<td>Meetings with Alumni to discuss issues</td>
</tr>
<tr>
<td></td>
<td>University Gazette could have higher profile</td>
</tr>
<tr>
<td>Externalisation</td>
<td>Perceived lower by female students</td>
</tr>
<tr>
<td></td>
<td>Meetings</td>
</tr>
<tr>
<td></td>
<td>E-mails (answered)</td>
</tr>
<tr>
<td>Combination</td>
<td>Perceived lower by non-Australian born students</td>
</tr>
</tbody>
</table>

The list is fairly brief in view of the large number of technologies assisting each knowledge transformation; however, some factors such as combination, are dependant entirely on these technologies. Hence, the factors that detract from this transformation should be of particular concern in an educational institution. Answering e-mails and the conduct of meetings is considered poor, particularly by female students. This would suggest these students might be able to suggest improvements in this area.

6 Validity threats

There are various factors that may threaten the validity of the study, which will be discussed in this section. Firstly, the internal threats to the validity of the statistical analysis used; secondly, the external threat to the type of study done. Also the validity of the construction of the study and the conclusions drawn is analysed in this section.
6.1 Conclusion validity

When running parametric analysis, the results may be affected by non-normal distribution of the population and univariate outliers. Hence non-parametric tests were used. Also the level of each population was estimated from the median not the mean. This approach was used as there were a significant number of outliers found in the data (Kutay and Aurum, 2005). Also some categories of data were small in number so hard to claim normal behaviour in the sub-population. Finally, regression testing was not used, except in one comparison of variation between predictors and KM as the SECI model does not describe whether the relationship between the predictors and KM is linear or even perhaps discrete.

6.2 External validity

The present study is applicable to other institutions and other courses in that we would expect similar relationship between the predictors and the final KM outcome. However, the level of each effect will vary across institutions. Also the effect will change with the type of technology used and the manner in which it is used to promote KM. The present study is just an example of how each construct of the SECI model is managed in an educational context and how this may be improved. The final effect on the overall KM by students in the programme will vary across institutions.

6.3 Construct validity

This study examined the effect of technology within four constructs, on the overall KM within a single workshop programme. That is the technology used in the courses is separated into the transformations it is said to influence. The questionnaire assesses students’ perception of the importance, or success, of each technology within each transformation construct. The sum of each construct is then compared to the students’ response to a standard series of questions designed to assess their perception of the level of KM in the educational organisation. In some areas students had not used the technology available, hence could not comment (e.g. industrial training). Also some questions focused on the importance of a technology that correlates well to the level of KM, but the questions relating to the success of a technology as used in the programme, may not correlate to their perception of the KM as a whole. If a technology is not successful, then students will attempt to achieve KM by other means available. However, it is reasonable to expect that the perception of the transformations, whether their success or their importance, is a fair assessment of the students’ perception of the level of use of that construct, and hence relates directly to their perception of the level of KM.

6.4 Internal validity

Another effect which may have caused students’ perceptions of the constructions to correlate to their perception of the overall level of KM in the programme is the fact that all KM in the programme is dependent on the technologies studied in the predictor questions. By dividing the technologies amongst separate transformations we can see the relative importance of each predictor on the final overall KM in the programme, but we would certainly not expect to see negative correlation between such constructs and KM.
Whether the effect is one of the predictors determining the perception of KM or the predictors being an integral part of KM is not clear from the theory; however, this study also verifies the initial four segments of the questionnaire as a tool to isolate aspects of the perception of KM in the education sector.

7 Discussion

The value of this research arises from the practical nature of the leverage for each of the four attributes of the KM model. By linking the predictors to the various technologies and activities, the research is able to provide some evidence for how to design technology support for KM in the programme.

7.1 Overview of results

In relation to the RQ1, the level of use of each type of transformation of knowledge, i.e. socialisation, externalisation, combination and internalisation, does have some effect on the level of KM in the programme. The effect of externalisation is significant, and internalisation as a correlated variable. However, in this study we would expect some residual constant effect in KM resulting from this being only one case study. We cannot generalise the results, as further research is required.

In analysing variation across other attributes, we found that some technology and activities are less accessible to first-year students, or they are less aware of how to use it, although in general both male and female students make equal use of all the predictor components.

In relation to RQ1 the current KM practices within educational organisations were found to be mainly in the area of externalisation and not directly in the areas of the other predictors, hence not matching the SECI model. However, educational theory does not support such a limited approach to learning. In fact, the importance of peer learning and group discussion (socialisation) in highly developed in constructivist theory (Savery and Duffy, 1995; Jonassen, 1998) and hence should be perceived as a crucial part of the level of KM in the programme. Furthermore, the combination technologies surveyed were all computer-based technologies that have not lived up to expectations and their lack of robustness would have reduced their effectiveness for learning.

In relation to RQ2, various technologies and factors, which students felt were underutilised in the programme, are listed and cover all components of the SECI model, except internalisation that was already well correlated to KM. Also, while combination rated highly overall in value, this was not significantly linked to KM.

Some of the difficulty in students utilising aspects of KM may be due to the different levels of enactment of KM in the university; an issue is raised by Muiña, Castro and Sáez (2002). In their paper, socialisation is presented as an inter-level process; externalisation as the developing group knowledge from individual knowledge; combination as the process that allows organisation to develop knowledge from the knowledge of the separate groups, and internalisation as the process to convert institutional knowledge into individual knowledge. Hence internalisation and externalisation would be processes more under the control and awareness of the individual students.
7.2 Socialisation

Socialisation was achieved through social activities, consortiums and industrial training. The effect of socialisation as a method of knowledge transformation was reduced by the fact that much of the opportunities for socialisation (such as industrial training) had not been used by about half the students. This did not affect the overall perception of KM from such students. This may contradict Nonaka’s concern that “the mere transfer of information will often make little sense if it is abstracted from embedded emotions and nuanced contexts that are associated with shared experiences” (Nonaka and Takeuchi, 1995). Alternatively, this may reflect how education has become abstracted from context and the role of peer learning has been greatly underutilised at universities. Hence students do not perceive the lack of such transformation supports.

Socialisation was a component that students felt should be encouraged in the programme and students felt various aspects, such as industrial training, should be increased as components of the course.

7.3 Externalisation

Externalisation was achieved through the assignments, the university newspaper, lecture notes, textbook and recommended reading. The effect of externalisation as a method of knowledge transformation was considered significant by the students. Also, this predictor had the greatest variation across years, showing a tendency for students to learn this transformation as they progressed through the degree. This may be either that they become more aware of the externalisation resources available or are better able to make use of such KM skills in later years. There may also be a similar effect as for socialisation, where the students initially do not perceive the value of learning form peers, in group meetings or alumni discussions. This becomes a more significant process in later years.

The SE workshops deliberately foster externalisation through group projects and mentoring. Hence the students’ expose to this effect is constant over the programme, which may encourage incremental appreciation of this component.

7.4 Combination

Combination was achieved through e-mails and message boards (physical and online). Combination was the hardest component to define, and may have been hard for students to comprehend. This component was not significantly correlated to KM, which suggests that the process of making knowledge systematic, or connecting explicit knowledge, is not valued in terms of KM at universities, or the technology available for this process is not sufficient. However, the value of this component was higher than other predictors. At university level the teaching of overriding concepts and abstractions should be a more valued aspect of the teaching and learning, and in an educational context the use of technologies such as e-mails, meetings and web discussion would seem to clearly increase the level of KM, although students may not use these technologies in this manner.
7.5 Internalisation

Internalisation is also perceived as a significant contribution to the level of KM in this context, but this was found to be due to its correlation with externalisation. Since much of learning is still perceived as a private study, and attempts at universities to reduce plagiarism only promote this, it is not surprising that students strongly hold this view. However, the change across years is reversed in trend, in that in year 2 the internalisation effect is less than year 1 and year 4 is less than year 3. Years 1 and 3 are comparable, so this may be an effect of the students in the year in that often the classes show different average approaches to learning across years. This would suggest that the perception of the value of internalisation is highly dependant on the students’ experiences, which is in turn affected by the lecturers’ reaction to the previous year’s students.

7.6 Relevance to education

We did not find the SECI model to be either necessary or sufficient to explain KM in an educational organisation. However, it is possible the SECI model is applicable in an educational context both for the aspects of the model, which do correlate with overall KM, and for those predictors that are not significant, yet should be. Procedures that are not being utilised effectively by students are procedures that are considered significant in educational theory. While students enjoy socialisation and discussion of ideas, they do not always see these processes as important in their absorption and transformation of knowledge.

8 Conclusion

The aim of this research was twofold: to examine existing KM frameworks in an educational context to provide an analysis of how they can be, or have been, applied to future educational programmes, such as mobile learning. In doing so, to investigate Nonaka’s SECI model, how it applies to education and how the model suggests improvement to KM in education.

The case study suggests that in relation to the hypothesis RQ1, only one component of the model is significant while another is related. However, the other components may be little understood or of increasing importance over years of study. In relation to hypothesis RQ2, the level of value placed on combination was generally greater than other components. Further responses from the questionnaire carried out showed that students felt that the use of some aspects of the model could be improved through the better use of technology or processes to assist their learning in the environment.

The research suggests that KM models developed in organisational contexts need to be reassessed before being applied to benefit educational institutions or programmes. In particular, due to the fluctuating nature of KM in an educational context, where change is encouraged, the model components cannot be expected to be closely linked to the outcome in terms of KM level. Also the research suggested there are other effects missing from the model which are perhaps more significant in determining the level of KM in an educational programme. In light of our interest in developing a framework for evaluating mobile learning programmes, we suggest that further work needs to be done for developing the evaluation model.
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References


Activity theory for designing mobile learning

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Abstract: Mobile computing offers potential opportunities for students’ learning. It is important to have an operational understanding of the context in developing a user interface that is both useful and flexible. The author believes that the complexity of the relationships involved can be analysed using activity theory. Activity theory, as a social and cultural psychological theory, can be used to design a mobile learning environment. This paper presents the use of activity theory as a framework for describing the components of an activity system for the design of a context-aware mobile learning application.

Keywords: activity theory; collaborative learning; context-aware learning environment; contradictions; design for context; mobile learning; usable.


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1 Introduction

Mobile telephone ownership and usage is now almost ubiquitous among student communities. More and more people are mobile-literate. Almost all young people today possess mobile phones. The increasingly powerful networks and handsets are making mobile learning a potential reality. The main advantages of using mobile computers for learning are that they assist students’ motivation, encourage a sense of responsibility, help organisational skills, help both independent and collaborative learning, act as reference tools, help track students’ progress and assessment (Savill-Smith and Kent, 2003). Ubiquitous computing is much talked about today. It is the situation where
technology becomes virtually invisible in our lives. Handheld technologies provide access to computing where student activities and learning occur, unlike desktop computers that are often segregated from other learning activities in the classroom.

Mobile technologies offer new opportunities for students’ educational activities in that they can be used across different locations and times. From a pedagogical perspective, there are many benefits to be gained by making the learning process interactive and collaborative. Mobile technologies offer us the flexibility of fitting learning into work process as a means of ensuring learning in practice (working). Learners have to continually strive to become an integral part of the community. Mobile technology also opens up the potential for children’s group collaboration (Danesh et al., 2001).

Group work with students and the research on psychology in education has demonstrated clear benefits of collaborative learning for young children (Rogoff, 1990; Topping, 1992; Wood and O’Malley, 1996). However, collaborative learning occurs only if the technology is designed to fit with the context of use for which it is intended.

The use of mobile technology is growing (Mandryk et al., 2001). Despite the rapid growth of mobile technology use by children, there is still little understanding of the ways mobile technologies can be designed to best support mobile collaborative learning. Mobile technology opens up potentials for students to work collaboratively rather than working with allocated partners at a desktop. Students can move around and interact with other students in different environments. Although there are potentials of mobile technology for students’ learning, a key restriction aspect of current handheld devices is the limited size of the screen. The design of usable mobile applications is not trivial. The environmental constraints of mobile devices, such as limited processing power and memory, affect not only the functional aspects of these devices but also the user interface.

Mobile applications must be carefully designed to account for the limitations of their size, lower processing power and low bandwidth. Designing of successful mobile interfaces requires that context be taken into account. Mobile devices are especially well suited to context-aware applications because they are available in different contexts so that it is possible for us to draw on those contexts to enhance the learning activity (Naismith et al., 2005). It is generally accepted that a key feature of mobile devices and technology is context-awareness, whereby context and functionality are adapted to the user’s situation. However, the design of context-aware mobile devices provides us with major challenges in terms of both defining use context as well as developing appropriate concepts relevant to the design of contextual information on mobile interfaces.

Context plays a crucial role in the understanding and development of mobile learning applications. This means that user actions cannot be isolated from the environment in which they take place, that is, actions cannot be understood without a context. The user is an actor within an environment and the actor possesses certain ‘thrownness’ in a situation (Winograd and Flores, 1986). Mobile devices and applications are susceptible to the contextual change and the user interaction with that context. It is the author’s belief that the complexity of the relationships involved can be analysed using activity theory. The structure of this paper is as follows. The implications of context for mobile design are discussed in Section 2. This is followed by a brief review of activity theory and its benefits in Section 3. The subsequent Section 4 describes how the principles of activity theory can be used to show the various components of the model for a mobile learning environment. The paper concludes with suggestions for further work in Section 5.
2 Context and its implications for mobile design

According to Preece et al. (1994), context is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. Dey, Abowd and Wood (1999) define context as any information that can be used to characterise the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and application themselves. If a piece of information can be used to characterise the situation of a participant in an interaction, then its information is context.

Traditional computer applications have to consider only a fairly limited set of contextual concerns. These might include user characteristics (i.e. education and skills), working environment, system goals and organisational culture. Users performing tasks on these computers are stationary. Context concerns could be concretely taken into account during the design process and changed greatly after system completion. However, with mobile and wireless devices, context is less predictable on the design and use of computer systems.

Mobile applications can vary continuously because of changing circumstances and different user needs (Tarasewich, 2003). The object of mobile learning design is inseparable from the design, the context or activity of use. Mobile technologies present new challenges to both theory and design of their applications such as mobile learning (or m-learning). Activity theory seems to provide appropriate abstractions and concepts to analyse design activity for m-learning. Tarasewich has developed a three-category context model as shown in Figure 1.

![Figure 1](image)

Environment is concerned with the properties of objects in the physical environment. Participants include the status of the user(s) and other participants in the environment. Activities cover user(s), participants and environmental activities. The model also includes interaction or relationships between participants, activities and the environment. Devices and applications can adapt themselves automatically to changing contexts.

Tessmer and Richey (1997) also describe the context as being composed of levels as well as factors. According to Tessmer and Richey, context is therefore a multi-level body of factors in which learning and performance is embedded. It is not the additive influence
of discrete entities, but rather the simultaneous interaction of a number of mutually influential factors. Factors such as physical, social and instructional aspects interplay to influence learning. Context plays an important role in learning. Firstly, learning does not occur in vacuum. Context is an influential and inevitable part of every learning experience. It is not possible to separate or avoid the context in which we operate. All cognition and reasoning is situated (Greeno, 1989).

Successful instructional design must be situation-specific (Tessmer and Richey, 1997). As in situated learning or a constructivist environment, cognition is defined and shaped by its relation to a given context. This means that we must not only learn in context but also by context (Snow, 1994). Context is multifarious, complex and enveloping (Tessmer and Richey, 1997). A given context has different aspects, such as social or political as well as cultural. A contextual factor may have different types of contextual impacts that differentially mirror the types of context that exist in a situation.

Knowing is an activity that is co-determined by the individual and the environment (Brown, Collins and Duguid, 1989). It is impossible to separate the learner, the material to be learned and the context in which the learning occurs. Knowing always occurs in a context. According to Barab and Duffy (1999), ‘knowing about’ refers to an activity – not a thing. It is always contextualised. Knowing about is reciprocally constructed within the individual – environment interaction. It is not objectively or subjectively created. Knowing and contexts are co-constituted, and learning is fundamentally connected with and constitutive of the contextual particulars through which it occurs (Barab and Krisht, 2001).

There may be multiple contexts in a given learning or performance. All of them influence the nature of learning. There are several techniques and tools that have been developed to support taking the context into account in the design of computer technologies. These include task analysis (Dix et al., 1998), participatory design (Bødker et al., 1988) and contextual design (Holtzblatt and Beyer, 1993). Kaptelinin, Nardi and Macaulay (1999) criticise that existing approaches to context design are mostly bottom-up. These authors suggest that a more useful approach is to have a bottom-up complemented by a top-down approach. They have suggested using activity theory as an ideal theoretical framework for describing the structure, development and human work and praxis, that is, an activity in context.

Context is an important instrument for promoting the achievement of cognitive and behaviour goals. However, despite the importance of context, there is very little formal consideration in any of the learning design models (Tessmer and Richey, 1997), yet context is everything to instructional design (Jonassen, 1993).

Although researchers have tried to use different types of context in their applications, context-aware applications have utilised only isolated subsets of their context such as location or a device’s state (Kaenamponpan and O’Neil, 2004). According to these authors, a truly context-aware system requires a holistic approach that takes into account the interrelated types of context and relationships among them. This requires a modelling approach that can take this complexity into account. According to Kaenamponpan and O’Neil, these relationships are important in order to use the context to represent the world of the user and to assist the system’s understanding of the user’s activities and intentions because humans assimilate multiple items of information to perform everyday tasks. The relationship between each element should also be clarified to define the reasoning process. Kaenamponpan and O’Neil (2004) have proposed activity theory be used as a model to clarify the relationships between different elements of the context and at the
same time cover key elements that influence human activity in a mobile application. These relationships between different elements of context can affect the efficiency of context-aware applications. They can be used to better understand the user’s activities and intentions.

It is the author’s belief that by improving the computer’s access to context, we can increase the richness of communication in human–computer interaction and make it possible to produce more useful computational devices. Context plays an important role both in learning and in the design of mobile technologies. However, contextual factors are elusive and difficult to pin down (Brown and Duguid, 1994). It is the author’s belief that activity theory offers us a powerful tool to model and understand the design of a mobile learning environment that is usable and contextual. A brief review of activity theory and its benefits for mobile design are given in Section 3.

3 A brief review of activity theory

Activity theory originated in the former Soviet Union as a cultural, historical psychology by Vygotsky (1978) and Leont’ev (1978). It focuses on understanding the human activity and work practices. It incorporates the notions of intentionality, mediation, history, collaboration and development (Nardi, 1996). The unit of analysis is the entire activity. The principles and components of activity theory have been used as analytical tools for many different subjects. These include: human–computer interaction (Kuutti, 1996), information systems (Bødker, 1991), interface design (Bødker, 1990), communities of practice (Engeström, 1993), education (Engeström, 1987), etc.

An activity consists of a subject and an object, mediated by a tool. A subject can be an individual or a group engaged in an activity. An activity is undertaken by a subject using tools to achieve an object (objective), thus transforming it into an outcome (Kuutti, 1996). Tools can be physical such as a hammer or psychological such as language, culture or ways of thinking. Computers are considered as special kinds of tools (mediating tools) (Kaptelinin, 1996). An object can be a material thing, less tangible (a plan) or totally intangible (a common idea) as long as it can be shared by the activity participants (Kuutti, 1996). Activity theory also includes collective activity, community, rules and division of labour that denote the situated social context within which collective activities are carried out. Community is made up of one or more people sharing the same object with the subject. Rules regulate actions and interactions with an activity. Division of labour informs how tasks are divided horizontally between community members. It also refers to any vertical division of power and status.

Activities always take place in a certain situation with a specific context (Engeström, 1987). Engeström (1987) formulated activity context as a network of different parameters or elements that influence each other. Figure 2 shows Engeström’s model (1987) of an activity system.
Just as artefacts or tools mediate the relationship between subject and object, rules mediate the relationship between subject and community. Similarly, division of labour mediates between community and object. Activity theory is often associated with three levels describing the hierarchical structure of activity. Each activity is conducted through actions of an individual, directed towards an object or another object. An action is a single task with a goal performed to achieve a self-contained, pre-conceived result relevant to the overall activity. Actions are performed by a sequence of operations. Operations are the work functions or routines with each action determined by the actual conditions and contexts of the action during its performance.

Activities in activity theory are not static or given, but are dynamic. They are changing and developing. This development takes place at all levels: new operations are formed from previous actions when participant’s skills are increasing. Correspondingly at the action level, the scope of new actions is enlarging. Totally new actions are also enacted, experimented and adapted as responses to new situations or possibilities encountered in the process of transforming the object. At the activity level, the object/motive itself is also reflected, questioned and perhaps adapted, reacting to larger changes and other activities (Kuutti, 1996).

Because activities are not static but more like nodes crossing hierarchies and networks, they are influenced by other activities and other changes in the environment. External influences change some elements of activities causing imbalances between them (Kuutti, 1996). Contradiction is the term given to misfits within and among elements, among different activities or different developmental phases of the same activity. They manifest themselves as problems, ruptures, breakdowns, clashes, etc. Activity theory sees contradictions not as problems but as sources of development. Activities are virtually always in the process of working through contradictions that subsequently facilitate change.

The concept of contradiction is important in activity theory. It provides a simple analytical tool for analysing the contextual design in mobile learning. Engeström analyses how contradictions, both internally in a considered central activity and between the central activity and related activities, are the driving forces in development. According to Engeström (1987), any activity system has four levels of contradictions that must be attended in the analysis of a working situation. Level 1 is the primary contradiction. It is the contradiction found within a single node of an activity. This contradiction emerges
from tension between use value and exchange value. It permeates every single corner of
the triangle and is the basic source of instability and development (Engeström, 1987).
Primary contradiction can be understood in terms of breakdowns between actions or sets
of actions that realise the activity. These actions are poly-motivated. This means that the
same action can be executed by different people for different reasons or by the same
person as part of two separate activities. This poly-motivation may be at the root of
subsequent contradictions.

Secondary contradictions are those that occur between the constituent nodes. For
example, between the skills of the subject and the tool he/she is using, or between rules
and tools. Tertiary contradictions arise between an existing activity and what is described
as a more advanced form of that activity. This may be found when an activity is
remodelled to take account of new motives or ways of working. Quaternary
contradictions are contradictions between the central activity and the neighbouring
activities, e.g. instrument-producing, subject-producing and rule-producing activities.

In our example, the student who is working on the project belongs to the community
that has rules, e.g. to learn specific subject with certain curriculum. To perform his/her
work, he/she uses the artefacts that the university makes available such as mobile
devices, notepads, books, internet, etc. Activities that are supported by mobile devices are
directed to specific goals. The goals guide how the student acts and also determines
the structure of the activity. The structure is organised in a hierarchical-sequential way with
goals, sub-goals and actions. The mobile device acting as artefact has to meet all the
goals and sub-goals and also has to mediate all related actions. The actions are not
isolated, but integrated in a social context related to the activity community and its rules.
Users of the mobile device are characterised with respect to their activity goals and their
roles.

3.1 Why activity theory is used for mobile learning design

There are several benefits of using activity theory for the design and understanding of
mobile learning environments. Learning is fundamentally situated and socially mediated
(Engeström, 1987; Lave and Wenger, 2000). Vygotsky (1978) depicts learning as an
interaction with more capable peers, helping the learner through the zone of proximal
development. There is a general relation between learning and development (Vygotsky,
1978). Vygotsky’s notion (1978) of mediation, where a more competent peer or adult is
viewed as assisting performance, bridging the gap between what the students knows and
can do and what the student needs to know. Vygotsky called this the Zone of Proximal
Development (ZPD). ZPD is the distance between the actual development level as
determined by independent problem-solving and the level of potential development as
determined through problem-solving under adult guidance or in collaboration with more
capable peers.

It is through the interaction with other learners and the teacher, mediated by mobile
technologies, that the ZPD emerges. Learning is not a neat transfer of information, but a
complex and often messy network of tool-mediated human relationships that must be
explored in terms of social and cultural practices that people bring to the uses of tools
they share (Russell, 2002).

Lave and Wenger (2000) depict learning as a legitimate peripheral participation in a
community of practice, where novices gradually move from the periphery, through
increasing participation towards the centre of mastering participation (Bødker and
This situated and social nature of learning from activity theory means that we need to be concerned with the context of use. Context comes into the picture through past experiences of users, and through the meaning that the artefact represents to the user (Bødker and Petersen, 2000).

Activity theory is ideal for analysing Constructivist Learning Environments (CLEs) because the assumptions of activity theory are very consonant with those of constructivism, situated learning, distributed cognition, social cognition and everyday cognition that underlie CLEs (Jonassen and Land, 1999). Individuals rarely perform activity on their own. Human activities always exist in a social context (Engeström, 1987). Individuals involved in a particular activity are simultaneously members of other activity groups that have different objects, tools and social relations. Activities are complex and introduce that required collaborative effort. Besides horizontal activity systems, there are dynamics that underlie any activity (verticalness) (Rohrer-Murphy and Jonassen, 1999). Each component of an activity is the result of other activities that produced it.

In this perspective, mobile technology is not perceived as the object of learning but as a tool to support students’ learning activities. Taking this view allows us to develop more useful learning environments and interpretations of students’ experience in these experiments than if we maintain a dualistic tradition. Only through acknowledgement of the distributed nature of knowing can meaningful learning contexts be fostered. Thus knowing and learning are perspectives of systems, not individuals. This means that in distributed cognition, individual functioning is considered to be distributed across and situated within the transaction of subject, available tools and community contexts with the division of labour or roles in which the entire systems, not individual or environmental components, are the minimal unit of analysis (Barab and Plucker, 2002). This distributed cognition fits well with the theoretical perspective of activity theory (Engeström, 1987).

Collaborative learning using mobile technologies is situated within and between activities. An activity can also be conceived as a system of distributed cognition (Hutchins, 1996). In constructivist learning, knowledge is constructed and is meaningful only within a particular community. A shared collective mind is developed over time in such a community. A collective mind is formed when people in close relationships enact a single memory that is complete with differentiated responsibilities for remembering different portions of a common experience (Weick and Roberts, 1993). The division of labour plays an important role in the development of the collective mind (Stein and Zwass, 1995).

The aim of activity theory is to understand the unity of consciousness and activity. It incorporates strong notions of mediation (activities mediated by artefacts, both internal and external), history (activity changes and develops so a historical analysis is needed to understand the current state) and collaboration (an activity is carried out by an individual to accomplish some desired outcome, within a community of other individuals controlled by a set of rules).

According to Rohrer-Murphy and Jonassen (1999), current approaches are inappropriate for designing CLEs because the epistemic beliefs of CLE are fundamentally different from traditional instruction. They suggested that activity theory could be used as a powerful framework for analysing needs, tasks and outcomes for CLEs. The author concurs with them that activity theory serves as a useful framework for understanding the totality of context of human activity. Activity theory is particularly
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suitable for dealing with the context of design of a CLE. Rohrer-Murphy and Jonassen have developed an activity theory framework for analysing CLEs (Rohrer-Murphy and Jonassen, 1999).

Describing elements of the activity describes the context of that activity. In activity theory, activity is a precursor to learning. Knowing can only be interpreted in the context of doing (Rohrer-Murphy and Jonassen, 1999). Individual actions are always situated in a meaningful context and are impossible to understand in isolation without the meaningful context as the unit of analysis (Kuutti, 1996). An activity always contains various artefacts such as procedures, signs, instruments, methods and laws, etc. through which actions on objects are mediated. Artefacts are created, manipulated and translated during the development of the activity and carry the historical aspect of the development. They are also the outcomes of previous actions on objects (Bødker, 1997).

In activity theory, all activities are mediated by culturally defined tools. Because activity is mediated, this has important implications for mobile learning. It redefines the nature of learning. Instead of viewing learning as the rational abstraction of mental representation from one's own experience, learning based on the activity theory is now re-conceptualised as learning to participate in a cultural practice (Bernard and Enyedy, 1999). Instead of designing learning based on teacher-centred or student-centred approaches in an activity theory perspective, students move through the activities and progress from being partial participants, who are heavily dependent on the material mediation of tools, to full participants, who are able to more flexibly use the cultural tools of the narrative practice (Bernard and Enyedy, 1999).

Another benefit of applying activity theory to mobile collaborative learning is concerned with the interface of the application. The interface of the mobile learning device is in constant development, changing the appearance as the user and use context develops. In the activity theory perspective, the interface and the computer artefact, such as the mobile device, are mediators of learning. Activity theory also assumes an asymmetric relation between people and things, in contrast to traditional symmetric relations offered by cognitive science or other computer science approaches, where computer programs and human behaviours are modelled using the same language and methods. Activity theory places computer applications, i.e. our mobile learning, as mediator of human activity (Bødker and Petersen, 2000).

Instead of designing mobile learning applications in isolation, using activity theory enables us to make important features of human endeavour to stand out through the hierarchical structure of activity. This allows us to focus on the context of use. Computer artefacts can only be understood in their context of use, as embedded in meaningful activity.

An activity is not a homogeneous entity. It comprises a variety of disparate elements, voices and viewpoints (Engeström, 1990). The multiplicity can be understood in terms of historical layers. Activities are not static or rigid, they are constantly evolving. To understand a phenomenon means to know how it is developed into its existing form (Kaptelinin, 1996). This applies to all the elements of an activity. The current relationship between subject and object includes a condensation of the historical development of that relationship (Kuutti, 1996).

History is also important because it is not simply an event in the past but also is alive in the present and may shape the future. The structures and behaviour of today’s learning reflect the culture and circumstance-specific historical development (McMichael, 1999). Historical analysis allows existing and emerging organisational structures to be examined
as the result of their evolutionary development, sometimes intentional and others not. This means that we must also describe and analyse the development and tensions within the activity system.

It is the author’s belief that by attempting to improve the user interaction by exploiting information relating to users, devices and environments through the notion of awareness using activity theory can bring about effective mobile learning. Context awareness plays a crucial role in reducing the user’s explicit input. Activity theory offers an ideal framework for the design of context-aware systems by providing guidance on what elements of context to take into account. It can also support the implementation process and both user and system-driven adaptability at run time.

In addition, this approach enables us to interpret the context of user behaviour in the application. This enables minimisation of explicit input and becomes personalised for the individual user. Minimising explicit input would enable us to provide better usability for our mobile learners. Using activity theory enables the covering of key elements of context that can influence user activity, and the explanation of how elements influence the user’s ability in the actual situation.

4 Activity theory for mobile learning design

There are two main barriers when designing mobile applications: the restricted input techniques typically available with these devices and the increased cognitive load on users when attempting to multi-task in busy environments. Usability can suffer when there is a need for explicit input. The need for explicit input can be reduced by increased use of implicit input (Schmidt, Beigel and Gellersen, 1999). Context awareness is important for reducing the explicit input by taking advantage of changes in information relating to users, devices and environments to improve usability for mobile applications. It is vital to take context into account when designing mobile applications for context-aware systems.

Activity theory provides an ideal theoretical framework for describing the structure, development and human work and praxis, that is, an activity in context. However, one of the criticisms of activity theory is that it is somewhat abstract when it comes to actually working on a design. To make activity theory more useful and practical, Kaptelinin, Nardi and Macaulay (1999) have developed an artefact – the activity checklist. The checklist makes concrete the conceptual system of activity theory for design. It is intended to elucidate the most important contextual factors of human–computer interaction.

Activity theory provides a powerful vehicle for developing mobile learning. Firstly, it can be used as a lens to analyse learning processes and outcomes for the design of mobile learning. Secondly, it provides us the design of context-aware applications that are crucial for mobile technologies. The theory helps structure analysis, but does not prescribe what to look for. It does not offer ready-made technologies and procedures for research (Engeström, 1993).

There are two basic ideas that are central to activity theory. Firstly, the human mind emerges, exists and can only be understood within the context of human interaction with the world. Secondly, this interaction, that is, activity, is socially and culturally determined. These ideas are elaborated in several principles that have important implications for the design of mobile learning. An activity-based approach to mobile
Activity theory for designing mobile learning

The remaining part of the paper shows how the principles of activity theory based on the above-mentioned work are used to design a mobile learning environment. The case study used is based on the design of a mobile learning environment for students to construct a knowledge management system for the construction industry. Students working as a team were expected to solve the problem. Each student was given a handheld PDA to use for collaborative work. Principles from activity theory are used to design the learning environment and the context of use. The methodology consists of steps and sub-steps as follows:

4.1 A framework for designing mobile learning

4.1.1 Step 1 Clarify of purpose of the activity

The first step in the design is to clarify the purpose of the activity. It uses the object-orientation principle of activity theory. In activity theory, learning and doing are inseparable, and they are initiated by an intention. Intentions are directed at objects of activity (Rohrer-Murphy and Jonassen, 1999). It is important to clarify the motives and goals of the activity system. The reasons are to understand the context within which activities occurred to reach a thorough understanding of the motivation for the activity being modelled and any interpretations of perceived contradictions. Techniques that can be used include observations, interviews and document analysis, etc. The information obtained will guide the construction of the problem space (deal with learning).

1 Generate a list of problems that students typically deal with. What are the participants and groups involved in the successful completion of the activity?

2 When and where do these problems normally occur?

3 Generate a concise list of subject-driven motives and goals for each of the groups involved that might drive the activity.

4 Who set those expectations of the learners?

5 What might contribute to the dynamics of the situation under review?

Deal with interface design

Human beings live in a socio-cultural world. They achieve their motive and goals by transformation of objects into outcomes in their environment. This section identifies the objects involved in target objects involved in target activities and constitutes the environment of the use of target technology (Kaptelinin, Nardi and Macaulay, 1999).

1 What resources are available to the parties involved in the design?

2 What tools and materials are accessible?
What rules, norms and procedures are regulating the social interaction and coordination?

Is targeted technology integrated with other tools and materials?

What are the roles of existing technology?

4.1.2 Step 2

A collective activity system is taken as the unit of analysis, giving context and meaning to seemingly random individual events. The first step is to translate the learning setting into the activity system by entitling its collective object of activity, different (groups of) actors who are involved in the learning environment, the way in which the labour has been divided among these actors, the mediating artefacts that are being used by the actors, the rules that apply between the actors involved, etc. (Figure 2). The components of activity systems are initially described from the perspective of one of the (group of) actors identified as the subject of the activity system.

4.2 Analyse the context for learning and use

Context is internal to people (involving specific objects or goals) and external (involving artefacts, other people and setting). In addition, there is also the location, technical and environment context concerning the mobile technologies.

Questions need to be asked include:

- How do things get done in this context?
- Why?
- Who is doing what and why?

In the design, it is important to understand how things get done in a context and why. This is because different contexts impose different practices. To analyse the context, we need to know the beliefs, assumptions, models and methods commonly held by group members, how individuals refer to their experiences in other groups, what tools they found helpful in completing their problem, etc. In addition, there are also external or community-driven contexts. These include issues such as (Rohrer Murphy and Jonassen, 1999):

- What type of limitations is placed on the activity by outside agencies?
- How are tasks organised among the members of the group working towards the object?
- What is the structure of the social interaction surrounding this activity?
- What activities are considered to be critical?
- How flexible is the division of labour? How well can these roles and their contributions to be evaluated?
4.2.1 Clarify the relevant context within which activities occur

Questions to ask include:

- What are the activities, goals and sub-goals to be supported by the learning environment?
- Who are the users or group members involved?
- Where do problems occur?
- What is the purpose of the activity/actions for the users?
- What is the user trying to achieve?
- How do user’s activities fit into the objectives of learning?
- What are the expectations about the outcomes?
- What are the beliefs, assumptions, models and methods that are commonly held by the working groups?
- How do individuals refer to their experiences in other work groups?
- What tools do users find helpful in completing these projects: In different contexts?

4.2.2 Analyse the activity system using Engeström’s activity diagram

The following scenario is used to help identify key elements of the activity context approach:

David is an undergraduate student. He is working collaboratively on a project with other members of the group to solve a problem. He is currently in the library. The phone rings and he is asked by Anne to find out the information about semantic web for his project. Anne is working in the project room with John and Alan. They need the information quickly so that they can get on with the design of the solution. David promises to send the information back as soon as possible. Using the above scenario, the activity system depicted is shown in Figure 3. The elements in the activity theory cover the key elements of context in David’s learning. Although time is a crucial part of context, the current diagram does not reflect this. It is important not only to include current time but also past time (a history element of context) and future time. (This allows for the prediction of user’s action from current context.) To do this we adopted the context modelling of Kaenampornpan and O’Neil (2004) as shown in Figure 4.
Figure 3  Classifying context of David’s learning using activity theory.

Source: Rohrer-Murphy and Jonassen, 1999.

Subject (User)
Who are the people participating in the activity system? What are their roles?
What is the outcome of the activity?
What are the criteria for evaluating the activity?
What are the rules (implied and formal) of the members of the group of learners?
What is the division of labour within the activity system?
Subject-user, in our case the learner (information about learners and action) and physical environment of the learner.

Tools
What tools are used in this activity? Are they available to learners?
What are the physical tools used to perform the activity? What are the psychological tools used? (Methods, procedures, techniques, languages, etc.)?
How have the tools changed over time?
What models, theories or methods guide the activity?
How learners used the tools?
The main tool here is the mobile device used by the learner, and any other non-computing tools such as books, manuals, notepads, internet, etc.

Object
What is the expected outcome of the activity?
What criterion is used to evaluate the outcome of the activity?
How will the object move the learners completely towards fulfilling the intentions of the individual?
User intention, objective including raw material that will be transformed to achieve an outcome. In our case, the learning of a particular problem.
Activity theory for designing mobile learning

Community

To what extent does the subject–work community impact the subject–object pair? What is the structure of social interaction surrounding the activity? How might conflicts that originate in other communities affect learner interaction?

Social and physical environment of other users that might have influence on the user’s activity.

Rules

What are the formal and informal rules that guide the activities learners are engaged in? How might those rules have evolved?

Can be explicit or implicit such as rules of engagement in the use of mobile devices, university regulations, etc.

Division of labour

Who traditionally have taken on the different roles? How does that affect work group activities or breakdowns? How do those roles relate to other roles? What factors drive the role change?

Roles of user or learner according to the relationship between them and community or user’s location. Who can perform which task?

Figure 4 Representing the history of activity theory

4.2.3 Analyse the activity structure

For each activity, decompose the activity into actions and operations (analyse the activity structure). An important key process in the learning system is to analyse the activity structure (all of the activities that engage the subject) that defines the purpose of the activity system. The hierarchy of activity, actions and operations describe the activity structure.

This step involves defining the activity such as:

- How is work being done in practice?
- How has the work (actions and operations) transformed over time?
- What historical phases have there been on the work activity?
- What are the goal motives of the activity and how are they related to other concurrent goals?
- For each activity, what actions can be performed and by whom?
- For each action, observe and analyse the operations that the subjects perform.

For the interface aspects of the learning environment, the following issues should be addressed. Understanding the use of technology should start with the identification of goals of target actions that are relatively explicit and then extend the scope of analysis both up (to higher level actions and activities) and down (to lower level actions and operations).

- Who are the people that will use this mobile learning?
- Goals of target actions.
- People involved in the design process.
- What are the basic limitations of the current technology?
- Are there conflicts between different goals of users?
- Criteria for the success or failure of achieving goals.

4.2.4 Externalisation/internalisation (from Kaptelinin, Nardi and Macaulay dealing with interface issues)

The activities include both internal and external components, which can transform into each other. The mobile technology should support both internalisation of new ways of action and articulation of mental processes, when necessary, to facilitate problem-solving and social coordination.

- What are the components of target actions that are to be internalised?
- What are the time and effort needed to learn how to use the technology?
- Is the whole life cycle from goal setting to the final outcome taken into account and supported?
- Does the system help to avoid unnecessary learning?
• Does the system provide problem representations in case of breakdowns that can be used to find a solution or formulate a request for help?
• Is externally distributed knowledge easily accessible when necessary?
• Are there external representations of user’s activities that can be used by others as clues for coordination?

4.3 *Historically analyse the activity and its constituent components and actions*

It is important to analyse the development of the activities such as the nature of changes that occur in different historical phases of the activity. In addition, it is also necessary to analyse the mediators and their transformation over time in order to provide important historical information about how and why activity systems exist as they do. Thus it is important to examine the role that persistent structures, such as artefacts, instruments and cultural values play in shaping the activity (Rohrer-Murphy and Jonassen, 1999).

Activities undergo permanent developmental transformations. Analysis of the history of target activities can help reveal the main factors influencing the development (Kaptelinin, Nardi and Macaulay, 1999). Analysis of potential changes in the environment can help anticipate their effect on the structure of target activities.

• What are the consequences of implementing the target technology on target actions? Did the expected benefits actually take place?
• Does the system show increasing benefits over the process of its use?
• Are there negative or positive side effects associated with the use of the system?
• How are the transformations of existing activities into future activities supported with the tools?
• What is the history of implementation of new technologies to support target actions?
• What are the anticipated changes of target actions after the new technology is implemented?

In order to model the time or historical aspect of the activity, we have adopted the context modelling of Kaenamponpan and O’Neil (2004).

### Time

Discrete time – a history of context sets when activity occurs. (System does something to serve the user – learner.) We are only interested in recording the context when the activity occurs.

4.4 *Search for internal contradictions as the driving forces behind disturbances, innovations and change of activity system*

Inner contradictions of the activity systems shall be analysed as the source of disruption, innovation, change and development of that system. By identifying the tensions and
interactions between the elements of an activity system, it is possible to reconstruct the
system in its concrete diversity and richness, and therefore explain and foresee its
development (Engeström, 1999).

4.4.1 Analyse the Contradictions

- What are the dynamics that exist between the components of the activity system?
- Are there contradictions or inconsistencies within the needs of these various
components of the activity system?
- What are the interrelationships that exist within the components of the system?
- How have these relationships changed over time?

Several types of contradictions are identified in our mobile learning design as shown in
Figure 5. These are:

- Potential primary contradictions in the mobile learning environment
1 At the object node, there is tension between the types of learning. It can be
traditional or acquisitional approach vs. constructivist learning.
2 At the tool node, there is the issue of using mobile technologies compared to
traditional classroom.
3 At the rule mode, there is the question of assessment regarding individual marks
against group work projects.

- Potential secondary contradictions within the mobile learning environment
4 There is tension between the rules (use of mobile technology), which will have
an effect on the division of labour. The tension exists because it is not clear what
rules or regulations determine who should be involved in the project.
5 There are different perceptions of the activity object, which reflects the
heterogeneous nature of the subject group and their object (e.g. learning as
knowledge construction or information gathering).
6 There is also tension between community (society) and the object node
(learning). Society would like to have problem-solving and thinking skills;
students are generally interested in passing examinations.

- Potential quaternary contradictions between mobile learning activity and other
co-existing activities such as traditional teaching activity and technology activity.
7 There is fundamental contradiction between the use of mobile technology for
learning and traditional classroom teaching.
8 There is also tension between the availability of technology and the use of
mobile learning environment.
Figure 5 Potential contradictions of the learning environment

5 Conclusion

Although mobile technologies offer the potentials for learning, there are usability problems in the design of these devices because of their small, limited input and dynamic context (Kjeldskov, 2002). There is still very little understanding of how mobile technologies can be designed to best support collaborative learning. Collaborative learning using mobile technologies comprises socio-technical, economic and historic facets. It should be studied within the context in which it is deployed.

Activity theory has been successfully used to analyse human–computer interaction such as interface and Computer-Supported Collaborative Learning (CSCL). It can be used to better understand distributed learning. A successful mobile application depends on the context of design. Activity theory can help designers to better understand the social and material relations that affect complex human learning and learners’ interaction with others as mediated by tools. This is because activity theory provides a philosophical framework for understanding collective human work activities as embedded within a social practice (e.g. an institution) and mediated by artefacts, such as mobile technologies.

Although activity theory offers benefits for designing mobile learning environments, it also has limitations. The key limitation of this approach is also its key strength. Firstly, the researcher involved in it must have a complete understanding of the activity system under observation, including the dynamic interplay of all the units of the activity system (McMichael, 1999). Secondly, the difficulty faced by researchers in unravelling activity systems. Thirdly, the difficulty of distinguishing between the levels of activity, actions and operations.

It is the author’s belief that the benefits outweigh these limitations. Using the activity system as its unit of analysis, activity theory avoids simple causal explanation of mobile learning design by describing an institutional setting as an ensemble of multiple, systematically interacting elements including social rules, mediating artefacts and division of labour. It also explicitly perceives an activity as a dynamic phenomenon in which not only consensus and stability but also conflicts, breakdown and discontinuities
play a crucial role. The process of context and the dynamic transformation of objects into artefacts can be taken into account. This approach also takes the perspectives of different actors of an activity system. However, further work is still needed for it to be used as a robust design method. For effective use of activity theory for designing context-aware mobile applications, it is important that research time be long enough to understand the objects of activity, the changes of those objects over time and their relations to objects in other settings. There should also be commitment to understanding things from the users’ viewpoint. This means that there should be a phased approach to the design and evaluation of technology use, such as mobile devices for collaborative learning.

References


