Assessing learning technologies for software design using CRC cards

David Parsons
Institute of Information and Mathematical Sciences
Massey University, Auckland, New Zealand

Hokyoung Ryu
Institute of Information and Mathematical Sciences
Massey University, Auckland, New Zealand

Software engineering practice supports the development of learning technologies, but we do not, perhaps, utilise these learning technologies as much as we could when teaching the practices of software engineering. One useful technique for both learning about and designing object oriented systems is the CRC (Class, Responsibility, Collaboration) card exercise. In this paper we describe an experiment based on a CRC card exercise to compare a learning task related to software design executed in three environments; classroom based, e-learning and mobile learning. Our results indicate that although the software engineering aspect of the task may be better executed in traditional classroom environment, some aspects of the learning process may be enhanced by a mobile solution.

Keywords: mobile learning, software design, email, SMS text messages.

Introduction

One of the ironies of learning technologies is that they are designed and built using software, but are relatively rarely used to support the teaching of software engineering. Rather, the tools of the technologies themselves, such as Integrated Development Environments (IDEs) and Computer Aided Software Engineering (CASE) tools tend to be used. An overview of significant major papers in the mobile learning field underlines this fact. There have been high profile projects in teaching about the natural environment (e.g. Rogers et al 2004) and the built environment (e.g. Walker 2004), but relatively few studies that have anything to do with the study of computing, and very few that relate specifically to software engineering. The few papers about distributed pair programming (e.g. Hanks 2004) seem to be the exceptions that prove the rule. We might make a similar case for the use of virtual worlds in education. Pedagogical uses of Second Life for example include literature studies, historical re-enactments etc. but relatively little work related to software engineering, though there are exceptions (e.g. Ye et al 2007.)

The purpose of the experiment described in this paper was to explore ways that technology might support learning about certain aspects of software engineering in ways that enhanced the learning experience and addressed certain difficulties in teaching those aspects in a more traditional setting. The chosen topic of study was the use of Class, Responsibility, Collaboration (CRC) cards as a way of both learning about object oriented thinking, and as a way of designing object oriented software. In the next section we introduce CRC cards, and explain why developing a technology supported distributed learning exercise might be potentially beneficial. We then explain the experiment that we designed and ran. The next section summarises our results, and we conclude with a discussion of our results and proposals for future work.

Class, Responsibility, Collaboration cards

Class, Responsibility, Collaboration (CRC) cards were developed by Beck and Cunningham (1989) as a way of teaching object-oriented thinking. A CRC card is a way of representing the name of a class in an object oriented domain model, the messages it receives when instantiated within the system and the other classes it associates with. It is divided into three areas that specify these three properties (Figure 1):
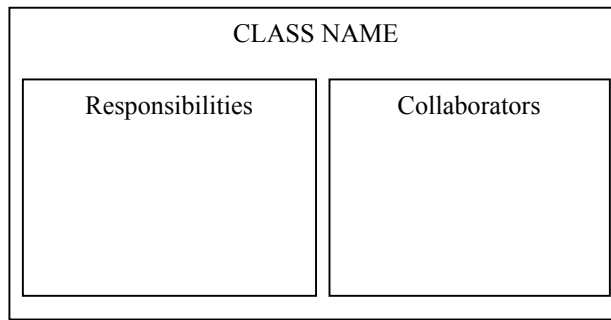
Figure 1: Class, Responsibility, Collaboration (CRC) card

Although the original idea behind CRC cards was to provide a way of learning about object oriented software design, they can also be usefully integrated into software engineering methods (Beck & Cunningham 1989). Indeed some subsequent methods have explicitly included CRC cards, for example SASY (McGregor & Korson 1994).

In a CRC exercise, the participants role play classes in use case scenarios, building up the class model with each use case. Each time a card is used in a use case role play, the messages it receives and the other classes that it sends messages to (i.e. collaborates with) are added to the card. Eventually, when all the use cases have been used in role play, a complete set of responsibilities and collaborators will have been defined for each class.

Using CRC cards for design has a number of benefits in terms of supporting software development teams. It encourages discussion of both the static and dynamic aspects of the software model, and the cards themselves support essential design heuristics (Biddle, Noble & Tempero 2002). An important aspect of the dynamic nature of the exercise is that it can assist inexperienced designers, such as those learning about object oriented design, to understand that there may be multiple solutions to a single problem (Borstler, Johansson, & Nordstrom 2002). However there are problems that can arise. These include the focus shifting away too early from the cards to other media such as whiteboards, compromising the democratic, collaborative behaviour of the exercise. Transferring to other media is not recommended in CRC exercises, because of the importance of physical interaction with the cards, including the ability to reposition the cards in the context of others as the exercise progresses. This is why the computerisation of the exercise was discouraged by the authors (Beck & Cunningham 1989). Also, performing a CRC exercise as a group can lead to shortcuts and lack of rigour (Biddle, Noble & Tempero 2002), though a testing by inspection process may be integrated into the exercise to counter this problem (McGregor & Korson 1994)

Some of the problems identified above, regarding the use of CRC cards by a group of participants in a single room, might be resolved by using a distributed learning platform. If the participants are separated physically, but communicating electronically, there is no danger of the focus shifting way too early from the cards. In addition, if separate individuals are made responsible for certain classes in the exercise in ways that make short cuts impossible, we are more likely to get more rigor in the overall process. Therefore we had the idea that it may be worth trying to run CRC card exercises in a distributed manner using simple technologies, namely email or SMS (short message service) text messaging. By separating the participants, with each participant solely responsible for certain classes within the system, and with no alternative to focus on the cards themselves, we hoped to promote greater focus on the core attributes of CRC without the potential distractions and shortcuts that can occur in a co-located exercise.

With this idea in mind, we designed an experiment to compare the performance and perceptions of multiple CRC exercise groups using different learning environments; face to face, email and mobile text messaging. The participants were divided into groups of four, with each group performing the same CRC exercise using either a traditional classroom environment, or a technology supported environment based on either computers using email, or mobile phone using text messaging.

Experimental materials

In order to run the experiment, we supplied various materials. Some of these were design artifacts, such as domain and use case diagrams, and some were physical support tools such as CRC cards and mobile phone SIM cards. Figure 2 shows an initial domain model for a home insurance company system. This

domain model was used in the experiment to provide the class names used in the CRC exercise. In addition to these classes, a 'Façade' class (Gamma et al 1995) called 'InsuranceSystemFacade' was included to represent the entry point to the system, giving 8 classes in total.
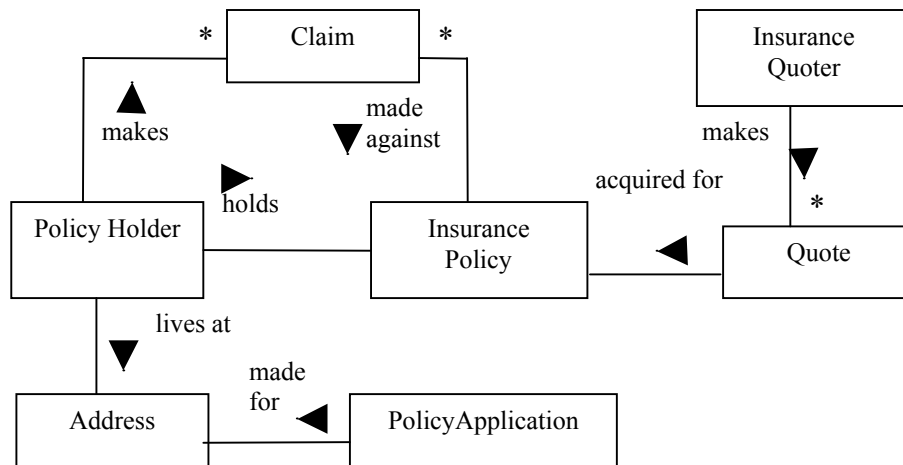

Figure 2: Domain model for the CRC exercise

Figure 3 shows some of the actors and use cases in the system. These use cases were available to be chosen from in the CRC exercise. Due to time constraints, only a small number of use cases were to be used, dictated by the experiment moderator. The use case diagram was intended to make it clear to the participants that the exercise they were undertaking was only a part of what in practice would be a longer and more detailed design exercise.
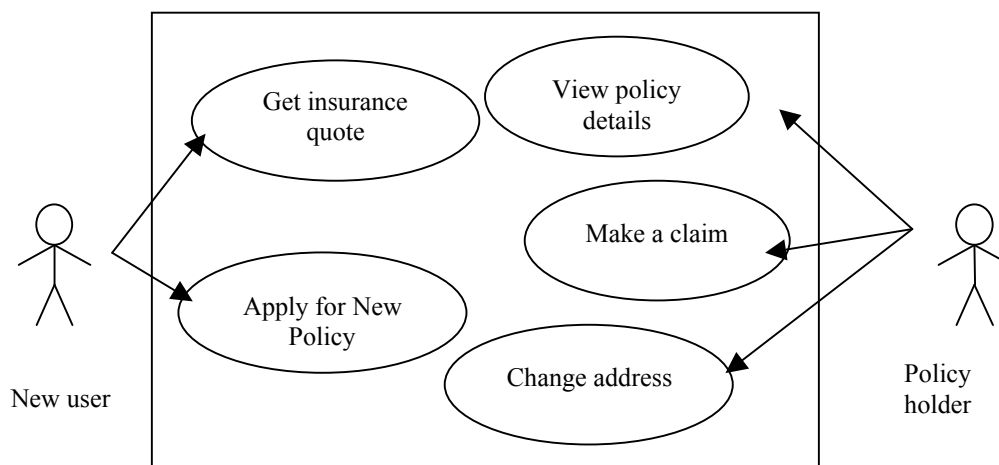

Figure 3: Use case diagram for the insurance domain

The pilot

Before the experiment which is reported in this paper, a pilot exercise was undertaken. This was intended to test the feasibility of the mobile aspect of the experiment. Students in a second year software design course were asked if they were prepared to volunteer to participate in a pilot experiment to test a mobile phone supported CRC exercise. This pilot was undertaken during the 2006 academic year. A small number of students agreed to participate in this test, which turned out to be unsuccessful for a number of reasons, namely:

• The task was too ambitious, leading to over complex instructions
• The students did not know enough about CRC already to understand how the activity was supposed to work

- The timing of the test, designed to enable the students to text for free at off peak times, meant that they were expected to participate outside of normal university hours. This was not popular.
- Students did not wish to share their mobile phone numbers, event though they would remain anonymous (phone numbers were associated with class names, not owners.)

We addressed these problems in the following ways:

- The task was simplified with a streamlined set of instructions
- The students were introduced to the CRC technique in a classroom setting so they already understood how the exercise worked in a traditional context
- A number of SIM cards were purchased, with prepaid credit so that students could participate for free during normal university hours and would not have to share their personal mobile phone numbers.

Following these modifications to the experimental method, a second pilot was run using groups of students from the same software design paper, undertaking CRC card exercises in the three contexts. We did not collect data from this pilot but used it to ensure that the modifications to the experimental method were effective. We also used this pilot to refine the organisation and timings of the experiment to ensure that the schedule was realistic. Following the second pilot, we ran an experiment from which we collected data. This took place during the 2007 academic year, with students from that year's intake of the same software design paper.

How the experiment was executed

The CRC exercise was performed in three different ways, two using technology and one using a traditional classroom environment. Two groups performed the exercise using mobile phone text messaging, two groups performed the exercise using email and two more groups did the exercise co-located around a table. The groups each comprised four participants in order to make the exercise collaborative but still simple to run. As Cockburn notes, a CRC exercise "may be done by one person, or up to 5 people, after which it needs careful facilitation." (Cockburn, 2002). The number of groups was dictated by the number of students present in the class who were willing to participate in the experiment. Each person in each team was allocated two CRC cards, named after one of the concepts in the domain model. One of these cards represented the boundary façade object ('InsuranceSystemFacade'). Each participant from the mobile phone group was provided with a SIM card with some prepaid credit. They were also given the mobile phone number of the exercise moderator. The moderator provided each member of the team with a list, mapping domain class names to mobile phone numbers. Each participant from the email group was provided with an email address (set up in advance using Hotmail accounts). They were also given the university email address of the exercise moderator. The moderator provided each member of the team with a list, mapping domain class names to email addresses

The allocation of pairs of classes to numbers/addresses was the same for both the mobile phone and email groups, namely:

- InsuranceSystemFacade and Address
- Claim and Quote
- InsuranceQuoter and PolicyHolder
- PolicyApplication and InsurancePolicy

The participants received the following instructions:

In each interaction, the InsuranceSystemFacade will receive an initial message from the moderator. The Façade forwards the message it receives from the moderator to the class it thinks can do this task or at least start this task off. The class that receives the forwarded message must decide if it:
(a) can do some of the task and get help from other classes (collaborators) to finish the task or
(b) can do all of the task without help from any other collaborators.

If (a)
the class waits to receive a return message from each collaborator (which means together they have finished their part of the task) and then it returns an answer to the Façade which replies to the moderator (a Boolean reply).

If (b)
the class replies to the Façade immediately (which indicates it has finished the task) and the Façade replies to the moderator.
Note:

Each class that receives a message must send a response to the class that sent the message when it has completed its part.

If that class also has to get help from another class, it waits until it gets its own reply before replying to its own sender.

There may be a chain of several classes carrying out parts of the task, each replying to their sender to indicate they have done their part of the main task. Eventually the chain of replies makes its way back to the Façade which sends its final "we've done it" message to the moderator.

However, the replies that are sent as part of a CRC exercise are not data e.g. "we've done it", they are the return datatype of the expected reply e.g. Boolean, String, Integer, void.

At the end of the exercise, each group was asked to pool together their cards and create a common class diagram.

Results and analysis

Of the six groups, only data from four of these groups could be usefully analysed, because in two cases one or more participants decided not to complete all aspects of the experiment. At the end of the exercise, the object models created by the four groups from their CRC cards were collected and analysed. The number of classes and operations on each diagram for the four groups can be seen in table 1.

Table 1: The number of classes and operations added to the diagram by the four groups

Group	Classes	Operations
Face to face	6	14
Mobile	3	4
Email 1	5	8
Email 2	4	4

From this data it can be seen that the face to face group made the most progress in the time available. The mobile group made the least progress. From the perspective of using CRC cards as a software engineering tool therefore it may be concluded that the traditional face to face approach is indeed the most effective. However there is another aspect to CRC which is that it provides 'a laboratory for teaching'. Therefore we also tried to assess the students' reactions to using the various teaching environments for the CRC technique and gathered their responses using a questionnaire after they had completed the exercise. The questionnaire asked them to respond to the following statements using a 7 point Likert scale, with a response of 1 corresponding to 'Strongly disagree' and a response of 7 corresponding to 'Strongly agree'. Therefore the neutral value in this study was 4. Table 2 lists the questions in the feedback questionnaire. These have been categorised under a number of different headings to specify the context of each question.

Table 2: Questions from the feedback questionnaire

	Question	Category
1.	My learning about CRC would be difficult to perform without the system	Learning effect
2.	Using the system gives me greater control over my learning of CRC.	Control
3.	Using the system improves my understanding of how to do CRC.	Learning effect
4.	I find this system to provide an enjoyable way to learn CRC.	Enjoyment
5.	The system helps me to understand how CRC works.	Learning effect
6.	I would like to use the system again for other learning purposes.	Intention to use
7.	Using the system saves me time rather than doing CRC in the classroom (for mobile / email groups only)	Learning effort
8.	The system enables me to accomplish learning of CRC more quickly	Learning effort
9.	The system helps me to understand the critical aspects of how CRC works.	Learning effect
10.	Using the system allows me to accomplish more learning than would otherwise be possible.	Learning effect
11.	Using the system enhanced my effectiveness in learning CRC.	Learning effect
12.	Using the system made it easier to learn CRC.	Usability
13.	Interacting with the system is often frustrating.	Usability
14.	I found it cumbersome to use the system to learn CRC.	Usability
15.	The system is convenient for communication with other students for learning about how CRC works	Communication
16.	The system would be more effective if it used graphics and illustrations.	Usability

Table 3 shows the results of the questionnaire for the four members of the face to face group (labelled F1 to F4) the four members of the mobile group (labelled M1 to M4) and from the two email groups. In both email groups, one of the participants declined to fill in the questionnaire. The three responses that were received from the first email group are labeled 'Ea1' to 'Ea3', while the responses from the second email group are labeled 'Eb1' to 'Eb3'. As part of the ethics approval process for the experiment we had to make it clear that not only was participation in the experiment voluntary, but so was filling in the questionnaire afterwards, and two participants chose to exercise this right not to respond. Therefore we do not have a full set of responses for the two groups. The left hand column (labeled 'Q') contains the question number. Note that question 7 did not apply to the face to face group so there was no response requested for this question from this group.

Table 3: Questionnaire results

Q	F1	F2	F3	F4	M1	M2	M3	M4	Ea1	Ea2	Ea3	Eb1	Eb2	Eb3
1	5	3	4	3	5	5	5	6	5	5	5	6	6	4
2	4	3	4	6	5	5	4	6	5	5	4	6	4	6
3	5	5	6	6	5	6	4	6	5	6	4	6	5	7
4	4	5	6	6	5	7	5	7	5	7	5	7	4	7
5	2	4	7	6	5	5	5	7	5	5	5	7	3	7
6	4	4	7	5	4	3	5	4	4	3	5	4	3	7
7					4	6	5	5	4	6	5	5	5	5
8	3	4	6	5	5	5	5	7	5	5	5	7	5	6
9	3	3	5	5	4	6	5	7	4	6	5	7	4	6
10	3	3	5	6	5	5	5	7	5	5	5	7	5	7
11	3	4	2	5	4	5	5	7	4	5	5	7	4	7
12	4	4	5	5	5	5	5	7	5	5	5	7	4	7
13	5	5	3	5	4	3	5	5	4	3	5	5	5	4
14	4	5	4	5	5	4	5	4	5	4	5	4	4	4
15	6	4	4	5	5	5	5	4	5	5	5	4	5	7
16	6	4	7	5	5	5	6	7	5	5	6	7	6	7

Figure 4: Graph and table of mean responses

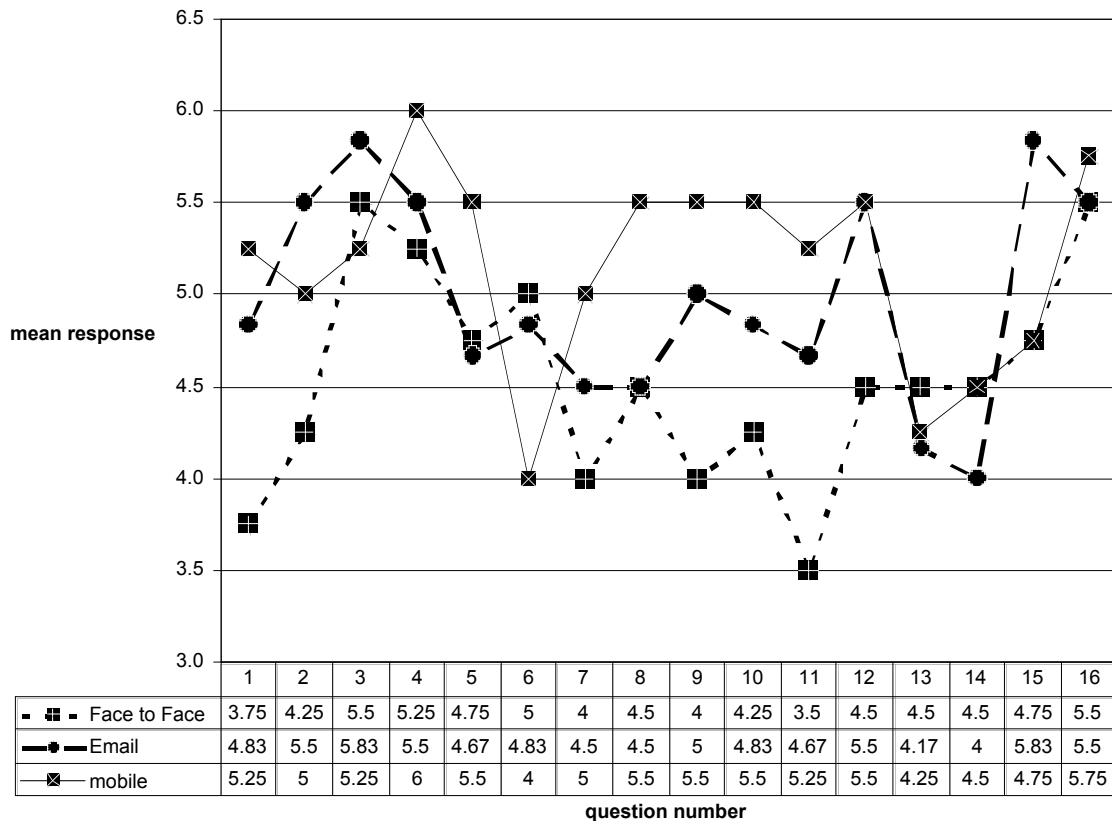|	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Face to Face	3.75	4.25	5.5	5.25	4.75	5	4	4.5	4	4.25	3.5	4.5	4.5	4.5	4.75	5.5
Email	4.83	5.5	5.83	5.5	4.67	4.83	4.5	4.5	5	4.83	4.67	5.5	4.17	4	5.83	5.5
mobile	5.25	5	5.25	6	5.5	4	5	5.5	5.5	5.5	5.25	5.5	4.25	4.5	4.75	5.75

Figure 4 shows a table and graph of the mean responses for the three types of group (face to face, mobile and mobile). Although the small sample size precludes any meaningful statistical analysis of the data, we can nevertheless note some features of the responses. In some of the questions relating to learning effect, in particular questions 1 ('My learning about CRC would be difficult to perform without the system') and 11 ('Using the system enhanced my effectiveness in learning CRC') there is a noticeably positive response from the mobile group when compared with the face to face group. Another feature worth noting is that, despite the very limited technology that was being used by the email and mobile groups, there is nothing to indicate from the three usability related questions (12, 13 and 14) that this was a major barrier to the groups using these technologies.

To provide some further insights into the data we have also applied an approach borrowed from "d" analysis in psychological studies (Table 4.) In this analysis, we have indicated for each group the number of responses that are on the positive side of the neutral value, i.e., 4 (the '>4' column in each case.) Using this approach, our questionnaire data indicated that there seemed to be a general trend towards positive responses to learning via the CRC method with a mobile platform. In most cases, the distinction between the responses is slight. However in one case we can highlight what appears to be a significant distinction between the face to face group and the mobile group. For question 1, 'My learning about CRC would be difficult to perform without the system', there is a difference of 3 (the number of participants who rated positively) between the positive responses from the face to face group and the mobile group. Differences of two (in the number of participants who rated positively) between the face to face group and the mobile group are evident in questions 2, 5, 8, 10 and 12. In all cases the positive scores favoured the mobile learning environment. It is also worth noting that the responses for questions 8 ('The system enables me to accomplish learning of CRC more quickly'), 10 ('Using the system allows me to accomplish more learning than would otherwise be possible') and 16 ('The system would be more effective if it used graphics and illustrations') were very high for both of the technology-supported environments. We should also note, however, that the answer to question 3 ('Using the system improves my understanding of how to do CRC') gained a very positive response from the face to face group. Perhaps this was because the participants could see the whole process unfold in front of them, rather than just their own part of it.

Table 4: "d" analysis of questionnaire responses

Q	F1	F2	F3	F4	>4	M1	M2	M3	M4	>4
1	5	3	4	3	**1**	5	5	5	6	**4**
2	4	3	4	6	**1**	5	5	4	6	**3**
3	5	5	6	6	**4**	5	6	4	6	**3**
4	4	5	6	6	**3**	5	7	5	7	**4**
5	2	4	7	6	**2**	5	5	5	7	**4**
6	4	4	7	5	**2**	4	3	5	4	**1**
7						4	6	5	5	**3**
8	3	4	6	5	**2**	5	5	5	7	**4**
9	3	3	5	5	**2**	4	6	5	7	**3**
10	3	3	5	6	**2**	5	5	5	7	**4**
11	3	4	2	5	**1**	4	5	5	7	**3**
12	4	4	5	5	**2**	5	5	5	7	**4**
13	5	5	3	5	**3**	4	3	5	5	**2**
14	4	5	4	5	**3**	5	4	5	4	**2**
15	6	4	4	5	**2**	5	5	5	4	**3**
16	6	4	7	5	**3**	5	5	6	7	**4**

Q	Ea1	Ea2	Ea3	>4	Eb1	Eb2	Eb3	>4
1	5	5	5	**3**	6	6	4	**2**
2	5	5	4	**2**	6	4	6	**2**
3	5	6	4	**2**	6	5	7	**3**
4	5	7	5	**3**	7	4	7	**2**
5	5	5	5	**3**	7	3	7	**2**
6	4	3	5	**1**	4	3	7	**1**
7	4	6	5	**2**	5	5	5	**3**
8	5	5	5	**3**	7	5	6	**3**
9	4	6	5	**3**	7	4	6	**2**
10	5	5	5	**3**	7	5	7	**3**

11	4	5	5	**2**		7	4	7	**2**
12	5	5	5	**3**		7	4	7	**2**
13	4	3	5	**1**		5	5	4	**2**
14	5	4	5	**2**		4	4	4	**0**
15	5	5	5	**3**		4	5	7	**2**
16	5	5	6	**3**		7	6	7	**3**

Conclusions and future work

What conclusions can we draw from the fact that although the mobile group performed the worst of all the groups, their responses to the mobile learning environment were positive? With this limited data set we cannot say anything for sure. However, one of the authors' motivations for this experiment was their experience that these exercises being carried out in a face to face environment can mean that the process is taken over by certain individuals. Thus it may be that the mobile approach has a democratising effect that enables individuals to participate more effectively regardless of their confidence or experience. Positive responses to some aspects of learning effect also suggest that there are some features of the mobile learning environment that that the participants responded to strongly. In particular, questions that indirectly related to applying tools to learning gained a positive response from the mobile group.

The experimental work carried out so far has given us some insights into what issues might be worth further investigation. From our limited analysis of a small data set, we may take some encouragement for the potential of this approach to the teaching of software design using the CRC card technique. However the participants clearly felt that the system was lacking in its interface, having no graphics or illustrations to work with. One aspect of our future work is to consider how a more sophisticated web based and/or mobile application might support such learning exercises in the future. This would help to address the inherent gap between the media richness of paper and coloured marker pens used by the face to face group and the simple text data used by the email and text messaging groups. It might also address the issue that the face to face context provides participants with a view of the whole process that was missing from our email and face to face groups. A richer interface could provide more information on the evolving model to remote participants.

We might also pay more attention to the group dynamics, perhaps to see if indeed there is greater progress because of certain individuals driving the exercise at the expense of the full participation of others. Thus the learning aspect of the CRC exercises might be suffering at the expense of progress from the software engineering perspective. Issues such as gender and culture may potentially have an impact here, as well as individual confidence and experience. Gaining a greater understanding of these issues would require monitoring the processes that actually take place during the exercise, rather than simply gathering and analysing the results at the end.

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Authors: Dr David Parsons, Institute of Information and Mathematical Sciences, Massey University, Auckland, New Zealand. Email: d.p.parsons@massey.ac.nz

Dr Hokyoung Ryu, Institute of Information and Mathematical Sciences, Massey University, Auckland, New Zealand. Email: h.ryu@massey.ac.nz

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