WHEN ARE TWO HEADS BETTER THAN ONE? A STUDY ON THE EFFECTS OF TASK DIFFICULTY ON PAIR COMPUTING.

by

Rainalee Mason, B. MM.

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AUSTRALIA

I, Rainalee A. Mason,

declare the following work presented in this thesis is, to the best of my knowledge and belief, original, except as acknowledged in the text, and that the material has not been submitted, either in whole or in part, for a degree at this or any other university.

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ABSTRACT

WHEN ARE TWO HEADS BETTER THAN ONE? A STUDY IN THE EFFECTS OF TASK DIFFICULTY ON PAIR COMPUTING

by Rainalee Mason

Paired computing – the practice of two people sitting at one computer, sharing one keyboard, display and mouse – has become more prevalent in recent times in both education, and the relatively new field of Pair Programming. Research into paired computing has generally concentrated on the advantages of paired computing over individual approaches, however little research has been done into factors that may make paired computing more or less effective. Anecdotal evidence suggests task difficulty (cognitive load) may affect whether paired approaches are preferable. It was hypothesized that more complex tasks (higher cognitive load) would be suited to paired approaches. Two experiments were performed using Primary and High School children to test this hypothesis. Results indicated a clear advantage for the paired computing approach over the individual approach, in moderately difficult problem-solving tasks. The problem presented to the students was logical and structured, and the findings should be transferable to all domains involving logical structured problems, but not necessarily creative tasks.

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LIST OF ACRONYMS AND ABBREVIATIONS

AR Augmented Reality

CSCW Computer Supported Collaborative Work

HMD Head mounted display

ICT Information and Computer Technology

ISP Internet Service Provider

MP3 A data file type (shortened version of MPEG, audio layer 3) and coding scheme which is used to compress audio signals.

MSN Microsoft Network

NSW New South Wales

PC. Personal Computer – self-contained desktop or laptop computer that contains a CPU, storage devices, a monitor, keyboard and mouse.

VR Virtual Reality

XP Extreme Programming

Chapter 1

INTRODUCTION

The benefits of working collaboratively are becoming well known, in both the workplace and education. As computers become ubiquitous in our daily lives, collaboration can often involve two people sitting at a personal computer, sharing one display, keyboard and mouse. This form of collaboration is known by several names – “co-present computer supported cooperative work”, “shoulder-to-shoulder computing” and “paired computing”.

While this is already happening in classrooms and workplaces, very little research has been done into the advantages and limitations of this approach, and into which problem domains this approach may be most suitable. One form of paired computing, in the programming field, has gained some interest in the last few years. Pair programming research indicates that paired approaches may lead to productivity, quality and enjoyment advantages over programming alone. Anecdotal evidence generally indicates that collaborative computer use is more effective, productive, accurate and enjoyable that individual computer use.

However, no research has been done into the effects of pairing by skill set, ability, gender, or by self-seeding. Also, anecdotal evidence has suggested that the utility of paired usage may be dependent upon the complexity of materials; however no research has been completed into this area.

Aim

The aim of this honours project is to investigate the effects of cognitive load (or task complexity) on the benefits and effectiveness of collaborative computer use.

Relevance

Paired computing forms of collaboration are already being used in schools, informally in workplaces, and in software development methodologies that include pair programming. However this use is often driven by budgetary constraints, allegiance to development methodologies (such as Extreme Programming) and desires to use collaborative methods whenever possible. Research into the effects of task complexity on the effectiveness of collaborative computer use may offer some insight into when and how to most effectively use paired computing techniques.

Report

To achieve this aim, Chapter 2 of this report provides a literature review on the history and present status of research into this area. This literature review covers the increase in computer use both in Australia and overseas, educational computer use, and the history and advantages of collaboration both in the workplace and in education. It also includes an overview of the field of Computer Supported Collaborative Work, and looks at directions of the research into co-

present collaboration on computers. Pair Programming – history and research – is also examined, and finally cognitive load theory and distributed cognition approaches are summarised.

Experiment

Chapter 3 describes a practical, testable experimental approach, which may determine whether benefits observed in paired over individual approaches are affected by task difficulty (or level of cognitive load). Chapter 4 reports on the results of both a pilot study and an experiment conducted in local schools and discusses the results of these experiments.

In conclusion, Chapter 5 discusses some possible implications of the research in educational, workplace and programming contexts. This final chapter also suggests possible further research directions.

Chapter 2

LITERATURE REVIEW

2.1 Computers, computers … everywhere!

2.1.1 The Technology Age

There should be no doubt that the Twenty First Century is indeed the Technology Age. Although computers have not attained artificial intelligence and taken over the world, as seen in the 1999 film "The Matrix" (Wachowski & Wachowski) or the 1984 film "Terminator" (Cameron & Hurd), personal computer use has exploded over the last twenty years. In 1981 the first IBM Personal Computer (PC) was unveiled with a price tag of over $US10000 (Polsson, 2004), with a state-of-the-art memory of just 16 Kb and a tiny 5-inch (12cm screen). By 2001, a mere twenty years later, 90% of all US children between the ages of 5 and 17 had used computers either at home, at school, or both. In addition, 92% of surveyed US workers said they were comfortable using Information Technology and equipment in the workplace (Kelsey, 2001).

Computers are everywhere in modern life – new cars can have up to 50 microprocessors (Nice, undated), mobile phones use computer chips to store numbers, games, and communicate with other phones (Tiscali, 2000), and computers are even utilised in "smart home appliances" that are intelligent and context aware (Friberg, 2004). Some of these smart appliances are already obtainable – for example, the Internet fridge (LG, 2004) with built in MP3 player, email and video mail access, camera and microphone. Other products, such as the

smart pillow (which plays favourite music, reads books, and checks pulse and body temperature while the user is asleep) are not yet readily available (Friberg, 2004).

Despite the ever-increasing use of computer technology within our lives, the humble Personal Computer is still the most familiar form of computing technology to humans in homes, business and education.

2.1.2 Australian Computer Use

In Australia, computer usage continues to grow. According to the Australian Bureau of Statistics (2004), 84% of all Australian businesses use at least one computer. All businesses with over 100 employees use computers, and 99% of these businesses have access to the Internet. The Australian Government spent an estimated $4.3 billion on information and computer technology in the financial year 1999-2000. However, the use of technology is not restricted to business -- 61% of homes now own at least one computer (ABS, 2004). This proportion increases to 77% if only homes with a child under 15 are considered. However, computer use is not confined to home or business.

2.1.3 Educational Computer Use Worldwide

Computer use in education has increased worldwide, as shown by the following graph of educational computer diffusion rates in the USA and Japan – Figure 2.1.

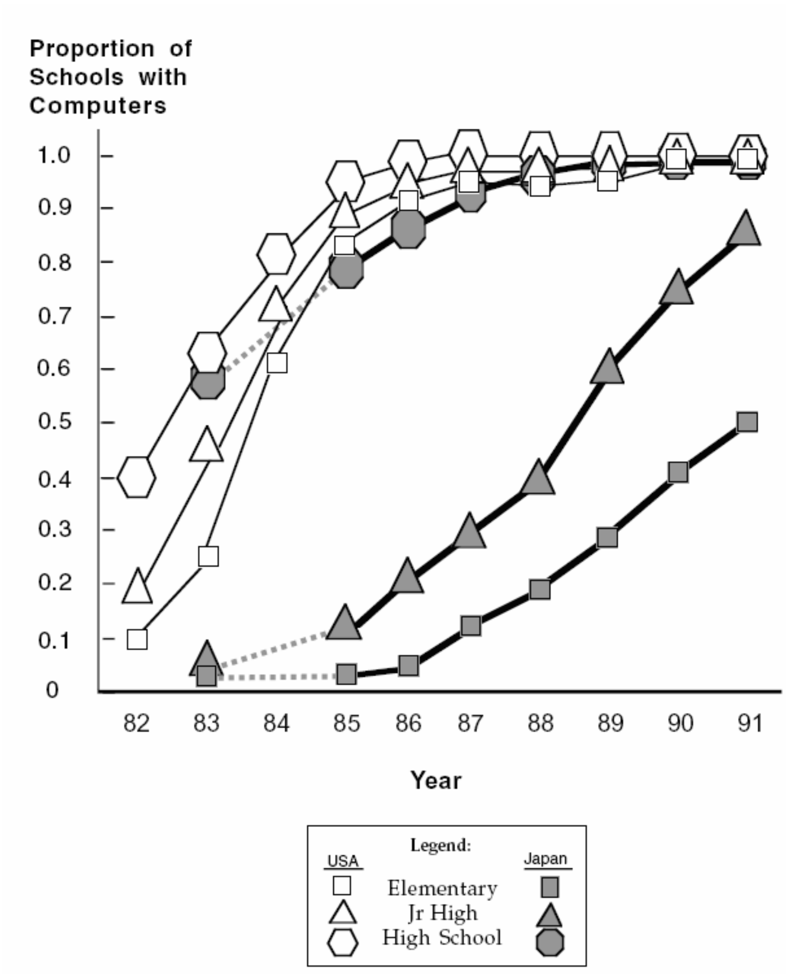


Figure 2.1 Computer Diffusion Rates in the USA and Japan
(*from* Knezek, Miyashita. & Sakamoto, 1993)

2.1.4 Education in NSW

Closer to home, according to NSW Department of Education figures, there were 125,000 computers available for teachers and students in NSW public schools in 2002 (NSW DET 2002a, p 89). The strategic direction of the Department of Education is a push towards new technologies, evidenced by departmental spending on computer education (NSW DET 2000b p 89):

- $22 million paid in computer coordinator allowance in 2001 – 2003 financial years;
- More than $48 million spent in leasing computer equipment in 2001/ 2002 financial year;
- 25000 multimedia computers distributed to schools during 2002/ 2003;
- Planned expenditure (2003 - 2007): $247 million to upgrade network bandwidth in schools and TAFE;
- Planned expenditure (2003 - 2007): $82.3 million for e-learning initiatives;
- Planned expenditure (2003 - 2007): $17.1 million to provide teacher training in schools in the use of the latest computer technology.

The stated objectives and priorities for education in NSW include the intent to "extend the use of new technology to support learning and teaching" (NSW DET 2000a, p 3), and a directive to teachers to "empower students to use information and communications technologies confidently, creatively and competently to enhance their own learning" (p 2). The NSW K-6 Science and Technology curriculum "Outcomes and Indicators" expects students to be able to "confidently and competently use a range of computer-based hardware and applications by the end of their primary schooling" (Board of Studies NSW, 2000),

and the compulsory Design and Technology syllabus for Year 7 and 8 includes at least 50 hours "devoted to learning about and using computers" (NSW Board of Studies 1991b, p23). Teachers are encouraged to ensure that students have basic competency in computer usage, early in this course (NSW Board of Studies 1991a, p46).

2.1.5 How do we use this technology?

With all the emphasis on learning about and using computer technology, and the amount of funds being poured into providing the latest technology to schools, some researchers are calling for more research into how this technology is being used to effectively support the learning of students. As pointed out in a recent paper in the NSW Computer Education Group newsletter, "many schools are feeling the pressure from educational policy makers, parents and of course technology corporations to constantly upgrade and improve upon the hardware and software in an increasingly consumer driven market" (Casey, 2003 p14). Casey suggests that technology has little value in the classroom unless it creates a learning experience that is engaging (p 14). Recent research at the University of Munich seems to suggest that increasing access to computers in the home and school does not necessarily improve basic reading and mathematics skills (MacDonald, 2004). The study concludes that more research is needed to know exactly where computers make the most difference in the educational process.

2.2 Collaborative Directions

2.2.1 Collaborative work teams

At the same time as the use of computers has increased, there has been a trend towards collaborative work practices. The idea of collaboration in the workplace is not new. In the 1950s and 60s Fredrick Herzberg looked at the relationship between job satisfaction and productivity. He found that certain factors increased job satisfaction:

- The challenge of the work itself;
- Responsibility;
- Recognition;
- Achievement;
- Advancement and growth. (Herzberg, Mausner & Snyderman, 1959)

When these factors are present, they spur employees to higher performance.

From Herzberg's work came the concept of job enrichment, where managers change job characteristics to motivate employees. For example, jobs that permit employees to make decisions, use their skills, and receive feedback, lead to high motivation which then leads to productivity gains (Hackman & Oldham, 1980). These concepts led to the rise in popularity of "self-managed teams" in the late 1980's (Hellriegel & Slocum, 1992, p 538). A self-managed team usually consists of five to fifteen employees, who work together to produce an entire product, major identifiable component or service. The employees are empowered to control how they perform their tasks, take action to resolve day-to-day problems, and improve operation.

2.2.2 Advantages of Cooperative Teams

Self managed (sometimes called self-directed) work teams effectively manage themselves. One social work organisation that successfully introduced the work team structure comments – “The advantage of a self-directed team is that everyone’s judgment is utilized in a continuous brainstorming process” (Dumay & Velardo, 1998). Other advantages include (Williams, 1995)

- Improved quality, productivity and service;
- Greater flexibility
- Reduced operating costs
- Faster response to technological change
- Increased employee commitment to the organisation

In fact, self-directed work teams can be on average, 30 to 50 percent more productive than individuals (Williams, 1995).

Apart from these productivity gains, the popularity of self-managed work teams is growing because they “are consistent with current trends in organisations towards decentralisation, teamwork, flexibility and improving the quality of work life (Robbins, et.al. 1994 p 314)

Ron Williams, a Quality Assurance advocate, points out that even though self-directed work teams are obviously an advantageous direction for business, requirements for successful collaboration are that “there must be interdependence and joint responsibility for outputs”, and team members must “learn to work effectively in teams and develop skills in problem solving and decision making”.

Another point to note is that with the increase in computers in the workplace, covered in the previous section, and the rise of use of the Internet, collaborative teams may now have computer-facilitated meetings online, rather than face-to-face. This negates the need for the members of the team to be in the same physical location to experience productivity and job satisfaction gains (Hall-Taylor, 1999, p 4).

There are clearly advantages to be achieved from working collaboratively in teams. However, collaborative approaches are not confined to the workplace – education has now trended towards *collaborative learning* – "the grouping and pairing of students for the purpose of achieving an academic goal." (Gokhale, 1995).

2.3 Collaborative Learning

2.3.1 History of Collaborative Learning

Again, the collaborative learning movement is not new. It can be traced back to the early 1800's to Colonel Francis Parker, who developed a school system in Massachusetts that had as its basis the practice of placing children into groups to learn (Rimmerman, 1996). The school system enjoyed huge success. John Dewey revived interest in cooperative educational practices in the late 1800's, believing that democracy and cooperation in the classroom would lead to a more democratic, cooperative society (Campbell, 1995). In the 1950's, educational psychologist Morton Deutsch researched the effects of cooperation versus individual work and found that cooperative groups were "superior in the communication of ideas, coordination of work, friendliness and group pride" (Deutsch, 1951).

More modern research and method development came from Johnson and Johnson (1986) who refined Deutsch's work and applied it to the normal classroom. Their method was called "Learning Together". During the same period, Dr R. Slavin worked on several methods that emphasise "the idea that students work together to learn and are responsible for their teammate's learning as well as their own" (Slavin, 1990).

For the sake of brevity, many contributors to the cooperative learning field of research have been omitted from this brief history, however the concept of

collaborative learning has been widely advocated and researched throughout professional literature.

2.3.2 Advantages of Collaborative Learning

Cooperative learning has been found to be generally more effective than traditional classroom structures, in a similar way to the previously stated advantages on collaborative work practices. Research into cooperative learning has found positive outcomes including increased student achievement, improved interpersonal relations, more effective mainstreaming of academically and physically disabled students, and improved student self-esteem and attitudes towards others and school (Rimmerman, 1996).

2.3.3 Principles of Cooperative Learning

It is important to realise that just putting individuals into groups does not constitute collaborative learning practice. Dr Spencer Kagan, from the University of California emphasises four principles of cooperative learning: "Positive interdependence, Individual accountability, Equal Participation, and Simultaneous interaction … when the four basic principles of cooperative learning (PIES) are incorporated in the learning activity, learning and other positive outcomes are assured. However, if the principles are left out, positive outcomes will not necessarily occur." (Kagan, 1992).

There are a number of theories as to why students who work in cooperative groups learn more than those in traditionally organised classes.

Motivational perspectives point out that the traditional classroom organisation presents a competitive environment where each individual's desire to succeed frustrates others' goal attainment (Deutsch 1951). In contrast, cooperative learning emphasises group goals, which require group members to exert maximum effort to help the group to succeed. Cooperative learning and group rewards creates an interpersonal structure where group members will give praise and encouragement in response to others' efforts (Slavin, 1995).

Developmental theories postulate that interaction between children increases mastery of concepts. Johnson and Johnson (1986) found through research that cooperative teams achieve at higher levels of thought and retain information longer than students who work individually. Earlier Lev Vygotsky, a Russian psychologist, theorised that mental functioning occurs first socially, and later within an individual's mind (Hunt, undated). He described a Zone of Proximal Development – "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" (Vygotsky, 1978). In his view, collaborative learning activities would foster growth because children of similar ages are likely to be operating within each other's "zone", therefore exhibiting behaviours more advanced than those they would display as individuals.

The constructivist school of thought emphasises that learning happens in a social context. "Conceptual growth comes from sharing our perspectives and testing our ideas with others, modifying our internal representations in response to that process of negotiation" (Grabinger & Dunlap, 1995).

Another viewpoint of why collaborative learning is effective is that of cognitive elaboration (Slavin 1995, p 18). Research in cognitive psychology has shown that learners should engage with information that is to-be-learned in a way that requires cognitive restructuring or elaboration of the information, if it is to be stored in memory and related to already retained knowledge (Wittrock, 1978). If a student is working in a collaborative group, a most effective means of elaboration is explaining the material to other members of the group.

2.3.4 Disadvantages in Collaborative Learning

Proponents of the collaborative learning strategies are aware of possible pitfalls in the collaborative learning process. In a strongly worded paper titled "Group Grades Miss the Mark" one of the most well-known proponents of cooperative learning speaks out against giving each member of a group an identical grade, based on their collective work (Kagan, 1996). He argues that collaborative methods allow for a "free-rider" effect where some group members do all the work and others provide little or no contribution. If group grades are given, the contribution of less able students may also be ignored in favour of those in the group who are perceived to have more academic prowess. This effect can be

minimised by either making each group member responsible for a part of the group's task (with its associated danger of task specialisation); or to give group rewards based on the sum of the students' individual scores or performances. This encourages the group to ensure that all group members achieve their objectives. (Slavin, 1995)

2.3.5 Computers and Collaborative Education

Given the increase of computer use in the classroom and the obvious advantages of collaborative learning, it should be no surprise that teachers have sought to use new technology in collaborative settings, to foster learning amongst students. The impetus for the use of collaborative computer learning methods comes from two directions.

Firstly, limited school resources often result in children working at a computer together (Stewart, et.al. 1998). In both the high school and the primary school used for the study detailed in Chapter 3 of this report, teaching staff stated that students commonly worked together on computer work due to limited school resources.

However there is a danger in labeling every situation where children work together on a computer as cooperative work. If cooperative methods are not explicitly used, this can result in one child controlling the application while others wait their turn. (Stewart, et.al. 1998).

The second factor pushing collaborative computer work forwards is the knowledge that collaborative work in other settings appears to be generally advantageous to student learning. Computer work would appear to be an opportunity for students to work in collaborative ways.

The Design and Technology Support Document for the Year 7-10 Syllabus in NSW discusses cooperative methods in connection with computer work. Students are to be encouraged to "talk amongst themselves, discuss problems, delegate tasks, make their own decisions, and be free to see what others are doing. This provides students with the opportunity to share and clarify ideas with a wider audience" (NSW Board of Studies 1991a, p 24). The support document goes on to emphasise that cooperative learning, in the context of design and technology work, contributes to the development of higher thinking skills and promotes greater levels of understanding (p 26).

Encouragement of Interaction

Research has indicated that collaborative computer work may actually be more effective than other collaborative activities. Computers facilitate both collaborative interaction (students sharing in the collaboration) and students acting as expert resources for others.

In a series of studies in the early 1980's, it was found that "… children engaged in more collaborative talk about their work when they were working with microcomputers than when they were doing other classroom tasks." (Sheingold, Hawkins & Char, 1990. p 175). In a related case study, researchers observed more

collaboration, more solicitation of help from other students, more suggestions and comments in programming studies than in non-computer activities in which students were encouraged to work together (Sheingold, et.al, 1990). Another researcher notes that "computers may prove especially potent in facilitating peer collaboration" (Crook, 1990, p 160).

Why would computer work be particularly suited to peer collaboration? The added effectiveness of collaborative learning using a computer as compared to other learning situations may be due to the nature and quality of the interactivity (Boyle, 1997).

Charles Crook worked with school students in various interactivity studies and noted that "… the machine seems to be 'taking part in' a total interaction, as a kind of partner." (Crook, 1990, p 162). He recognised that the role the computer was taking would be more likely to define and organise potential interactions amongst users. He also commented that even in the simplest of computer tasks, where the computer issues discrete challenges or problems, interactions are structured differently compared to any other task children might complete in a classroom, as the computer offers precise feedback on the user's possible solutions. He felt that this may "exemplify one distinctive feature of the computer partnership that could prove significant" (Crook, 1990, p 162).

Some of the above data on the increased benefits of collaborative learning on a computer may be dated, given the large changes that have occurred in technology since the studies were published in the 1980's. However, it could be

argued that computers have increased in capacity for meaningful feedback in this time, and if feedback and interactivity is the impetus for more collaborative benefit then these studies will be even more relevant.

If computers support strong interaction due to the rich level of task feedback, then they should support cooperative work differently compared to other activities. As Crook expressed "… there is a real need here for research that pays more attention to task structures and the way in which they promote different styles of interaction." (p 170).

As a result of the increasing collaborative use of computers in the learning environment as well as in the work environment, a discipline has been formed to encourage research into using computers to support groups as they work or learn cooperatively, Computer Supported Cooperative Work, or its acronym, CSCW (IEEE, 2004b).

2.4 Computer Supported Collaborative Work

2.4.1 Introduction to CSCW

Computer Supported Collaborative Work (CSCW) is a inter-disciplinary field, incorporating study from the computer sciences (human-computer interaction, office systems, distributed systems), the social sciences of psychology, organizational science, management, linguistics and cognitive science, and media, technology and education studies (Hunt, undated). In contrast to the man-machine focus in other computer-related disciplines, there is a concentration on supporting cooperative, or person-to-person activities. There has been a large amount of interest in CSCW under various banners by major players in the ICT industry. Both IBM (http://www.research.ibm.com/SocialComputing/index.html) and Microsoft (http://research.microsoft.com/scg) have research groups formed specifically to examine 'social computing' – with projects ranging from online environments aimed at supporting communication between work groups (IBM, 2001) to conversation clusters – grouping email conversations based on text indexing (Microsoft Research, 2003). There is also a wide body of research from academic institutions into this area – some of which will be covered in the following sections.

2.4.2 Dimensions of Study of Collaborative Work

As CSCW covers such a wide area – software to support face-to-face meetings or remote meetings, electronic mail (e-mail) uses, hardware to support

collaboration, human factors impacting on successful collaborations, and interface issues, just to name a few subjects of research – it would be prudent to find factors that could define areas of CSCW work. Two such factors are time and space (Ellis, Gibbs & Rein, 1991).

Asynchronous vs. Synchronous

Cooperative work on the computer can be asynchronous or synchronous. A familiar example of asynchronous communicative collaboration is email. Both parties are not required to be on the computer at the same time - instead messages are held on a mail server until the receiver uses software to receive the communication. Another common example would be the use of electronic forums – a virtual meeting place where messages may be posted by participants, and then read and replied to by others at a later time. A good example of this is the Whirlpool Forums (http://forums.whirlpool.net.au), originally instituted to provide a place to discuss Australian broadband access issues. These forums have now grown to approximately 6,500 posts per day, and subject matter, while still of interest to those with a technical lean, now includes web coding, gaming, entertainment, news, hardware, and other sub-forums, as well as the Internet Service Provider and broadband information for which it was originally designed.

In contrast, synchronous collaboration requires both participants to be using a computer at the same time. A very familiar example of technology used to facilitate synchronous collaboration would be the free MSN Messenger application distributed by Microsoft (http://messenger.msn.com), and now commonly used in the workplace (Slatalla, 1999 in Herbsleb, et.al. 2000). This tool enables users to

chat online to others, send files, use video or audio communication, or even play games such as tic tac toe, checkers or chess at a distance.

Another example of synchronous collaboration using computers is multiplayer computer games and their virtual communities. Although most of these games are competitive, rather than collaborative, users can synchronously play at a distance (via a network or the wider Internet), or play side-by-side at a computer, with either turn taking of input devices or multiple inputs (such as joysticks) if the software supports this.

Space

Gaming is a good example of another factor that may be used to examine areas of CSCW – space. Collaboration using computer technology may be *remote* (at any distance from the other users – as in online gaming over a network or via the Internet) or *co-present*, where the other users are physically present. An example of remote (asynchronous) collaborative technology is email, which involves people in different places – even if it is an adjoining office – sending and receiving messages. Computer aided video conferencing would be an example of synchronous remote collaboration. Much research in CSCW focuses on supporting remote collaborative work (Bricker, et.al. 1998; Moran, 2000).

Co-present CSCW is when members of a group come together in the same place, and use computing technology to support or perform their collaborative activities. An example of this would be research into how people make group

decisions using computer technology, using the Virtual Decision Maker (Microsoft Research, 2003). Members of a co-present group of up to four people use remote controls simultaneously to respond to a stream of constantly adjusted images. From the responses, film recommendations are displayed using a filtering backend.

A common form of co-present CSCW is that of collocation in a physically larger space – an open-style office plan or “war-room” -- that allows workers on a project to work cooperatively (Olson & Olson, 2000). There is some evidence that co-present CSCW is more effective than remote CSCW. Peripheral awareness and informal conversations in co-present situations help to coordinate group activities, whereas remote work loses opportunities for rich interaction (Herbsleb, Mockus, Finholt & Grinter (2000). This can lead to less communication, coordination problems, and subsequent project delays. Other remote CSCW challenges include human factors - a 2002 study by two researchers at the University of California shows that “subjects (were) more likely to deceive, be less persuaded by, and initially cooperate less, with someone they believe is in a distant city, as opposed to the same city as them” (Braden & Mark, 2002).

Other researchers comment on some of the associated difficulties of remote collaboration:

> “Even when others are clearly present – as in a chat room or on a conference call – it is difficult to see who is present, who is paying attention, or who wishes to speak. Things that require little effort in face-to-face settings – taking turns when speaking; noticing when someone has a question; seeing who is responding to whom – require a lot of effort in online settings, if they are possible at all.” (IBM Research, 2001).

This report focuses on co-present synchronous collaborative practices using a computer.

2.4.3 Co-present Collaboration – Research Directions

Much research on co-present collaborative computer activities has concentrated on improving technology in one way or another, to facilitate collaboration.

Alternative Technologies

New technologies are being explored to support small group collaboration. Various "wall" technologies have been examined - for instance electronic 'walls' that allow pen-based user interface techniques in small group meetings, in a whiteboard metaphor (Moran, et.al. 1995). Other physical wall technologies are based on camera capture – for example the ZombieBoard "captures freeform scribbling on large whiteboards" and

> "the Collaborage system … captured and interpreted spatially arranged collages of information elements on tackboard walls, such as arrangements for collaborative project planning and coordination." (Moran, 2000, p 1).

Other physical technological advances to support co-present collaborative work include tabletop displays, coordination of distributed room displays, collaborative handheld applications, wearable computers (Inkpen, et.al. 2000) and 'augmented reality interfaces' such as the Shared Space Project (Billinghurst, et.al. 2000). The last of these is particularly interesting.

Multi-user immersive virtual environments have been shown to be effective and intuitive for collaborative work (Carlson & Hagsand, 1993 in Billinghurst, et.al, 2000). However virtual environments have the drawback that items in the real world – notes, documents and tools – cannot be accessed from the environment. The Shared Space technology comprises an overlap of virtual objects on the real world, enabling users to refer to physical objects such as notes while interacting with virtual images. Co-located users can see each other's expressions and body language. Effectively the collaboration occurs in both the real and virtual worlds. The technology was demonstrated at the SIGGRAPH99 conference, with approximately 3000 conference participants trying the exhibit. According to the organisers, users who played a game with the project:

> ".. had no difficulty with the AR [Augmented Reality] interface and exhibited the same sort of collaborative behaviour seen in typical face-to-face interaction with physical objects. … The physical, tangible nature of our interface made collaborative interaction very easy and intuitive. … even young children could play and enjoy the game." (Billinghurst, et.al. 2000, p 4)

A downside to this technology, which involves spatial 3D interfaces and computer vision tracking and registration, is the necessity of wearing a head-mounted display incorporating a camera (Billinghurst & Kato, 1999)

Enhancing existing environments

Another way that technology is being changed to suit collaborative, co-present activities is by enhancing existing environments. This can be done through software or hardware. One factor to consider in this area is that often collaborative work involves both individual and shared activities – and groupware (software

designed to support collaborative work) design should take this into account. Topics of interest in this area include

- Workspace navigation: who controls the workspace -- one user or multiple users? Collaboration is simplified when the group sees the same artifacts simultaneously, but individuals need to be able to access and manipulate the objects that they need for their tasks.
- Artifact manipulation: what information should be provided to the group about user's actions with the system? How does this impact on usability for the individual?
- View representation: should users be able to personalise their representation of the workspace so that it is more meaningful for them? If so, what implications does this have for group work?

(Gutwin & Greenberg, 1998).

To answer these and other issues, research has been undertaken into custom groupware that attempts to support collaborative practices with a balance for both individual and shared activities.

2.4.4 Paired Computing

Most current computer CSCW applications are designed to support the one person-one computer paradigm (Bricker, et.al. 1998). Alternative technologies such as augmented reality and electronic whiteboard walls aside, email, forums, instant messaging, collaborative groupware (to be used co-presently or remotely) and other commonly used tools are all designed to be used by one user at a computer or terminal.

Yet a very common form of group work is that of two users gathered around one computer, sharing one display, one keyboard and one mouse – ***paired***

computing. This collaboration happens naturally in work and educational settings and requires no special equipment. Paired computing also appears to have some inherent advantages over working alone or other forms of computer collaborative work.

An empirical study conducted by Kori Inkpen with school children observed three groups of children playing a commercial problem-solving computer game. The first group was formed of children playing alone on the computer, the second of children playing in parallel (side-by-side, each with their own computer) and finally integrated play (a pair of children playing together on one computer). The results of the study showed clearly that children were more motivated and successful when playing in the paired computing condition, than in either of the other two conditions (Inkpen, Booth and Klawe, 1995).

Paired Computing Research Directions

Other research has been completed into this form of collaboration – primarily into what differences result from removing some of the restrictions inherent in the interaction, by changing aspects of the software or hardware.

Non-computer collaboration activities allow simultaneous interaction and input – for example, two children drawing may both use a pencil on the paper at the same time, while talking about the drawing process. In fact, simultaneous interaction is one of Kagan's four principles of cooperative learning, considered necessary for positive outcomes (Kagan, 1992) .

Paired computing is different from other forms of collaboration in that there is not only interaction between the users to consider, but an interaction between each user and the computer itself (Crook, 1990). There is also usually only one input device usable at a time – either a keyboard or a mouse. If the keyboard is used at the same time as the mouse, it can cause conflicts with the software, or result in unexpected results for the other user (Bricker, et.al. 1998). Studies using children working with existing software tools in a collaborative setting with one input device showed such behaviours as the passive user (not in control of the mouse) pointing at the screen constantly, users fighting for control of the input device, frustration and irritation by the passive user at the lack of equal participative effort, the passive partner issuing orders to the active partner, or lack of attention from the passive user (Stewart, et.al. 1998; Regan, Lofstrom & Davis, 2002).

Some technological solutions to the problem of limited inputs have been suggested. One such project is a "remote commander" which allows users to take turns controlling a PC's main cursor and keyboard via PalmPilots, so regular applications can be used (Myers, 2002). While this negates the necessity of users physically moving themselves or the devices back and forwards to control the system, it still does not allow simultaneous collaborative input. Other studies have examined work with multiple input devices, with one cursor visible on the screen and one mouse active at any time. Various turn-taking protocols were studied, and the results showed that children preferred to use two input devices, and that control of the input was shared much more equally between the pair of children

when two input devices were used. Interestingly, performance (number of puzzles solved) was not increased by having two input devices for boys, but there was a significant statistical increase in performance for girls (Inkpen, et.al. 1997).

Simultaneous collaborative input

Simultaneous collaborative input on one machine has also been researched, but note that the software needs to be changed to suit this configuration. For example, menus and controls must be shared, and use of these may adversely impact on the other user - consider the case of a pull-down menu, that may obscure a portion of the screen where the other user is working (Bricker, et.al. 1998). Also interface cues may be counterproductive – as in the following problem that appeared while modifying a children's drawing program to accept multiple simultaneous inputs:

> "Palettes, such as those to show the current drawing mode or the current color, normally show the current mode by highlighting one of the items in the palette. This no longer works if there are multiple people with *different* modes. … The conventional way to identify different users is by assigning each a different color, but in a drawing program, each user might want to select what color is being used to draw, causing confusion between the color identifying the user, and the color with which the user will draw." (Myers, et.al. 1997)

There has been some research with paired adults into differences in performance and enjoyment using multiple concurrent input devices, caused by user interface enhancements such as increased feedback. This experiment, which involved 12 adult pairs, a shared keyboard, multiple mice, and two conditions involving a

sparse interface and an enhanced interface, showed that the enhanced user interface promoted awareness of the partner's actions – which is important to achieve a shared understanding of the task (Regan, Lofstrom & Davis, 2002).

Concurrent collaborative input has also been researched using a variety of display configurations – shared display, side-by-side displays, and separated displays. Considering that giving children two mice had resulted in positive outcomes, it seemed reasonable that children were also given individual displays (Scott, Mandryk & Inkpen, 2003, p 223). A study was designed where children played a mathematics game in one of these three conditions. Quantitative and qualitative analysis of the data concluded that sharing a physical display positively influenced the children's collaboration. It appears that sharing a display "fosters the development of a shared understanding of the workspace" and hence makes the collaborative task easier to perform (Scott, Mandryk & Inkpen 2002).

This is good news for common paired computing situations, where no special equipment (concurrent and/ or multiple input devices, multiple monitors, specialised software) is usually available in the environment. For example, children commonly work in classrooms or in other social situations with non-technical media, at the same computer (Scott, Mandryk & Inkpen 2003; Bricker, et.al. 1998). Although the possibility of new technologies to support this type of collaboration is exciting, most users do not have access to these technologies.

It would be useful to find out what factors lead to the success of paired computing, without changed conditions in the form of software and hardware

changes. Although children and adults have differences in the way they interact with computers (Inkpen, 1997), some research into a new use for paired computing – pair programming -- may give some insight into success factors for paired computing generally.

2.5 Paired Programming

One of the forms of paired computing that has attracted much attention in the ICT field recently is “pair programming’. Pair programming involves two programmers sitting at one computer, writing production code. One programmer operates the keyboard and mouse, and the other observes and communicates. Each person in the pair takes a role; one codes the particular method and the other looks for potential problems and thinks strategically (Beck 2000, p 58).

2.5.1 History of Paired Programming

Pair programming has gained popularity in the last ten years, after being formally identified in the mid 1990’s. Larry Constantine, in his 1995 computer software development book “Constantine on Peopleware”, discusses observing programmers working in tandem at Whitesmiths, Ltd, a software development company. He called these programmers working in pairs “Dynamic Duos”. He pointed out that these programmers produced code that was less error-prone, and also produced code faster that programmers working alone.

> “Having adopted this approach, they were delivering finished and tested code faster than ever . . . The code that came out the back of the two programmer terminals was nearly 100% bug free . . . it was better code, tighter and more efficient, having benefited from the thinking of two bright minds and the steady dialogue between two trusted terminal-mates . . . Two programmers in tandem is not redundancy; it’s a direct route to greater efficiency and better quality.” (Constantine, 1995, p 118)

Also in 1995, Jim Coplien discussed working in pairs in "Pattern Languages of Program Design" (Coplien & Schmidt, 1995). However, the notion of Pair Programming really took hold in the late 1990's when Kent Beck developed the Extreme Programming (XP) software development methodology.

Extreme Programming

Extreme Programming (XP) is a holistic approach to software development, involving

- An incremental planning approach, and evolutionary design;
- Constant concrete feedback;
- A strong reliance on automated tests written by programmers and customers;
- Reliance on close collaboration of programmers through pair programming. (Beck, 2000).

In XP, "all production code is written with two people looking at one machine, with one keyboard and one mouse" (Beck, 2000, p 58). In XP pair programming, pairs change continually and any programmer in the team may be paired with any other programmer. Beck claims that this improves communication within the team, and emphasises communication between programmers as paramount to the success of a project.

Beck in fact insists that any code written solo should be thrown away and rewritten as a pair, and states strongly "The most productive form of programming I know (functionality/ person/ hour) is to have two people working with one

keyboard, mouse, and monitor." (Beck, 1995, in Sharp, 1997). The anecdotal advantages of pair programming, according to Beck, are many:

- Encourages communication amongst the team;
- "in my experience is more productive than dividing the work between two programmers and then integrating the results" (p 101)
- Higher quality code;
- Peer pressure means there is encouragement to write tests and adhere to the methodology.

Improvements in software design and productivity in development are to be welcomed in an industry that is facing pressure over lack of attention to good design (Standish Group, 2003; Kreitzberg, 2003) and increasingly long development times (van Vliet, 2000; Krant & Streeter, 1995).

The perceived advantages of pair programming have meant that other programming methodologies have now included it as a development strategy, including Robert Martin's "Agile Software Development" (Martin, 2003). Pair programming has now gained acceptance in many spheres and even has its own website dedicated to promoting and encouraging research into the practice (http:/ / www.pairprogramming.com).

2.5.2 Research into Pair Programming Benefits

The research that has been conducted into pair programming so far has concentrated on measuring the benefits of pair programming as opposed to working alone. Some research has been case study based due to the difficulty of arranging controlled studies with sufficient numbers of experienced programmers.

Chrysler Study

Extreme Programming (and pair programming) came to the attention of many in the software development community on the publication of a case study paper "Chrysler Goes to Extremes" published in "Distributed Computing" in 1998. The paper described a real world large scale project involving a payroll system at a large company, servicing 86,000 employees in four major groups (C3 Team, 1998).

The project had previously been attempted using traditional software development methods, and had been declared a failure. It was restarted using XP development methods and came to a successful result in a shorter than expected timeframe. All production code was written in pairs. The authors explain:

> "We go fastest when we work in pairs. Every line of production code must be written by two people sitting together at the same terminal. This gives fast progress with high quality on everything we do. Plus, there are always at least two developers intimately familiar with any part of the system. (page 27)"

This apparent evidence for increased productivity meant that interest in paired programming grew strongly.

Experienced Programmers

One of the very few controlled studies into paired programming was undertaken by John T. Nosek, an Associate Professor in Computer and Information Sciences, in 1998. He conducted an experiment using fifteen experienced programmers, working on a real-life problem, on equipment and in an environment with which they were familiar. The problem given was to write a

script that performed database consistency checks with output written to a file. This complex and challenging problem was considered to be generally beyond the skill of in-house programmers. The fifteen programmers were randomly divided into five 'teams' of paired programmers and five individuals, all working at the same task. All participants were also required to complete a post-experiment questionnaire to communicate their level of confidence in their solution and their enjoyment of the exercise. Time taken to code was recorded, and performance was measured by the readability of the resulting code as well as its functionality. Results gained by using a two-sided t-test on the data collected show that teams outperformed the individuals (readability and functionality of produced code), pairs enjoyed the process more, and also had greater confidence in solutions (Nosek, 1998).

Although the sample size in this real-world field experiment was small (fifteen programmers, ten data points) as Nosek points out "... it is rare, if not impossible, to obtain the time and cooperation of experienced programmers to perform the identical task." (p 107).

It is much more common to find experimental research performed with students, who are more plentiful and available. Two significant studies on pair programming were completed with University of Utah students – one group of 28 software engineering students and a web programming class (Williams, et.al. 2000).

University studies

In the software engineering class, one third of the class coded projects individually while the remaining two thirds coded in pairs. The time spent on the project was recorded as well as the number of defects in the code, and the lines of code in the solution. Students were also interviewed to determine satisfaction levels with working as a pair.

This study found that the programmer-hours for each project completed by the pairs were 15% higher than those logged by individuals working on the same project – not twice the hours as perhaps would be expected. The code produced by the paired students had 15% less defects and the pairs consistently implemented the same functionality as the individuals in fewer lines of code, which would suggest better design by the paired students. Also, the results of the interviews showed that pair programming was considered generally more enjoyable than solo programming (Wlliams, 1999).

One of the authors of the previous study, Laurie Williams, conducted further pair programming research with a class of twenty web programming students (Williams & Kessler, 2000b). The course was described as "complex" and the students involved were familiar with programming but had no experience with the web programming languages taught in the class. Pair programming was used exclusively during the semester, and students were required to give periodic feedback in the form of web-based journal entries with specific questions about collaborative experiences, anonymous surveys, and (as part of the final exam) a

letter written to give advice to future collaborative programmers. The feedback on programming as pairs was primarily positive, with 84% of the class agreeing with the statement “I learned Active Server Pages faster and better because I was always working with a partner” (page 8).

The research into pair programming benefits appears to be overwhelmingly positive, with respect to increased programmer enjoyment and efficiency benefits over working alone. There has also been some interest in factors that may impact on the success of paired programming collaborations.

2.5.3 Other Research into Pair Programming

There has been very little research into pair programming other than that designed to determine the benefits of working in pairs over working alone (Hanks, 2003). For example, no controlled research has been done into the effects of pairing based on ability and experience, gender, skill set or self-seeding.

There has been some research investigating which general personality traits and personal skills would be desirable when building a pair programming team (Dick & Zarnett, 2002). This case study found that some personal traits and skills were beneficial for paired programming – effective communication skills, being comfortable with the other partner, confidence in one’s own abilities and willingness to compromise.

There is also anecdotal evidence from practitioners of factors that may be detrimental to paired programming, such as working with someone at a significantly different level of expertise, arguing over the best solution without being willing to compromise, and antisocial behaviour such as personally offensive humour, deficient personal hygiene, talking constantly, not talking at all or ignoring the other user or the method under construction or revision (Talbott, 2003). It is considered critical to the success of paired programming that “both members of a pair maintain a high degree of interest and engagement with the problem at hand” (Talbott, 2003, p 2)

This appears to imply that interesting and engaging tasks would be more suited to pair programming; however there appears to be no studies into whether some tasks are more suited to the pair programming condition than others.

2.5.4 Task Differences in Pair Programming

With the demonstrated productivity gains and other benefits of pair programming, it would seem to make sense to use it in all situations, as advocated by XP proponents. However, interestingly enough, despite their obvious preference for being in pairs, the students involved in the pair programming university studies detailed earlier appeared not to use paired methods at all times. In the web programming class:

> "all realized it was essential to do design collaboratively. Many groups also consistently performed complex coding and design/ code reviews collaboratively. Some migrated towards doing simple/ rote coding and testing separately (though perhaps side-by-side on two computers)." (Williams & Kessler, 2000b, p 9)

From the feedback from students, it would appear that some tasks are more suited to paired methods.

Laurie Williams, one of the researchers in the University of Utah studies, also conducted a pair programming survey amongst experienced programmers and found that while 96% of respondents said they enjoy their jobs more when pair programming, around 50% believed it is acceptable to work alone 10-50% of the time. However they reviewed as pairs any work that had been done independently before it was incorporated into the project (Williams & Kessler, 2000b). This contrasts with the XP methodology which says that all code written independently must be 'flushed' and rewritten.

There appears to be anecdotal evidence for why pair programmers would choose to work alone on some tasks.

> "They often deliberately split for the more rote, routine, simple coding of a project. They find performing this type of programming is more effective done individually. It seems that some tasks, such as GUI drawing, are largely detail-oriented in nature. Developers report that having a partner for this work doesn't help much." (Cockburn & Williams, 2001, page 5)

and:

> "Many prefer to do experimental prototyping, tough, deep-concentration problems and logical thinking alone. Most agree that simple, well-defined rote

> coding is more efficiently done by a solitary programmer and then reviewed with a partner." (Williams & Kessler, 2000b, p 113)

It is clear that the anecdotal evidence appears to point to task characteristics being a factor on whether pair programming is chosen as the preferred methodology. Feedback from students indicates that working with a partner was particularly helpful when solving complex problems:

> "One problem with single programming is that you can forget what you are doing and easily get wrapped in a few lines of code, losing the big picture. Your partner is able to constantly review what you do; making sure that it is in line with the product design." (Williams & Kessler, 2000b p 8)

> "There were times we felt that we would have given up except that we "tag teamed". I'd be on the ropes and I'd describe the problem in such a way that he had a valuable insight. Then he'd fight on as long as he could and stop … then I'd have an insight... and so on. I suppose others would call it brainstorming, but it feels different to me." (Cockburn & Williams, 2001 p 6)

This effect was named 'pair relaying' by the researchers.

Cognitive theories, including Distributed Cognition work and Cognitive Load Theory may help to explain both this 'pair relaying' effect and the preference of pair programming advocates to work alone during some tasks.

2.6 Cognitive Theories

2.6.1 Human memory organisation and limits

Cognitive Load Theory begins with research into the working of (and limits to) human memory. Human memory appears to be divided into short term or working memory, and long term memory.

Working memory is used to process and transmit information to and from long-term memory – it enables us to think logically, solve problems and be creative. Long-term memory seems to be virtually unlimited, however short-term memory appears to have severe limits.

Miller (1956) examined the limits of short term memory and found that it cannot deal with more than about seven elements of information simultaneously. If this limit is reached and exceeded while processing information then information will be irretrievably lost. This limited capacity can be slightly increased if mixtures of modes of information input are used – for example, if some information is auditory and some is visually presented (Tindall-Ford, Chandler & Sweller, 1988). Peterson & Peterson (1959) also showed through psychological studies that short term memory is extremely volatile – distractions mean that subjects have difficulty remembering even three elements after 18 seconds. Further studies have shown that short term memory may decay after about two seconds (Marsh, et.al. 1997)

2.6.2 Chunking

At first glance, the limit of 'around seven items of information' seems unworkable, considering some problem-solving thought requires quite complex concepts. Miller also presented the idea of 'chunks' where a chunk is any meaningful unit. For example, a chunk could refer to digits, words, game positions or people's faces. The human mind organises information into chunks of information, enabling an increase in how much information it can deal with at one time by progressively building larger chunks. As an example:

> "A man just beginning to learn radio-telegraphic code hears each *dit* and *dah* as a separate chunk. Soon he is able to organise these sounds into letters and then he can deal with the letters as chunks. Then the letters organise themselves as words, which are still larger chunks, and he begins to hear whole phrases. … the *dits* and *dahs* are organized by learning into patterns … as these larger chunks emerge the amount of message that the operator can remember increases correspondingly." (Miller, 1956, p 14)

Miller related this to the concept of *recoding* in communication theory, where input events are re-grouped so that there are fewer chunks to remember, with more information in each chunk. A new name is applied to the larger chunk and then the new name is remembered rather than the group of information comprising that chunk. We can easily confirm this by looking at the process of reading this page – we are no longer required to look at the individual letters that make up each word as we did when learning to read, but can confidently read sections of words.

An experiment conducted in 1954 by Sidney Smith demonstrated exactly this process of chunking, using sequences of digits (Miller, 1956). Subjects can

usually repeat back eight decimal digits (using the numerals 0-9) and around nine binary digits (using only the numerals 0-1). If the binary digits are divided into groups of three digits, each can be expressed as an octal digit (using the numerals 0-7 – 001 = 1, 010 = 2, 011 = 3, and so on).

Smith measured the immediate memory span of 20 subjects for binary or octal digits. He found the spans were 9 for binary digits and 7 for octals. Smith then gave a recoding scheme to five of the subjects (about 10 minutes was given to learn the scheme, in each case), so they could *recode* the binary digits as octal. Even with this short time spent learning the process, the recoding schemes increased their memory span for binary digits in every case.

Smith then taught himself recoding into octal (3 binary units), hexadecimal (4 binary units --- 1101 = D or 13, for example) and even coding whereby 5 binary units were coded into decimal numbers. After extensive drilling in the recoding schemes, he could repeat any 40 binary digits ‘from memory’, simply by recoding using the 5:1 recoding scheme to break down the information into meaningful chunks.

It is clear that by organising input successively into meaningful chunks that the amount of information (limited by working memory) processed can be increased. Closely related to the idea of chunks is the concept of schema.

2.6.3 Schema

Barlett (1958) is credited with being the first to propose the concept of schema – mental frameworks in long term memory that are used for understanding and remembering information. He based this on experiments where subjects recalled details of stories that were not in the original story (Kearsley, 1994b).

Sweller (1988) and others have used this idea of schema, or combinations of elements, being the cognitive structures that make up an individual's long term memory, or knowledge base. Cooper (1998) gives an example of an information network involving cars – see Figure 2.2.

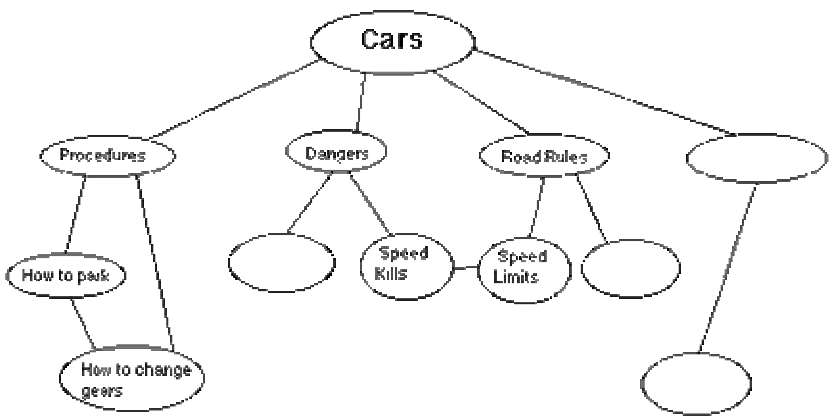


Figure 2.2. The beginnings of an information network about cars.
(*Reproduced from* Cooper, 1988)

Most people could extend this network along each of these paths and more with little mental effort. Cooper points out that

> "… almost everyone living in modern society holds an enormous amount of knowledge regarding cars, their use, road rules, and so on. This knowledge base is held in a well structured information network which is itself connected to other networks." (Cooper 1998, page 7)

These networks of schema may contain or be contained by other schema in a hierarchical structure. In the example above, the 'cars' network may be part of a 'transport' schema and will contain smaller schema as well. Schemas "build in detail and complexity as more extensive knowledge is gained in a content area." (Cooper, 1988, p 14).

A very simple example of witnessing the building of schemata was when this author observed her twin daughters' attempts to learn the alphabet when very young. The material used to teach the alphabet always presented the lowercase letter 'A' in Century Gothic or similar font face [the left of Figure 3.3]. This is also the form of lowercase 'A' that young children are encouraged to form when learning to write.

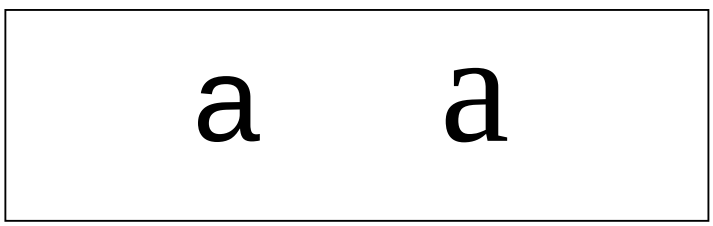


Figure 2.3 Forms of the letter A.

Both girls had no difficulty identifying the letter as lowercase "A". Subsequently other materials were introduced that presented the letter in a more traditional serif font, such as Times (as in the letter on the right of the figure above). Both girls did not recognise the letter as a representation of lowercase 'A'. However, once the girls were told that this form also represented the letter, they had no further difficulty identifying it as an alternate form. The new information

had been added to their schema about the letter "A". Today they are young women of 16 years, and would have no difficulty reading most handwriting, which includes multiple variants of this letter.

> "As we experience new information, it is up to our working memory to weave these new experiences into similar and related experiences we have had stored in long-term memory. This is what schema formation does for us. It is up to our working memory to form the schemas, commit them to long-term memory, retrieve them as single units to be used to process other information that has yet to be formed into schema." (Chipperfield, 2004, p3).

Automation -- the ability to perform tasks 'without thinking' or without using much of working memory – is a direct result of building extensive schemas, and using them repeatedly, so that it is known what response is required for each situation.

It should also be obvious that just as no two individuals have the same life experiences, so no two individuals will have the same networks of schema.

2.6.4 Experts vs. novices

Some individuals will have more experience in some areas than others, and hence have more extensive schema about those content areas. Chi, Glasser & Farr (1988) demonstrated that the difference between novice and expert performance relies on the "expert's possession of an organised body of conceptual and procedural knowledge that can be readily accessed and used with superior monitoring and self-regulation skills" (Chi, Glasser & Farr, Soden & Pithers, 2001 p 207). In contrast to a novice, who would have "trouble recognizing any but the

most basic and common situations as ones that they have encountered previously" (Cooper, 1988, p 9), experts have expansive schemas, have effectively seen almost every problem in the content previously, and have a high level of automation – the ability to perform tasks without concentrating or using much working memory. Put simply:

> "The difference between an expert and a novice is that a novice hasn't acquired the schemas of an expert. Learning requires a change in the schematic structures of long term memory and is demonstrated by performance that progresses from clumsy, error-prone, slow and difficult to smooth and effortless. The change in performance occurs because as the learner becomes increasingly familiar with the material, the cognitive characteristics associated with the material are altered so that it can be handled more efficiently by working memory." (Soloman, 2002, page 1)

The application of this research to learning and tasks is that some people will reach the limits of their short term memory faster than others, given the same task. The difficulty they will have with a task will depend on what schema they have already available about the characteristics of that task, and hence how much working memory has to be used by the task. Task difficulty is intimately related to cognitive load. Cognitive load is defined as the "total amount of mental activity imposed on working memory at an instance in time." (Cooper, 1988, p10).

2.6.5 Intrinsic, Germane and Extraneous Cognitive Load

Cognitive load can be of several types. Sweller (1994) and Cooper (1988) identify two types of cognitive load – intrinsic and extraneous. Kirschner (2002) adds another type – germane. An example can be used to demonstrate the three types of cognitive load.

Take the example of a student solving an algebra problem from a textbook, in a normal classroom situation. The *intrinsic load* is the load on memory required by the task at hand. In the process of solving the algebraic equation, the student would need to solve a series of steps, all of which are highly dependent on one another. The intrinsic load would be substantial.

The *germane cognitive load* is that part of the cognitive load that is used in formation of new schema. Working memory must also be used for this process – slowly changing the novice into an expert.

The *extraneous cognitive load* is everything else that is handled by working memory – the distractions in the classroom situation such as other students talking, the manner in which the teacher has presented the information, the textbook formatting of the problem, and any concerns the student may have, such as getting the problem completed in a short span of time. The intrinsic, germane and extraneous loads add up to the total cognitive load. If the total cognitive load is within the limits of mental resources, then the learner may learn from the experience – that is, have enough cognitive resources to build, revise, or add to appropriate schema. If cognitive load is higher than total mental resources, then

learning (using the germane cognitive component) may fail to occur (Cooper, 1988). Intrinsic cognitive load cannot be altered, however some extraneous cognitive load can be removed by redesign of instructional materials. Much of Sweller's work (1985, 1999) has been on methods of reducing extraneous cognitive load by reformulating problems to be 'goal-free', providing worked examples, and integration of text into diagrams to remove split attention (Cooper, 1990).

The effects of cognitive load and schema acquisition on learning are demonstrated by an experiment where a subject was asked to write a computer program eight times. Figure 2.4 illustrates the results:

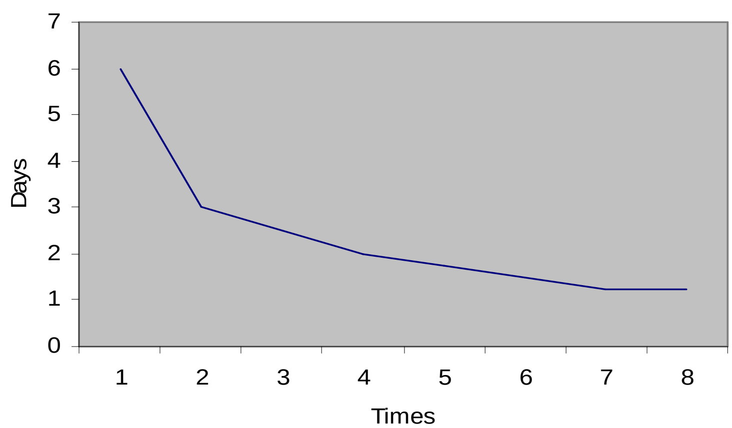


Figure 2.4: Days taken to write a computer program repeatedly.
(From Lui & Chan, 2003)

At first the subject takes some time (six days) to write the program, because the algorithm and required processes used in solving the problem are unfamiliar. As the subject repeats the process, schemas are built that reduce the cognitive load required, making the writing process faster. As the researchers state, by the eighth

time, the subject "just sits down and codes it *without pausing for thought* [emphasis added]" (Lui & Chan, 2003, p 226).

The researchers postulate that using a pair programming approach will be most beneficial when the problem is new, rather than when the problem space is well known (and the cognitive load is lower) – see Figure 2.5.

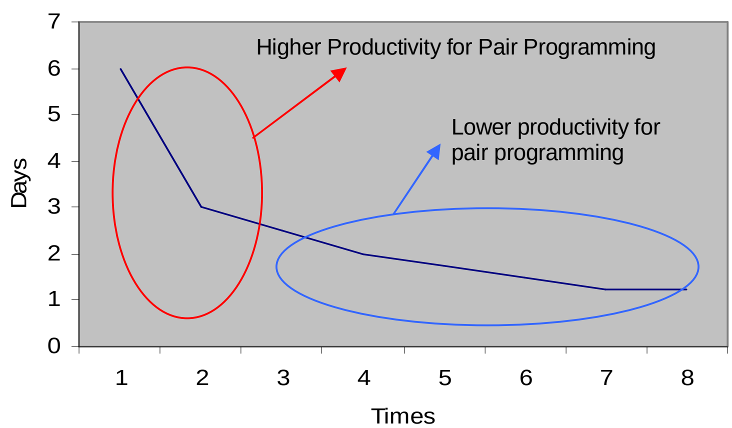


Figure 2.5. Productivity for Pair Programming
(from Lui & Chan, 2003).

Studies in distributed cognition may give some insight into why this is true.

2.6.6 Distributed Cognition

Distributed cognition is a theoretical approach that does not see cognition as mental processes that only occur within an individual. Instead it is concerned with the interactions between people, artefacts and internal and external representations. The distributed cognition approach was developed by Hutchins and his colleagues in the mid to late 80s. Its focus is on systems rather than individuals (Hutchins, 1995).

Studies on distributed cognition have been performed in small sociotechnical systems such as an airline cockpit (Hutchins 1995) or navigation on the bridge of a ship (Hutchins 1995b).

The most well-known example of an extensive distributed cognition analysis is study of the navigation of a ship. To steer a ship into harbour, coordination is needed between several members of a navigation team, taking and plotting bearings of the ship at regular intervals. It is highly routinised, requiring complex interactions of people and artefacts to bring the ship into harbour. Hutchins describes how the experience provides individual learning of procedures and also cultural practices of the navy.

Cognitive systems have different properties from the individuals that participate in them. For example, Hutchin (1995a) points out that individuals working together on a collaborative task possess different kinds of knowledge and interact in ways that will enable them to pool the various resources to accomplish the task. This fits in well with the theories of cognitive load established earlier in

this report. The individuals in a group each possess different schema, and interaction of these individuals will enable both a decrease in cognitive load (as the task is shared) and learning experiences for each individual (as they gain knowledge by communication that the other person has already processed).

There is another aspect to the view of distributed cognition – that of the role the environment plays in cognition. To give a very simple example, often subjects who are assembling a complex piece of equipment, first lay down the pieces in order of assembly. They are using the environment to encode ordering information and so reducing the cognitive load on short-term memory.

Hollan, Hutchins & Hirsh (2000) have also suggested that distributed cognition may be useful in understanding interactions between people and computer technologies. Study into how individuals work with computers in collaborative and networked settings may also inform design of digital work materials and collaborative workplaces.

This research and framework should be compared with the case studies on children's collaborative learning on computers by Charles Crook (1990), referred to in Section 2.3.5 of this paper. Crook noted that the computer appeared to be taking part in the total interaction as a kind of collaborative partner.

Distributed Cognition in Programmers

Of particular interest to this report, is a case study performed in 1991 by Nick Flor, a masters student of Cognitive Science. Flor studied a collaborative programming pair, working on a software maintenance task. He recorded the interaction via video and audiotape, and correlated their behaviours, both verbal and non-verbal, with known distributed cognition theories. One of the theories mentioned is "Searching Through Larger Spaces of Alternatives".

> "A system with multiple actors possesses greater potential for the generation of more diverse plans for at least three reasons: (1) the actors bring different prior experiences to the task; (2) they may have difference access to task relevant information; (3) they stand in different relationships to the problem by virtue of their functional roles … An important consequence of the attempt to share goals and plans is that when they are in conflict, the programmers must overtly negotiate a shared course of action. In doing so, they explore a larger number of alternatives than a single programmer alone might do. This reduces the chances of selecting a bad plan." (Flor & Hutchins, 1991, in Williams & Kessler, 2000b, p 2)

2.7 Conclusion to Literature Review

Computers are a ubiquitous part of our lives – used constantly in a myriad of devices, and most familiarly as the Personal Computer, or PC. Computer usage in Australia continues to grow, with most households owning at least one PC, and PCs used increasingly in business and education.

At the same time, there has been a trend towards collaborative practices in vocational and educational fields. Self-directed work teams, a cooperative team approach in the workplace, have demonstrated advantages in improved quality of products, productivity, flexibility, and employee satisfaction. In education, collaborative practices are being encouraged as they promote increased student achievement, improved interpersonal relations, self-esteem and attitudes towards school.

For successful collaboration, four principles are considered mandatory: positive interdependence, individual accountability, equal participation and simultaneous interaction (presented as the acronym PIES, by Dr Spencer Kagan (1992)). There are a number of theories as to why students who work in cooperative groups learn more than those in traditionally organised classes. Motivational perspectives point out that cooperative learning emphasises group goals, rather than competition, as in the traditional classroom environment. Developmental theories postulate that interaction between children increases mastery of concepts – mental functioning occurs first socially, then later within an individual's mind (Vygotsky, 1978). Cognitive elaboration theories focus on the

fact that collaboration requires a student to explain material to other members of the group, thereby restructuring and elaborating the material to help store it in memory. With the proven effectiveness of collaborative settings in the workplace and education, and the rise in use of computers, computers are being used increasingly for collaborative education.

CSCW (Computer Supported Collaborative Work) is an interdisciplinary field which concentrates on supporting cooperative or person-to-person activities with or involving computer technology. CSCW can be examined by dimensions of time (synchronous and asynchronous) and space (remote or co-present). It is recognised that co-present collaborative work presents particular issues such as the necessity for 'turn-taking' behaviours in traditional computing environments. This would sometimes seem counterproductive due to the 'simultaneous interaction' principle required for successful collaborative activities. Much research into co-present CSCW focuses on overcoming this boundary with strands covering:

- Research into new technologies such as electronic walls, tabletop displays, collaborative handheld applications, meeting rooms and tools to support small group collaborative work and brainstorming;
- Augmented Reality projects, where notes, documents and real-world artifacts can be accessed at the same time as virtual objects and processes in a multi-user immersive virtual environment.
- Enhancements to user interfaces (hardware and software) designed to surmount shared software interface issues (workspace navigation, artifact manipulation, view representation).
- Research into the effects of multiple input devices, and multiple display devices in shared computing situations.

Even though these enhancements and projects are of interest, the limited resources of many workplaces and schools mean that new technologies are out of reach.

Of particular interest to this report is the practice of *pair computing*, the familiar practice of two people sitting side by side at one personal computer, and sharing one keyboard and mouse. Some research into the relatively new practice of pair programming confirms that paired approaches encourage communication, are generally more productive, and result in higher quality output than individual approaches. There has been little research into pair programming other than that designed to determine the benefits of working in pairs over working alone. A survey of pair programmers found that even those who are staunch advocates of the practice prefer to work alone at some times. Anecdotal reports point to factors such as "level of interest and engagement with the problem at hand" (Talbott, 2003, p2) and task composition as factors in choosing whether to work in pairs or alone.

Cognitive load theory and distributed cognition work may explain why paired approaches are more effective in some problem solving situations. Limits to working memory and differences in schema formation amongst individuals mean that when a pair is faced with a problem with a high intrinsic and/ or extraneous cognitive load, they can work together to solve it, effectively sharing the cognitive load and reducing to a manageable level. This is seen in pair programming where the cognitive task of strategic planning ("where does this fit into the bigger picture") is offloaded to one person, so the other programmer can concentrate on

the details of the method being coded. When problems in the code need to be solved, both users can use their differing expertise (differing schema) to find the best solution to the problem.

All of the above would seem to indicate that complex tasks – those requiring a heavier intrinsic cognitive load – would be more suited to paired computer usage than those tasks that have a smaller cognitive load, and could be generally completed by one person. With this in mind, a practical, testable experiment was designed that would determine whether benefits observed in paired over individual approaches are affected by task difficulty (level of cognitive load). The experiment is detailed in the next chapter of this report.

CHAPTER 3

EXPERIMENT

3.1 Experimental Design

3.1.1 Research Method

As established in the previous chapter, cooperative methods are increasingly being employed in business and educational settings. With the ubiquitous use of computers, paired computer usage has become more commonplace, driven by budgetary constraints in the educational system, trends in the software development industry, and the natural tendency of humans to communally use artefacts.

From experimental evidence, paired computing methods appear to generally increase efficiency, functionality, learning experiences, product quality and user enjoyment. Anecdotal evidence would seem to indicate that these benefits can be affected by the cognitive load required by the task being undertaken.

Considering these facts, a practical, testable experiment was designed that may contribute some insight into the topic.

Experimental Design

Two dimensions were required to be examined – degree of cognitive load, and paired/ individual approaches – as well as the interaction between the two. For this reason, an experiment comprising four groups was designed.

Experimental design	Simple task (low cognitive load)	Complex task (higher cognitive load)
Single usage	Individual-Simple Group	Individual-Complex Group
Paired usage	Pair-Simple Group	Pair-Complex Group

A minimum of twelve (12) data points per group was expected to be required for meaningful statistical results, based upon the experience of many studies in cognitive load (Sweller, 1999). Note that the Pair-Simple and Pair-Complex groups comprise twelve pairs each - this meant that a minimum of seventy-two (72) participants would be required. In addition, extra participants would be required if previously researched tasks were used, in case participants had seen or attempted the tasks prior to the study, as this could be a confounding factor. For this reason it was estimated that a minimum of eighty-two (82) participants were required for the experiment to give meaningful statistical results.

This topic has both quantitative and qualitative aspects. Quantitative aspects include the speed and accuracy of task performance (Sweller, 1999). Qualitative aspects include user enjoyment and perceived benefit as these have a

bearing on the continued success of paired computing approaches (Dick & Zarnett, 2002). Subsequently, in addition to time and number of moves taken to complete tasks, a questionnaire about user enjoyment and perceived user benefit of paired or individual approaches would also be given to participants. In addition, videotape would be used to capture data about quantity and quality of user interactions in both paired treatments – verbal and body language interactions such as gestures.

Constraints:

The experimental design was constrained by several factors. It was impractical to try to obtain the time and cooperation of enough real-life programmers willing to work on repeated tasks (Nosek, 1998). It was similarly impractical to use University students to perform repeated tasks at a regional university where there were limited numbers of students. The number of participants required to obtain meaningful results meant that the only population available was high school students. Furthermore, the requirement to gain approval for the study from both the University and Department of Education ethics committees, as well as the constraints of school holidays and student exams and excursions resulted in a time frame available for the experiment that was extremely limited. It was also apparent that accessing participants from higher years would be more problematic than those from lower years.

Tasks:

Two logic puzzles were chosen to be used by the participants. For the simple task, the "Towers of Hanoi" puzzle – a well researched puzzle with several variants – was chosen. The simplest variant of this puzzle comprises three vertical rods ("needles") situated in a row. The left-most rod has three discs (flattened cylinders with a hole in the centre) of varying sizes on it. The largest disc is placed on the bottom, followed by the medium disc, with the smallest disc on top. The object of the puzzle is to move this "tower" to another rod, so the discs are in the same order.

The three rules of the puzzle are:

- Only one disc may be moved at a time;
- Only the top (smallest) disc on a needle can be moved at any one time
- A larger disc cannot be placed on a smaller disc.

The puzzle may be optimally solved in seven moves. Variants of the puzzle have four, five, six discs, and so on, with corresponding increases in minimum moves required to solve the puzzle (*moves)* specified by the formula "$moves = 2^n - 1$" where n is the number of discs.

Kotovsky, Hayes & Simon (1985) investigated several isomorphs of this puzzle. An isomorph is a problem with an identical problem space, but different representation. The problem space is identical in "size, branchiness and minimum solution path length" (p 249) and the puzzles also have the same number of rules, with identical relevance and restrictiveness. However human subjects solving these

for the first time display large differences in relative difficulty experienced in solving the puzzles.

The isomorph "Monster Move" was chosen for the second, more difficult puzzle. This puzzle is identical to the Towers of Hanoi, but with a different cover story. As it is an isomorph, it can also be solved in a minimum seven moves. The cover story is as follows:

> "Three five-handed extra-terrestrial monsters were holding three crystal globes. Because of the quantum mechanical peculiarities of their neighbourhood, both monsters and globes come in exactly three sizes with no others permitted: small, medium and large. The small monster was holding the large globe, the medium sized monster was holding the small globe, and the large monster was holding the medium sized globe. Since this situation offended their keenly developed sense of symmetry, they proceeded to transfer globes from one monster to another so that each monster would have a globe proportionate to its size.
>
> Monster etiquette complicated the solution of the problem since it requires that:
>
> - Only one globe may be transferred at a time;
> - If a monster is holding two globes, only the larger of the two may be transferred; and
> - A globe may not be transferred to a monster who is holding a larger globe."
>
> (Kotovsky, Hayes & Simon, 1985 p 251)

Despite these problems being isomorphs, adult subjects who have not encountered the problems before have an average solution time for Tower of Hanoi of 1.83 minutes, while the average time taken to solve Monster Move is 13.95 minutes (Hayes and Simon, 1977). The finding of these studies was that "Monster Move" appears to impose a greater load on working memory than

“Towers of Hanoi”, making it more difficult to solve. The puzzles consequently appear to fit the requirements for a simple (lower cognitive load) task, and a more complex (higher cognitive load) task required for the study. The two puzzles were chosen to use in a multimedia setting, with both paired and individual approaches.

Several tasks or content domains could have been chosen for the study – there is nothing significant about the fact that puzzles were chosen, rather than algebra problems, language problems or any other meaningful form of interaction that children may have with a computer. Logic puzzles were chosen as games of this type would be meaningful to the participants (children), and because the Tower of Hanoi isomorphs are well-defined transformation problems, with a well-documented difference in task difficulty.

3.1.2 Design of Research Instruments

The experimental design involved data collection by means of two purpose-built instruments (multimedia puzzles), a questionnaire examining perceived user enjoyment and benefits of paired computing, and videotape of paired usage of the computer.

Purpose Built Applications

The two puzzles were built using Macromedia Director™, an application designed to build multimedia content for CDs, DVDs, kiosks and the Internet. A Towers of Hanoi application by P. McClellan (undated) from the Director Online User Group (http://www.director-online.com) was used as a prototype, and

adapted for the purpose of the study. The Monster Move application was also built using some of McClellan's code, purposefully adapted. Each application was designed to record the date, session, whether pair or individual approach was used, time taken to read the instructions, time taken to solve the puzzle, number of moves made, and the number of times in-context help was accessed. This data was recorded to a separate text file for each session.

Each puzzle began with a data entry screen (Appendix A1) accessed by the researcher, where the treatment (pair or single) and session number was recorded. The data text file was named with the date and the session number.

The next screen was a simple title screen (Appendix A2 & A3) with the name of the puzzle, to identify the puzzle to the participants, to aid in the subsequent questionnaire. As an example, the Title Screen for the Towers of Hanoi puzzle is presented in Figure 3.1.

Figure 3.1: Towers of Hanoi Title Screen.

Each title screen had a clearly marked "Instructions" button, which when clicked began a timer and displayed the story and rules of the puzzle (Appendix A4 & A5). As an example, the Monster Move Instructions Screen is presented in Figure 3.2.

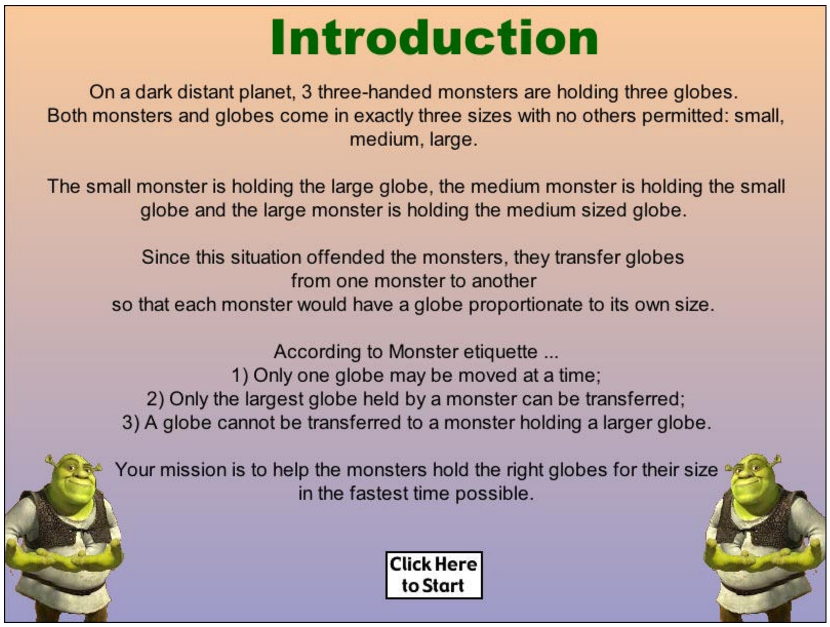


Figure 3.2: "Monster Move" Instructions Screen

The "click here to start" button displayed prominently at the end of the instructions stopped the initial timer, started a game play timer, and displayed the puzzle ready for solution. Discs or balls (dependent on the puzzle) could then be dragged with the mouse back and forwards until a solution was reached (Appendix A6 & A7).

As an example, a screen capture from the Towers of Hanoi game in progress is presented in Figure 3.3.

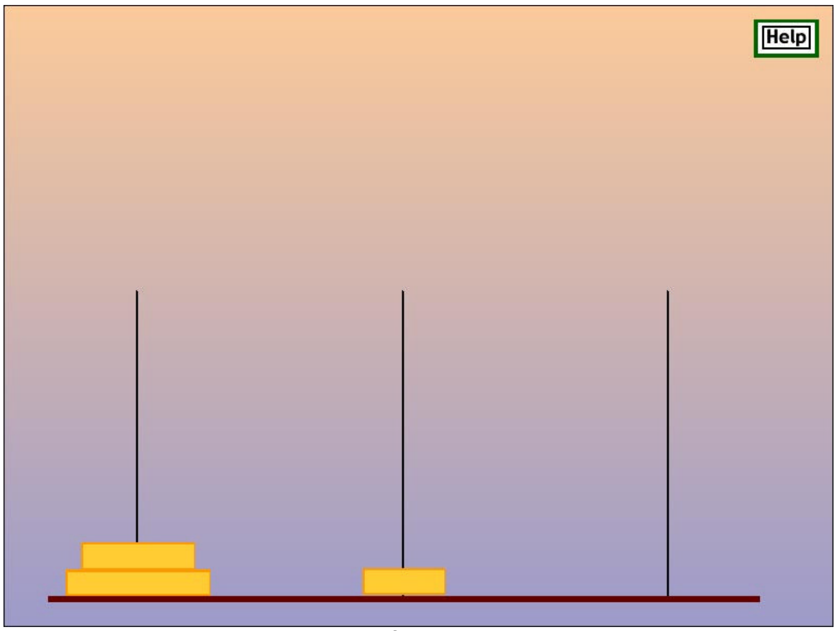


Figure 3.3: Towers of Hanoi Game in Progress

In the Towers game, discs were dragged to the target rod, and then dropped. As long as the disc was over the target rod, and the move was not illegal, the disc “dropped” to the bottom (on top of another disc if there was one there already). There was a differentiation between illegal (contravening the game rules) and incorrect moves – those that were not along the optimal solution path, but were not illegal. If an illegal move was attempted, the game returned the disc to the previous position.

The Monster Move game screen allowed the coloured balls ("globes") to be dragged back and forwards from one monster to another. Again, a distinction was made between illegal moves (which when attempted, made the ball return to the previous position) and incorrect moves (those which did not advance the user along the solution path, but were legal).

Figure 3.4: Monster Move – Game in progress.

For both puzzles the number of moves that were made that were illegal was not recorded. In hindsight this was unfortunate as it may have provided useful data concerning participants' problem solving activities. For each puzzle there was also no penalty for making illegal moves. Again in hindsight, inclusion of such a condition may have been desirable because it may have acted as a motivator for participants to try and focus their attention and efforts upon learning the rules and

avoiding illegal moves. Theses issues will be discussed further in the Results and Discussion section, but are noted here for future reference.

The game screens on both games were also designed so that in-context help was available via a "Help" button in the top right-hand corner – a reiteration of the rules, and the object of the game (Appendix A8, A9).

When a successful solution was reached, a congratulatory message was displayed, the time taken and the number of moves made (Appendix A8, A9). A quit button was also displayed, which ended the application, and closed the data text file.

Questionnaire

A questionnaire was designed to capture feedback on perceived user benefit and enjoyment of paired usage as opposed to individual usage. The design of the questionnaire comprised ten questions [Appendix B1]. The first question was a simple question establishing whether the participant was paired for the activity, and the next eight questions each used a five point Likert scale to determine participant's attitudes. Three of these questions were taken from the Young Children's Computer Inventory Project (Knezek, Miyashita, & Sakamoto, 1990), which was a longitudinal study of childhood computing in schools. These questions would be used as a baseline to determine user enjoyment of the task and working with or without a partner. A further question was asked about enjoyment of the specific task, and another four questions (one phrased negatively) asked

about perceived enjoyment and benefits of working with a partner on a computing task. The remaining question left room for comments on the process of working or not working with a partner. The number of questions was kept to ten so the questionnaire would not be too taxing or time consuming for the participants.

Videotape Recording

It was decided to videotape the paired interactions to determine if the quantity and quality of interactions changed between the "Towers of Hanoi" (lower cognitive load) and "Monster Move" (comparatively higher cognitive load) puzzles. Both verbal communication and body language interactions such as gestures would be captured on videotape.

3.1.3 Hypotheses

The hypotheses that were to be tested in this experiment are listed below:

- **H1: (Task Difficulty)** The Monster Move puzzle is more difficult than the Tower of Hanoi Puzzle.
- **H2: (Pairing)** Individual users will find the puzzles more difficult than the paired users.
- **H3: (Interaction Effect)** The benefits of pairing will be more evident on complex tasks.

Measures

The measures that would be used to determine the validity of these hypotheses would be the dependent variables *moves* (number of moves taken to solve each puzzle) and *time* (time in seconds taken to solve each puzzle). In addition, the interpersonal interactions between the students in the paired group were videotaped to determine quality and quantity of their interactions.

3.2 Pilot Study

3.2.1 Participants

The design of the experiment called for a minimum of 82 students of similar age and profile in history of computer usage. For this reason, Year 7 of a large regional New South Wales High School was chosen for the study. Before participating, all students were required to both give consent, and gain consent from their parent(s) or guardian(s) [Appendix C1]. Participation was on a voluntary basis.

After discussions with the head of the Computer Studies department, it was decided to add a question to the bottom of the informed consent form, to be answered by the student, regarding computer use at home. The teacher noted that students who had access to a computer at home and used it regularly were usually more computer literate than those who had only (limited) use at school.

The Year 7 curriculum includes a compulsory Design and Technology unit (NSW Board of Studies, 1991A). As part of this unit, every student is required to acquire basic computer skills, including typing, mouse skills, identifying parts of a computer and using a word processing program (NSW Board of Studies, 1991B). As a result of this unit, all participants could be expected to have at least basic computer competency skills, although this level of competency could be expected to vary according to familiarity with a computer, and the individual student's interest in computing. Participants were allocated to groups in a randomised fashion taking into account the need for a balance of computer competency (based

on responses on the consent form), and gender (Inkpen, 1997; Gansmo, undated). As all the participants were from the same year/ age group, the groups would not be required to be balanced for age. In forming pairs, only same sex pairs would be used, as previous research into collaboration has shown that mixed-gender pairs behave differently to same-gender pairs (Lockheed & Hall, 1976). In addition, the teachers would be consulted as to which participants would be uncomfortable working with each other, and these would not be paired, as personality conflicts have previously been found to have a detrimental effect on paired usage (Dick & Zarnett, 2002).

3.2.2 Experimental Method

Each participant was to attend one session of approximately 40 minutes duration, either individually (Individual-Simple and Individual-Complex groups) or as one of a pair of students (Pair-Simple and Pair-Complex groups). Each session would consist of:

- A welcome from the researcher, including a short explanation of the study [Appendix D];
- Verbal instructions from the researcher;
- As long as required to complete one of the two puzzles, dependent on group;
- As long as required to complete the questionnaire;
- Query as to whether the puzzle had been encountered in the participant's experience;

- Thank you and closure by the researcher.

The Pair-Simple and Pair-Complex groups would be videotaped, and the Individual-Simple and Individual-Complex groups would be also told they were being videotaped, to balance the groups for any nervousness the participants may feel through being recorded.

Individual-Simple group	Simple puzzle (lower cognitive load)	→ Questionnaire
Individual-Complex group	Complex puzzle (higher cognitive load)	→ Questionnaire
Pair-Simple group	Simple puzzle (lower cognitive load)	→ Questionnaire
Pair-Complex group	Complex puzzle (higher cognitive load)	→ Questionnaire

Figure 3.5 Experimental Design

3.2.3 Participation Rate Problems

A short time before the day the experiment was scheduled to begin, it became apparent that the required number of participants would not be returning consent forms. From one hundred and twenty forms that were distributed amongst four Year 7 English classes, only seven forms were returned by the Thursday before the Monday on which testing was to commence. A further sixty forms were distributed to Year 7, and another forty forms were given to those Year 8 students who were not already participating in the annual school camp. It was apparent that the estimated required eighty-two participants would not be obtained, even though the High School concerned had the largest student numbers in the district.

In the opinion of the Deputy Principal of the school, the timing of the study, at the beginning of the traditionally busy fourth term of the school year, combined with the length of the consent form – two typewritten A4 pages – meant that parents and guardians were inclined to ignore the request for participation in this purely voluntary study. Unfortunately both of these factors were unavoidable, caused by the necessity of passing the proposed study through both the University Human Research Ethics Committee and the Department of Education Research in Schools application process, and the requirements of full disclosure in the content form of research risks, responsibilities and procedures, mandated by Governmental Research Ethics guidelines.

It was anticipated, perhaps optimistically, that forty participants could be expected to respond to the two hundred and twenty forms that were distributed in total. With this in mind, it was decided to redesign the experiment, although recognising that the changes to the experimental design would have flow-on effects.

3.2.4 Redesign of Experiment

The experiment was redesigned to incorporate just two groups: an Individual group and Pair group. With a cohort of forty students, this would give approximately thirteen data points per group, which could reasonably be expected to give statistically significant results. Both puzzles would be administered to each group (firstly the Tower puzzle and then the Monster Move puzzle), and the questionnaire redesigned to become two questionnaires, one administered after the Towers of Hanoi puzzle, and one after the Monster Move puzzle [Appendix B1 and B2]. Additional questions were added to the second questionnaire, requesting the participants to comment on which puzzle they enjoyed solving most (Question 6) and for those participants that worked with a partner, which puzzle they believed was solved more easily because they worked with a partner.

Individual group	Simple puzzle (lower cognitive load) → Questionnaire A → Complex puzzle (higher cognitive load) → Questionnaire B
Pair group	Simple puzzle (lower cognitive load) → Questionnaire A → Complex puzzle (higher cognitive load) → Questionnaire B

Figure 3.6 Amended Experimental Design

It was recognised that knowledge and skills obtained in the first "simple" task (Towers) may be transferred to the second more complex task (Monster Move). The experimental design was not as well-controlled as the first design; however it was born of necessity from the low participation rate.

Unfortunately, even with additional consent forms distributed to the rest of Year 7 and some of Year 8, the total number of respondents was thirteen – 10 boys and 3 girls (4 pairs and 5 individuals) - well short of the thirty-nine estimated required participants. It was decided to go forward with the study as a pilot study, to gain some insight into possible trends of the data, and the suitability of the tasks to the target group.

3.2.5 Experimental Method for Pilot Study

Participants each attended one session of approximately 30 minutes duration, either individually (Individual group) or as one of a pair of students (Pair group). The experiment was conducted in an audiovisual room. Most students were familiar with the room as it was also used for Year 7 introductions to timetabling. Students were welcomed by the researcher and seated in front of the computer. If the session was to involve paired usage, two chairs were provided, otherwise one chair was provided.

A short introduction to the study was given, and then verbal instructions to start and complete the Towers of Hanoi puzzle. Students were told they were allowed to discuss the puzzle (Williams, 1999) if in the Pair group, or told it may help if they "thought aloud" if in the Individual group. The students were allowed as much time as necessary to complete the puzzle, and told to inform the researcher when the "Congratulations" message was displayed.

Upon completion of the first puzzle, students were given the first questionnaire. They were reminded that there were no right or wrong answers, and that the questionnaire was to determine their attitudes towards working with a computer, and towards the puzzle they had just completed. Upon completion of the questionnaire they were asked to close the Towers of Hanoi if they had not already done so, and to click on a "Monsters" button at the bottom of the screen. The Monster Move puzzle was minimised on the Windows™ task bar, so this restored it to full size, in a state that was ready for the student to begin. The students were told to read the instructions, complete the puzzle, and inform the researcher when the puzzle was solved. The second questionnaire was then administered, with a reminder that there were no right or wrong answers. Students were then thanked for their participation, and went back to their normal classes.

Results of the pilot study and discussion of these results are covered in the Results and Discussion section of this report.

3.3 Experiment (Primary School)

3.3.1 Participants

With available time getting shorter, it was decided to go back to the Department of Education and obtain permission to repeat the study in a large regional New South Wales Primary School. Discussions with the teachers and principal at a local Primary School suggested that they believed that participation rates would not be as problematic as experienced in the High School.

Year 6 was chosen for the study, and as before, all students were required to give consent, and gain consent from their parent(s) or guardian(s). [Appendix C2]. A cover note [Appendix C3] was attached to the consent form, briefly explaining the purpose of the study, to attempt to mitigate the problems experienced with return-rate at the High School.

Ninety students (all of Year 6) were invited to participate in the study. Of these, thirty-one students responded – 14 girls and 17 boys. (Two of these students, both boys, later withdrew from the study due to illness, leaving a total of 29 students). Again, these were divided into two groups in a randomised fashion, taking into account the need for balance of computer competency (again based on responses on the consent form) and gender. The computer studies teacher was consulted as to any potential personality conflicts between the paired students in the Pair group.

3.3.2 Changes to Experimental Design

The only changes that were made to the design compared to the Pilot Study were to the questionnaires, which at eight questions each were felt to be slightly too long for the Year 6 respondents. The questionnaire lengths were reduced to four and five questions respectively [Appendix B4 and B5], and the questions were made more direct. Questionnaire 1 contained four questions, each of which used a five point Likert scale to determine participants' attitudes. The first two questions regarded the respondent's attitude towards working on a computer generally, and computer-aided instruction. The next question asked about enjoyment of the Towers of Hanoi puzzle, and the final question asked if the student believed the puzzle was suitable for working with a partner.

Questionnaire 2 contained two questions using a five point Likert scale, repeating Q3 and Q4 on Questionnaire 1, but regarding the Monster Move puzzle. The students were then asked which puzzle they found easiest to solve (Q3) and in which puzzle they felt it would be most helpful to have a partner (Q4). These questions were followed by an open comment question about perceived benefits of working with or without a partner.

3.3.3 Experimental Method

Participants each attended one session of approximately 30 minutes duration, either individually (Individual group) or as one of a pair of students (Pair group). The experiment was conducted in a disused teacher's office rearranged for

the study. Students were welcomed by the researcher and seated in front of the computer.

A short introduction to the study was given, and then verbal instructions to start and complete the Towers of Hanoi puzzle. Students were told that they were allowed to talk in case they believed that was cheating (Williams, 1999) if in the Pair group. Individual students were also told that it may help to "think aloud". The students were permitted as much time as necessary to complete the puzzle, and informed the researcher when the puzzle was complete. Each student was then given the first questionnaire, and asked to complete it. They were reminded that there were no right or wrong answers and that the questionnaire was to ascertain their attitude towards computers and the puzzle.

As with the Pilot Study, on completion of the questionnaire, the participants were asked to close the Towers of Hanoi puzzle if it was still open, and to click on the "Monsters" button at the bottom of the screen. The students were then told to read the instructions and to inform the researcher when the puzzle was solved. The second questionnaire was then administered, with a reminder that there were no right or wrong answers. Students were then thanked for their participation, and went back to their normal classes.

Results of this experiment and subsequent discussion of the results are covered in the next section – Results and Discussion.

Chapter 4

RESULTS AND DISCUSSION

4.1 Hypotheses

The time and number-of-move measurements were analysed using two-way Analysis of Variance. For all statistical results a level of significance at 0.05 was used.

4.1.1 Hypothesis 1 (Task Difficulty)

H_A1: The Monster Move puzzle is more difficult than the Tower of Hanoi Puzzle.

H_01: (Null hypothesis) There is no difference in difficulty between the Monster Move puzzle and the Tower of Hanoi puzzle.

4.1.2 Hypothesis 2 (Pairing)

- H_A2: Individual users will find the puzzles more difficult than the paired users.

H_02: (Null hypothesis) There will be no difference between students in the paired condition and students in the individual condition in difficulty experienced solving the puzzles.

.

4.1.3 Hypothesis 3 (Interaction)

- H_A3: The benefits of pairing will be more evident on complex tasks.

  H_03: (Null hypothesis) Any benefit of pairing will be consistent across the "Monster Move" puzzle and the "Towers of Hanoi" puzzle.

Analysis – Time spent on instructions:

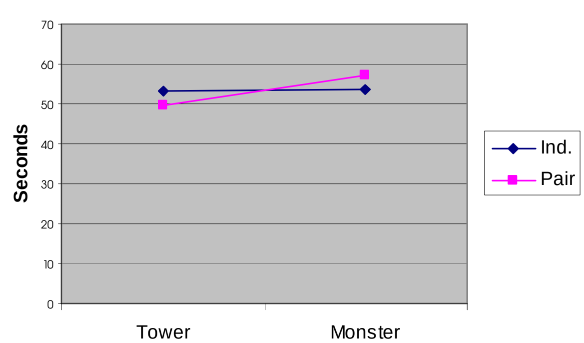
Although there were no hypotheses concerning time spent on instructions, this data was collected and so has been analysed using a 2-way ANOVA. The time in seconds for each group to read the instructions is presented in Table 4.1. Standard deviations are given in brackets () after the mean.

Table 4.1: Time in seconds to read instructions

	Tower of Hanoi	Monster Move
Individual Condition	53.3 seconds (22.00)	53.5 seconds (15.18)
Paired Condition	49.6 seconds (9.18)	57.4 seconds (11.88)

A graph of the means is presented below in Figure 4.1

Figure 4.1 Graph of Means



A two-way Analysis of Variance returned the results presented in Table 4.2.

Table 4.2 Summary Table for 2-way ANOVA (time on instructions)

Source of Variation	SSquares	df	Variance estimate	F	p
Between groups	280.42	3			
A (Ind/ pair)	0.184	1	0.184	0.00074	> 0.05
B (puzzle)	133.225	1	133.225	0.53627	> 0.05
A X B (interaction)	147.01	1	147.01	0.59177	> 0.05
Within group (error)	8943.35	36	248.426		
Total	9223.775	39			

No statistically significant difference was observed between the Pair and Individual groups. There was also no statistically significant difference in the time taken to read instructions between the two puzzles, and the interaction effect between Pair/ Individual groups and the puzzle difficulty was also not statistically significant. As no statistically significant differences were observed regarding time on instructions, this excludes time on instructions being a contributing factor to any performance difference found between groups or puzzles.

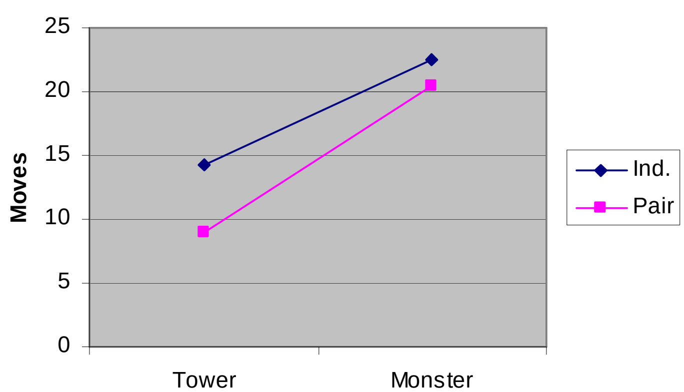
Analysis - Moves:

The number of moves for each group to solve the puzzles is presented in Table 4.2. Standard deviations are given in brackets () after the mean.

Table 4.3: Number of moves to solve puzzles		
	Tower of Hanoi	Monster Move
Individual condition	14.2 moves (10.50)	22.5 moves (12.44)
Paired Condition	9 moves (2.83)	20.4 moves (15.61)

A graph of the means is presented below in Figure 4.2

Figure 4.2 Graph of Means



A two-way Analysis of Variance returned the results presented in Table 4.4.

Table 4.4 Summary Table for 2-way ANOVA (number of moves)

Source of Variation	SSquares	df	Variance estimate	F	p
Between groups	1093.82	3			
A (Ind/ pair)	128.02	1	128.02	0.988418	>0.05
B (puzzle)	940.9	1	940.9	7.264725	<0.05
A X B (interaction)	24.90	1	24.90	0.192238	>0.05
Within group (error)	4662.59	36	129.52		
Total	5756.41	39			

Although the difference between the Individual and Paired groups in mean moves to solve was in the predicted direction, no statistically significant difference was observed between the two groups. There was a statistically significant difference in the mean moves to solve between the two puzzles, as previously found by Kotovsky, Hayes and Simon (1985), however the interaction effect between pairs/ individual groups and the puzzle difficulty was not statistically significant.

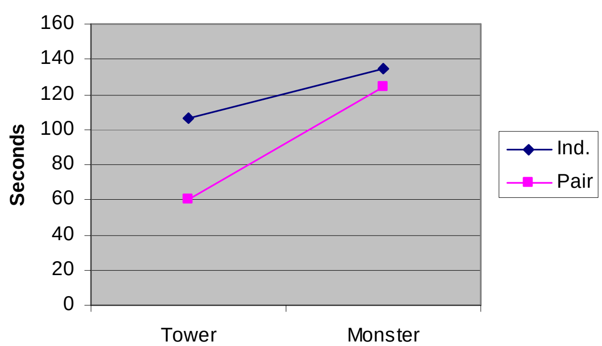
Analysis - Time

The mean time in seconds for each group to solve the puzzles is presented in Table 4.5. Standard deviations are given in brackets () after the mean.

Table 4.5: Time in seconds to solve puzzles		
	Tower of Hanoi	Monster Move
Individual Condition	106.4 seconds (157.35)	134.5 seconds (105.26)
Paired Condition	60.3 seconds (39.56)	123.8 seconds (112.86)

A graph of the means is presented below in Figure 4.3

Figure 4.3 Graph of Means



A two-way Analysis of Variance returned the results presented in Table 4.6.

Table 4.6 Summary Table for 2-way ANOVA (time in seconds)

Source of Variation	SSquares	df	Variance estimate	F	p
Between groups	30465.96	3			
A (Ind/ pair)	7984.38	1	7984.38	0.607928	>0.05
B (puzzle)	19404.03	1	19404.03	1.477418	>0.05
A X B (interaction)	3077.55	1	3077.55	0.234324	>0.05
Within group (error)	472814.8	36	13133.74		
Total	503280.76	39			

Although the difference between the Individual and Paired groups in mean time to solve was in the predicted direction, no statistically significant difference was observed between the two groups. There was also no statistically significant difference in the mean time to solve between the two puzzles, and the interaction effect between pairs/ individual groups and the puzzle difficulty was not statistically significant.

Analysis – Quantity and Quality of interaction

Quantity and quality of interpersonal interactions was determined by analysis of the conversations between pairs. A useful aspect of this analysis involves the concept of grounding -- coordination between partners to relate their conversation to the mutual knowledge, beliefs and assumptions held by both partners. Conversations include many grounding statements to establish that the conversationalists mutually understand one another (Clark & Wilkes-Gibbs, 1986). Indicative gestures – pointing, looking or touching – are a common method of grounding (Hunt, undated).

With this in mind, one measure of quantity of interaction could be determined by the number of times students physically pointed at the screen. The number of times students in the paired condition physically pointed to the screen is presented in Table 4.7.

Table 4.7: Quantity of interaction between pairs

	Tower puzzle	Monster Move Puzzle
number of pointing gestures (mean)	3.33	6
standard deviation	3.08	2.18

A statistically significant difference was found for the number of pointing gestures during the Monster Move puzzle compared to the Tower of Hanoi puzzle (p = 0.026).

In regards to quality of interaction, most interaction, if any, between students solving the *Towers of Hanoi* puzzle in the paired condition consisted of pointing and directive statements by the student not controlling the mouse.

Example: "Put that one over there" (Pair 1)

"That there and that one there (*pointing*)" (Pair 3)

In three of the nine pairs, there was no visible cooperative behaviour at all from the student not controlling the mouse, in the form of talking or gestures. Effectively the *driver* – the student controlling the mouse – solved the puzzle by themselves. In other pairs the non-driving student leant back on the chair for a majority of the time and then interjected a few directive remarks – "down there … that one there … and then that one there (*pointing*)" – without waiting to see if the other student understood or was going to follow the directions.

In contrast, every pair exhibited collaborative behaviours during the Monster Move puzzle, and most discussed what to do as the next move. For example: the following exchange (L is student on left of screen, R is student on right, operating the mouse):

R: I seriously don't know where that one goes…

L: Ok, does that one go on that one?

R. Nuh

L. (*Rubbing head*) (*points*) Hang on, does that one go on that one?"

R: Oooh, oh

R. (*points*) Hang on, can that one go there?"

L. (*Shakes head)*

R. Oh, cause you can only transfer …

(and so on). [See Appendix E for the full transcript of this pair's interactions in both puzzles].

It was clear from both the quantitative analysis, and the analysis of the video transcripts that the quantity and quality of interaction between paired students was greater during "Monster Move" puzzle than in "Towers of Hanoi" puzzle. From these results, the null hypothesis $H_0 3$ can be rejected in favour of the alternative hypothesis, that benefits of pairing are more evident on complex tasks.

4.2 Limitations of Instruments

In analysing the results of the experiment, some deficiencies in the design of the experimental instruments (the purpose built software puzzles – “Tower of Hanoi” and “Monster Move”) became apparent.

Firstly, illegal moves – those contravening the game rules – were not permitted by the software. When an illegal move was attempted, the game returned the disc (Tower puzzle) or globe (Monster puzzle) to the previous position. While this was not a deficiency in itself, when an illegal move was made it did not increase the “moves made” count recorded by the software. There was also no count kept of the illegal moves made by the students.

For this reason, it was difficult to determine if the students were actually using the rules to attempt to find the solution path for each puzzle or whether they were using the features of the software to randomly make moves in the hope of happening upon a solution. Observation of the students (particularly in the individual condition) would appear to indicate that this was sometimes the case. Keeping in mind that both puzzles may be solved in seven moves, the large number of moves in many cases [see Table 4.8 below], even in the paired condition, seems to point to students making random movements without thinking about movement along the solution path.

Table 4.8: Number of Monster Move sessions where number of moves made >= 20	
	Monster Move Puzzle
Individual condition	6 out of 11 sessions
Range of moves	8 to 42
Paired condition	3 out of 9 sessions
Range of moves	8 to 52

The second design deficiency in the software was that there was no penalty for illegal moves. Providing some form of penalty for each wrong move – such as losing one of three 'lives' as seen in many commercial computer games – may have provided a motivation for students to focus on learning the rules and avoiding illegal moves. Instead, due to the design of the software, the students were able to either

- learn the rules by experimentation (of the form 'does it allow me to move this globe to here?') instead of being required to keep the rules in their working memory; or
- move the globes or discs around randomly until the software displayed the congratulatory message, thereby requiring minimal cognitive processes.

The fact that some students solved the puzzles in this second way was evidenced by looks of surprise when a solution was reached.

4.3 Comparison between the pilot study and the experiment

The two logic puzzles used for the study were chosen because they were a 'simple' and a 'complex' isomorph of the same problem. *Simplicity* and *complexity* were decided on the basis of Kotovsky, Hayes & Simon's research (1985) into these puzzles, where they found that subjects solving these puzzles for the first time displayed large differences in relative difficulty. Adult subjects who have not encountered the puzzles before have an average solution time for Tower of Hanoi of 1.83 minutes, while the average time taken to solve Monster Move is 13.95 minutes (Hayes and Simon, 1977). The explanation for the difference in difficulty is that Monster Move appears to impose a greater load on working memory than Towers of Hanoi, making it more difficult to solve. These puzzles appeared to fit the experimental requirements of the current study for a simple (lower cognitive load) task, and a more complex (higher cognitive load) task. With this in mind, the pilot study was performed at a High School with Year 7 and 8 students.

4.3.1 Pilot Study

The students typically found the Tower puzzle easy. Three out of the five students in the individual condition solved the puzzle in the minimum number (seven) of moves possible. Even those two individual students that did not solve the puzzle in the minimum amount of moves solved it in 9 and 10 moves, respectively. All four pairs in the paired group solved the puzzle in the minimum amount of moves.

The students clearly found the Monster Move problem more difficult. None of the students in individual or paired conditions solved the puzzle in the minimum number of moves. Some of the students recorded excessive numbers of moves – up to 45 moves in one instance in the individual condition. There was clear indication that the puzzles fitted well into the required experimental conditions of a simple (lower cognitive load) puzzle and a more complex (higher cognitive load) puzzle.

The number of students in the pilot study was so small that it was meaningless to do a statistical analysis of the results. However videorecorded evidence appears to indicate that the use of pairs was more effective -- in terms of collaboration -- in the Monster Move puzzle, with more task-related chatter and gestures between the paired participants as compared to the Tower puzzle.

The results from the pilot study appeared to indicate that the puzzles chosen were suitable for the experiment, even though the original changes to the experimental design meant that students were seeing both puzzles instead of one, and could transfer knowledge and skills from the simple to the complex problem-solving situation.

The changes made to the experimental design involved redesigning the two questionnaires. It was recognised that questions did not need to be repeated over both questionnaires, and could be simplified for the Year 6 students who were going to participate in the study. It was also recognised that as the students would

be seeing both puzzles, they could be asked to compare the two in terms of difficulty, and suitability for paired approaches.

4.3.2 Primary School Study – Year 6

It is apparent from analysis of the video and audio recording taken of the pairs, that all of the students in the Primary School study found the Monster Move puzzle very difficult, even after working through the Towers of Hanoi puzzle. Students in 7 of the 20 experimental sessions verbally expressed opinions about this difficulty either during the puzzle or immediately afterwards to this researcher – "Man, this is hard", "That one was a lot more difficult than the first one!", and "This is a fair bit harder, isn't it".

Students involved in the Primary School study also found the Tower puzzle quite difficult in some instances. The pilot study with Year 7 students at the High School had indicated that students generally were finding the Tower puzzle simple, and the Monster Move more difficult. In comparison, the Year 6 students were finding the Tower puzzle somewhat difficult, and the Monster Move extremely difficult.

Seven out of 20 student sessions at the Primary School solved the Tower puzzle in the minimum seven moves, in comparison to 7 out of 9 student sessions in the pilot [See Table 4.9].

Table 4.9: Minimum Move Solutions – Tower of Hanoi

	number of times puzzle solved in minimum moves	Total sessions
Pilot study (Year 7 and 8)	7	9
Primary School Study (Year 6)	7	20

Using a Chi Square test on this data yields χ^2 = 4.1048, with one degree of freedom, which equates to $p = 0.0329$. Therefore the difference between the pilot study and the Primary School study, in respect to students solving the Tower puzzle in minimum moves possible, is statistically significant.

The corollary to this is that the Primary School children involved in the study (Year 6) found the Tower puzzle significantly more difficult (higher cognitive load) than the High School children (Year 7 and 8) participating in the pilot study. Instead of the experiment being a movement of simple -> difficult, it became difficult -> very difficult.

The obvious difference in difficulty experienced by the children in the two studies could be explained by Piaget's theory of cognitive development stages (Piaget, 1970). The children participating in the Primary School study were aged from 11 – 12 years, which corresponds roughly to the cross-over point from

Piaget's 'concrete operational' to 'formal operational' stage. The students participating in the pilot study (Year 7 and 8) were aged from 12 to 14 years, which would characteristically correspond to when children have moved to the formal operational stage. Children in the concrete operational stage have logical thinking but difficulty with abstractions, while children in the formal operational stage can test hypotheses systematically and think logically about abstract propositions. The difference in cognitive development between the Primary School children and Pilot Study children could explain the differences in performance and task difficulty.

Evidence of the heavy cognitive load for the Year 6 children can be seen in the dialogue between the pairs during the Monster Move puzzle. In contrast to the Tower puzzle, students continually reiterated the rules to themselves or their partners, or questioned the rules – for example: "(*said to herself)* Only one globe may be transferred at a time … ". Students also accessed the online help (up to 5 times) during the Monster Move puzzle, even when they had a partner to help remember the rules of the game. This can be compared to the High School where no students accessed the online help during the Monster Move puzzle.

It is noteworthy that none of the students involved in the Primary School study made any mention of the similarity or relationship to each other of the two puzzles. This may indicate that due to the difficulty they were experiencing with the puzzles, they were most probably not recognising the puzzles as isomorphs, and not transferring any skills or processes learned in the first puzzle to solve the second. The surface cues of the puzzle (appearance and the cover story)

dominated and the students were obviously not linking the problem solving strategy of the first puzzle with the second. This is further evidence that for *these* children the first puzzle required quite high intrinsic and extraneous cognitive load, leaving little cognitive resources for the task of schema formation and learning.

It was decided to look more closely at the data collected from the Tower puzzle with these aspects in mind, and recognising that for this cohort of students, the Tower puzzle more accurately fitted the definition of a moderately complex puzzle rather than a simple puzzle.

4.4 "Breeze" condition

The data collected from the Tower puzzle solutions was examined, and it was found that students either tended to solve the puzzle in the minimum number or moves, or close to it (two or three incorrect moves – those not along the optimal solution path), or they made many incorrect moves, obviously finding the problem much more difficult. It was decided to analyze these trends, by defining a *Breeze* condition; breeze being an idiomatic word denoting "a task that is easy to do" (http://dictionary.reference.com/search?q=breeze).

The Breeze condition was defined as number of moves made (n) as less than 11. This allowed for 3 incorrect (not along the optimal solution path) moves. The data results are presented in Table 4.10.

Table 4.10: Breeze Condition for Tower Puzzle

	$n < 11$ moves	Total sessions
individual condition	5	11
paired condition	8	9

Analysis of this data using Chi Square analysis yields $\chi^2 = 4.1048$, with one degree of freedom, or $p = 0.0428$. The difference in results is statistically significant, and indicates that there is a clear advantage in paired approaches in moderately difficult problems – those requiring a higher cognitive load.

4.5 Perceived Benefits

Not only was there a measurable benefit of paired approaches over individual approaches, when solving moderately difficult (higher cognitive load) problems, but the students themselves identified that a partner was progressively more useful as difficulty increased.

Analysis of the questionnaires showed that 20 out of 29 students in the study answered "Monster Move" when asked the question "In what puzzle do you think it would be most helpful to have a partner". Analysis of this data using binomial distribution probability gives a result of 0.0121, which is statistically significant.

When asked "which puzzle did you find easiest to solve?", 20 out 29 students answered "Towers of Hanoi" – again this is statistically significant at the 0.05 level. The students were clearly identifying the paired approach as being more effective as difficulty of the problem increased.

This is supported by some of the comments made on the returned questionnaires:

- "I like working with a partner because it makes things easier" (made by one of the students in the individual condition group)
- "I like working with a partner because you have twice the brain power to figure the problem."
- "it is good working with pairs because you can share thoughts about the game"
- "we had different ideas and that helped a lot"

- "it would proble [sic] be easier to work with a partner because two heads are better than one (sometimes)"

The students themselves identified that it was the different problem-solving approaches and experiences (based on each individual's schema) as well as sharing the problem-solving task (hence reducing the actual short term memory load) that was an advantage to the paired approach.

Chapter 5

CONCLUSION AND FURTHER RESEARCH DIRECTIONS

The increase in use of computers and in computing power has happened at the same time as there has been interest in collaborative practices in the workplace and in education. Recognising the advantages of some collaborative learning practices, education departments have called for an increase in collaborative approaches while using and learning about computing technology (NSW Board of Studies 1991a). Workplaces have also recognized the benefits of collaboration, forming self-directed work teams that are often located in 'war rooms' with the equipment they will need for their project. At the same time, other fields, such as software development, have developed approaches which include pair programming – the practice of two people coding on one computer, with one display unit, keyboard and mouse. The increasing interest in collaborative practices involving computing technology has resulted in a new interdisciplinary field of study - Computer Supported Cooperative Work or CSCW.

The particular area of interest of CSCW in this study is that of co-present, synchronous collaboration. Research into this area has generally concentrated on surmounting the difficulties inherent in sharing technology that is designed for one person-one computer use. Approaches taken have included designing new technologies such as electronic walls, tabletop displays, augmented reality (with its head-mounted displays and ability to function in both virtual and real world at the same time), and enhancements to user interfaces, such as changes in software, and

adding multiple input devices and displays. However, it is apparent that despite technological innovation, the paired computing approach of two people sitting at one computer and sharing one keyboard and mouse will continue to be used for some time to come.

Research into paired computing has concentrated on the advantages of paired computing over individual computing, with little attention paid to factors that may make paired computing more or less effective. Anecdotal evidence appears to point to task complexity affecting whether paired approaches are preferable.

With this in mind, an experiment was designed that would compare paired usage to individual usage in two puzzles requiring differing amounts of working memory load. It was predicted that the paired approaches would be most beneficial in the problem requiring heavier memory load. It was also predicted that collaborative behaviours would increase as the cognitive load required by the problem increased.

Problems with the initial study organised in a High School with Year 7 and 8 children (detailed in Chapter 3) meant that the study was repeated with Year 6 Primary School students. This meant that the participants were not as cognitively advanced as the original students, and the puzzle designated as “simple” was actually at least “moderately difficult” for this cohort.

Experimental Findings

Further analysis of the data showed a clear advantage for the paired computing approach over the individual approach, in moderately difficult problem-solving tasks. There were also significantly more collaborative behaviours displayed as problem difficulty (and hence cognitive load) increased.

Therefore the findings of this study are that paired computing approaches may be suitable and effective in tasks requiring moderate to high cognitive load. Also recall that there was no significant difference between groups or tasks concerning time spent on reading instructions, so this can be discounted as a contributing factor to the results.

It should be noted that the problem presented to the students was logical and structured, not creative. The findings of this study should be transferable to all domains involving logical structured problems, but not necessarily to creative tasks.

There are several implications of this research. In the educational field, with limited resources and often the necessity for children to at times share a computer, it would be beneficial to use paired approaches when the task involves new material (thereby requiring a heavier cognitive load, as children form and extend schema), or when the intrinsic qualities of the task mean that a heavier cognitive load is required. In the field of pair programming, it would be beneficial to use paired approaches during solution of new or complex problems, and divide to

perform individual work for the more rote well-known (and hence lower cognitive load) tasks required.

This research also may have significance in the area of interface agents – software programs that act on behalf of the user. Interface agents can be seen as a personal assistant that collaborates with the user, and assists with the cognitive load of a task (Maes, 1994). This research may give insight into during which tasks such interface agents are most useful. As a partner can be unhelpful or even a hindrance or annoyance during tasks of low cognitive load, so an interface agent could become irrelevant or a hindrance. In contrast, in tasks of moderate to high cognitive load, an agent could help to reduce the cognitive load, and hence simplify the problem-solving task for the user.

Future Research Directions

Some recommendations should be noted if this research experiment were to be repeated or adapted. Firstly, the software should be adapted to better record relevant data – for example the number of illegal moves (those contravening game rules) attempted, and pattern of moves along the solution path. The addition of penalties for illegal moves, common in educational problem-solving games of this type, would act as a motivator for participants to learn the rules of each puzzle, rather than rely on the inherent attributes of the software to solve the puzzle.

The Tower of Hanoi isomorphs were also found to be only suitable for students in Year 7 and older, if a “simple” puzzle is required as one of the

experimental puzzle solving task states. Year 6 students generally found the least complex puzzle – Towers of Hanoi – at least moderately difficult.

The Kotovsky, Hayes and Simon (1985) research into these isomorphs included four variations of the puzzle. Future experiments could use all four puzzles for research into the effectiveness of paired computing approaches when solving problems of increasingly higher cognitive load.

Other related research is suggested into how pair composition (differences in ability, skill set or gender, and self-seeding) impacts on the effectiveness of paired computing problem-solving.

BIBLIOGRAPHY

Abdel-Hamid, T.K. (1990), Investigating the Cost/Schedule Trade-off in Software Development, *IEEE Software,* January 1990, 97-105.

Abowd, G.D., Edwards, W.K. & Grinter, R.E. (2003), Smart Homes or Homes That Smart? *SIGCHI Bulletin,* March/April, 2003.

Australian Bureau of Statistics (2004), *Year Book Australia 2004 – Communications and Information Technology – Use of Information Technology,* [Online]. Available: http://www.abs.gov.au/ausstats/abs@.nsf/94713ad445ff1425ca25682000192af2/f6b13fe76704e2a7ca256dea000539c1!OpenDocument. (Accessed 9th June 2004)

Barlett, F.C. (1958) *Thinking*, Basic Books, New York.

Beck, K. (2000), *Extreme Programming Explained – Embrace Change,* Addison-Wesley, Boston MA.

Bellis, M (2004) *The History of Computers – Computer History Timeline*. [Online] Available: http://inventors.about.com/library/blcoindex.htm (Accessed: 1st December, 2004)

Big Boards (2004) *Statistics for Whirlpool Forums*, [Online] Available: http://www.big-boards.com/board/277/ (Accessed 20th November, 2004).

Billinghurst, M. & Kato, H. (1999) Collaborative Mixed Reality, *Proceedings of ISMR '99.* Springer Verlag. pp 261-284.

Billinghurst, M., Poupyrev, I., Kato, H. & May, R. (2000) *Mixing Realities in Shared Space – An Augmented Reality Interface for Collaborative Computing.* In Proceedings of the IEEE International Conference on Multimedia and Expo (ICME2000), July 30th - August 2, New York [Online] Available: http://www.hitl.washington.edu/magicbook/papers/icme2000.pdf (Accessed 7th July, 2004).

Board of Studies NSW (2000) *Science and Technology K-6 - Outcomes and Indicators*. [Online] Available: http://bosnsw-k6.nsw.edu.au/scitech/pdf-doc/k6scitech_outcomes.pdf (Accessed 10th October, 2004).

Boyle, T. (1997), *Design for Multimedia Learning*, Prentice Hall, London.

Braden, E. & Mark, G. (2002) Why Distance Matters: effects on cooperation, persuasion and deception, *Proceedings of the 2002 ACM Conference on Computer Supported Cooperative Work* pp 226 – 235.

Bricker, L., Inkpen, K.M., Stewart, J. & Myers, B (1998) *Single Display Groupware: Exploring Computer Support for Co-Present Collaboration* [Online]. Available: http://www-2.cs.cmu.edu/~pebbles/papers/panelcscw98.pdf (Accessed 15th August, 2004).

C3 Team (1998), Chrysler Goes To Extremes, *Distributed Computing*, October 1998, 24-28.

Cameron, J. & Hurd, G.A. (1984) *The Terminator,* Film. Director: James Cameron.

Campbell, J. (1995) *Understanding John Dewey. Nature and co-operative intelligence*, Open Court, Chicago.

Casey, S (2003), Using Old Technology in Engaging Ways, *Information Transfer the NSWCEG Journal*, Vol 23/4 pp. 14-16.

Chi, M., Glaser, R. & Farr, M. (1988). *The Nature of Expertise*. Erlbaum: Hillsdale, NJ.

Chipperfield, B. (2004) *Cognitive Load Theory and Instructional Design*[Online] Available: http://www.usak.ca/education/coursework/802papers/chipperfield/ (Accessed: 4th December, 2004).

Clark, H.H. & Wilkes-Gibbs, D. (1986) Referring as a Collaborative Process. *Cognition.* 22/1 PP 1-39.

Cockburn, A & Williams, L. (2001) *The Costs and Benefits of Pair Programming* Paper presented at the XP2000 Conference, Sardinia.[Online] Available: http://collaboration.csc.ncsu.edu/laurie/Papers/XPSardinia.PDF (Accessed 17th June, 2004).

Coffs Harbour High School (2003) *Computer User Policy,* Coffs Harbour High School Policy Document.

Constantine, L.L (1995) *Constantine on Peopleware*, Yourdon Press: Englewood Cliffs, NJ.

Cooper, G. (1990). Cognitive load theory as an aid for instructional design. *Australian Journal of Educational Technology*, 6/2, pp.108-113. [Online] Available: http://www.ascilite.org.au/ajet/ajet6/cooper.html (Accessed: 12th September, 2004)

Cooper, G. (1998) *Research into Cognitive Load Theory and Instructional Design at UNSW*, [Online]. Available: http://education.arts.unsw.edu.au/CLT_NET_Aug_97.HTML (Accessed 11th June 2004).

Coplien, J.O. & Schmidt, D.C. (1995) *Pattern Languages of Program Design*, Addison-Wesley, Workingham, England.

Crook, C. (1990), *Computers in the Classroom*, in O. Boyd-Barrett & E. Scanlon (Eds.) 1990, Computers and Learning, Addison-Wesley: Workingham, England.

Culley, L. (1987), Girls, Boys and Computers, *Educational Studies,* Abingdon, UK. Carfax Publishing Company, Vol 14.1, 3-8.

Deutsch, M. (1951) Social Relations in the Classroom and Grading Procedures, *Journal of Educational Research,* Vol 45, pp 145-152.

Dick, A.J. & Zarnett, B (2002) *Paired Programming and Personality Traits,* XP2002 Conference 2002, Alghero, Sardinia, Italy. [Online} Available: http://www.xp2003.org/xp2002/atti/Dick-Zarnett--PairedProgrammingandPersonalityTraits.pdf (Accessed: 16th August, 2004).

Dumay, H.E. & Velardo, E (1998) Self-Directed Work Teams: An International Learning Experience at Vinfen, in *Impact* – Journal of College of Education and Human Development, University of Minnesota; Vol 10/4, Winter 1998 pp 20-21. [Online] Available: http://ici.umn.edu/products/impact/104/IMPACT_Volume10_Issue4.pdf (Accessed: 11th September, 2004)

Ellis, C.A., Gibbs, S.J. & Rein, G.L. (1991) Groupware, Some Issues and Experiences. In *Communications of the ACM.* 34/1 pp 38-58.

Flor, N.V. & Hutchins, E.L. (1991) Analyzing Distributed Cognition in Software Teams: A case study of team programming during perfective software maintenance, *Empirical Studies of Programmers, Fourth Workshop.* Ablex Publishing Corporation.

Friberg, H (2004) *A Paper On Smart Homes and Smart Houses – What is the meaning of Intelligence in Intelligent Homes?* [Online] Available: http://www.cs.chalmers.se/idc/ituniv/student/2003/portfolior/it3frha/public_html/uppsats_ubicomp_hanna_friberg.pdf (Accessed 24th October, 2004)

Gansmo, H. J. (undated) *Primary and Secondary Education – The Distinctive Role of Schools in the Inclusion of Girls in ICTs,* Information Society Technologies [Online] Available: http://www.rcss.ed.ac.uk/sigis/public/documents/SIGIS_D08_04_schools.pdf (Accessed 15th October, 2004)

Gokhale, A. A. (1995) Collaborative Learning Enhances Critical Thinking, *Journal of Technology Education,* 7/1 Fall 1995. [Online] Available: http://scholar.lib.vt.edu/ejournals/JTE/jte-v7n1/gokhale.jte-v7n1.html (Accessed 16th August, 2004).

Grabinger, R.S. & Dunlap, J.C. (1995) Rich Environments for Active Learning: a definition, in *The Changing Face of Learning Technology*, D.Squires, G. Conole and G. Jacobs (Eds.) University of Wales Press, Cardiff.

Gutwin, C & Greenburg, S. (1998) *Design for Individuals, Design for Groups: Tradeoffs Between Power and Workspace Awareness.* In Proceedings of the ACM CSCW'98 Conference on Computer Supported Cooperative Work, pages 207—216 [Online] ACM Digital Library: Accession no. n.a. (Accessed 18th August, 2004).

Hackman, J.R. & Oldham, G.R. (1980) *Work Redesign,* Addison-Wesley, Reading, Mass.

Hall-Taylor, B. (1999) *SY106 Group Processes Study Guide*, SCU Press, Lismore, Australia.

Hanks, B. (2003) *Empirical Studies of Pair Programming,* 2nd International Workshop on Empirical Evaluation of Agile Processes (EEAP 2003). [Online]. Available: http://www.soe.ucsc.edu/~brianh/papers/EmpiricalEvaluationWorkshop.pdf (Accessed: 18th September, 2004).

Hayes, J.R. & Simon, H.A. (1977) Psychological differences among problem isomorphs. In Castellan, N.J., Pisoni, D.B. & Potts, G.R. (Eds), *Cognitive Theory*, Erlbaum.

Hellriegel, D. & Slocum, J.W. (1992) *Management* (6th Ed.) Addison-Wesley, Reading, Mass.

Herbsleb, J.D., Mockus, A., Finholt, T.A. & Grinter, R.E. (2000) Distance, Dependencies and Delay in a Global Collaboration, *Proceedings of the 2000 ACM conference on Computer Supported Cooperative Work* pp 319-328

Hollan, J. Hutchins, E. & Kirsh, D. (2000) Distributed Cognition: Toward a New Foundation for Human-Computer Interaction Research, *ACM Transactions on Computer-Human Interaction,* 7/2 174-196.

Hunt, W.T. (undated) Shared Understanding: Implications for Computer Supported Cooperative Work, [Online] Available: http://www.dgp.utoronto.ca/people/WilliamHunt/qualifier.html (Accessed: 10th August, 2004)

Hutchins, E. (1995). How a cockpit remembers its speed, *Cognitive Science,* 19, pp 265 – 288.

Hutchins, E. (1995) *Cognition in the wild,* MIT Press, Cambridge, MA.

IBM Social Computing Group (2001) *Social Computing Group Introduction,* [Online] Available: http://www.research.ibm.com/SocialComputing/index.html (Accessed: 18th August, 2004)

IEEE (2003) *Other Useful Resources for Collaborative Computing*, Distributed Systems Online. [Online] Available: http://dsonline.computer.org/collaborative/resources/ (Accessed: 10th May 2004).

IEEE (2003) *Collaborative Computing* Distributed Systems Online. [Online] Available: http://dsonline.computer.org/collaborative/about/ (Accessed: 10th May 2004).

Inkpen, K., Booth, K.S., Gribble, S.D. & Klawe, M. (1995) *Give and Take: Children Collaborating on One Computer*, Conference on Human Factors in Computing Systems [Online] ACM Digital Library: SIGCHI, Accession no. n.a (Accessed 24th September, 2004).

Inkpen, K. (1997), *Three Important Research Agendas for Educational Multimedia: Learning, Children and Gender,* In Proceedings of the World Conference on Educational Multimedia and Hypermedia'97 (Calgary, Alberta, Canada). 521-526 [Online] Available: http://www.edgelab.ca/publications/edmedia97.pdf (Accessed: 10th August, 2004).

Inkpen, K., McGrenere, J., Booth, K. & Klawe, M. (1997), The effect of turn-taking protocols on children's learning in mouse-driven collaborative environments, in *Proceedings of Graphics Interface '97,* Kelowna, B.C., Morgan Kaufmann, San Francisco, pp 138-145

Inkpen, K., Mandryk, R., Scott, S., Greenburg, S. & Zanella, A. (2000) *Shared Environments to Support Face-to-Face Collaboration* Workshop at ACM 2000 Conference on Computer-Supported Cooperative Work, December, 2000, Philadelphia, PA, USA. [Online] ACM Digital Library: Accession no. n.a. (Accessed 16th July, 2004).

Johnson, R.T. & Johnson, D.W. (1986) Action Research: Cooperative Learning in the Science Classroom, *Science and Children,* 24, 31-32.

Kagan, S. (1992) *Cooperative Learning*, Kagan Cooperative Learning, San Juan Capistrano, CA.

Kagan, S (1996) Group Grades Miss the Mark, in *Resources in Cooperative Learning,* H Rimmerman, Ed. , Kagan Cooperative Learning, San Juan Capistrana, CA.

Kearsley, G. (1994) *Information Processing Theory (G. Miller)* [Online] Available: http://tip.psychology.org/miller.html (Accessed: 27th September, 2004)

Kearsley, G. (1994) *Schema* [Online] Available: http://tip.psychology.org/schema.html (Accessed 27th September, 2004)

Kelsey, D. (2001) Most U.S. Workers Comfy With Technology – Study, *Newsbites*, July 5, 2001. [Online] Available: http://www.findarticles.com/p/articles/mi_m0NEW/is_2001_July_5/ai_76330087. (Accessed: 5th September, 2004)

Kirschner, P. (2002), Cognitive load theory: implications of cognitive load theory on the design of learning, *Learning and Instructions, 12* pp 1-10.

Knezek, G., Miyashita, K.T. & Sakamoto, T. (1993), *The Young Children's Computer Inventory*, [Online]. Available: http://www.tcet.unt.edu/research/survey/yccidesc.htm. (Accessed 15th August, 2004).

Kotovsky, K., Hayes, J.R. & Simon, H.A. (1985) Why are some problems hard? Evidence from Tower of Hanoi, *Cognitive Psychology,* 17, 248-294.

Krant, R.E. & Streeter, L.A. (1995) Coordination in Software Development, *Communications of the ACM*, March 1995, Vol 38/3. 69-81.

Kreitzberg, C.B (2003) *Ending the Software Struggle*, [Online] http://www.cognetics.com/papers/charlie/charlie9.html (Accessed 8th August, 2004)

LG, (2004) *Digital Multimedia Side-by-side Fridge Freezer with LCD Display*. [Online] Available: http://www.lginternetfamily.co.uk/fridge.asp (Accessed: 18th November, 2004)

Lockheed, M. & Hall, K. (1976) Conceptualising sex as a status characteristic: Applications to leadership training strategies. *Journal of Social Issues*, 32/3, 11-124.

Lui, K.M. & Chan, K.C.C. (2003). When Does a Pair Outperform Two Individuals?, *Proceedings of XP 2003 (Springer LNCS 2675)*, 225 – 233.

MacDonald, G.J. (2004) Contrarian Finding: Computers are a drag, *CS Monitor*, Dec 2004 [Online] Available: http://www.csmonitor.com/2004/1206/p11s01-legn.htm (Accessed 7th December, 2004).

Martin, R.C. (2003), *Agile Software development – Principles, Patterns and Practices,* Prentice-Hall: New York.

Marsh, R.L., Sebrechts, M.M., Hicks, J.L. & Landau, J.D. (1997) Processing strategies and secondary memory in very rapid forgetting. *Memory & Cognition*, 25, pp 173-181.

McClellan, P. (undated), *Multimedia Handyman – Towers of Hanoi Game*, [Online] Available: http://www.director-online.com/buildArticle.php?id=810. (Accessed 3rd June, 2004).

Microsoft Research (2003) *Social Computing Group* [Online] Available: http://research.microsoft.com/scg/ (Accessed 14th May 2004)

Miller, G.A. (1956) The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information, in *The Psychological Review*, 63. pp 81-97; also [Online] Available: http://www.well.com/user/smalin/miller.html (Accessed 8th September, 2004)

MIT News Office (2001) *MIT team reports tips for successful virtual collaborations*, [Online] Available: http://web.mit.edu/newsoffice/2001/vcollaboration.html (Accessed 15th September, 2004)

Moran, T.P., Chiu, P., van Melle, W. & Kurtenbach, G. (1995) Implicit Structures for Pen-based Systems Within a Freeform Interaction Paradigm, *Proceedings of CHI'95 Conference on Human Factors in Computer Systems*, 487-494.

Moran, T. (2000) *Shared Environments to Support Face-to-Face Collaboration*. Proceedings of CSCW-2000. [Online] Available: http://pages.cpsc.ucalgary.ca/~sdscott/cscw/cscw2000/cscw_moran.pdf (Accessed: 22nd June 2004).

Myers, B. (2002) *Pebbles Software* [Online] Available: http://www.pebbles.hcii.cmu.edu/software/index.php (Accessed: 22nd July, 2002)

Myers, B.A., McDaniel, R.G., Miller, R.C., Ferrency, A.S., Faulring, A., Kyle, B.D., Mickish, A., Klimovitski, A. & Doane, P. (1997). The Amulet Environment: New Models for Effective User Interface Software Development. *IEEE Transactions on Software Engineering*, 23/6 pp. 347-365.

Neilson, R. (1997) *Collaborative Technologies and Organisational Learning*, Idea Group Publishing, London UK.

Nice, K (undated) *How Car Computers Work* [Online] Available: http://electronics.howstuffworks.com/car-computer.htm (Accessed: 10th November, 2004)

Nosek, J.T. (1998), The Case for Collaborative Programming, *Communications of the ACM*, Vol 41/3.

NSW Board of Studies (1991), *Design and Technology Years 7-10 Support Document*, NSW Board of Studies, Sydney, Australia.

NSW Board of Studies (1991), *Year 7-10 Design and Technology Syllabus*, NSW Board of Studies, Sydney, Australia.

NSW Department of Education and Training (2002), *NSW Public Schools: Strategic Directions 2002-2004*, [Online]. Available: http://www.det.nsw.edu.au/aboutus/strategy2002_2004.htm. (Accessed 9th June 2004).

NSW Department of Education and Training (2002), *NSW Department of Education and Training Annual Report 2002.* [Online] Available: http://www.det.nsw.edu.au/media/downloads/reports_stats/annual_reports/year02/chapter1.pdf (Accessed 9th May 2004).

ObjectMentor Inc. (2002) *Pair Programming.com* [online] Available: http://www.pairprogramming.com (Accessed 12th May 2004).

Olson, G.M. & Olson, J.S. (2000) Distance Matters. *Human-Computer Interaction*15(2/3) pp 139- 178.

Peterson, L.R. & Peterson, M.J. (1959) Short-term retention of individual verbal items. *Journal of Experimental Psychology,* 58, pp. 193 – 198.

Piaget, J. (1970) *The Science of Education and the Psychology of the Child*. Grossman: New York.

Polsson, K. (2004) *Chronology of Personal Computers*, [Online] Available: http://www.islandnet.com/~kpolsson/comphist/ (Accessed: 16th October, 2004.)

Regan, T., Lofstrom, M. & Davis, J. (2002). *Impacts of Enhanced UI Feedback on Shoulder to Shoulder Computing*, Technical Report, Microsoft Research, Redmond, WA.

Ridgway, J. (1988), *Of Course ICAI is Impossible.., Worse, Though, it might be Seditious,* in J. Self (Ed) Artificial Intelligence and Human Learning: Intelligent Computer-Aided Instruction, Chapman and Hall, London.

Rimmerman, H. (1996) An Introduction to Cooperative Learning, *Resources in Cooperative Learning*, H. Rimmerman (Ed.), Kagan Cooperative Learning, San Juan Capistrano, CA.

Robbins, S.P., Waters-Marsh, T., Cacioppe, R. & Millet, B (1994) *Organisations Behaviour – Concepts, Controversies and Application – Australia and New Zealand*, Prentice-Hall, Sydney.

Rosenzweig, G. (undated), *Lingo Lounge – Text Files and the FileIO Xtra"* Director Online User Group. [Online]. Available: http://www.director-online.com/buildArticle.php?id=896. (Accessed 23rd August 2004).

Rouse-Ball, W.W & Coxeter, H.S.M (undated), *The Tower of Hanoi Story,* [Online]. Available: http://www.rci.rutgers.edu/~cfs/305_html/ProblemSolving_Planning/TOHstory.html. (Accessed 16th July, 2004).

Samuelson, R.J. (2002) Debunking the Digital Divide, *Newsweek,* March 5, p 37.

Scott, S.D., Mandryk, R.L. & Inkpen, K.M. (2002) Understanding Children's Interactions in Synchronous Shared Environments. In *Proceedings of Computer Supported Collaborative Learning (CSCL '02)* pp. 342-351.

Scott, S.D., Mandryk, R.L. & Inkpen, K.M. (2003) Understanding Children's Collaborative Interactions in Shared Environments, *Journal of Computer Assisted Learning* Vol 19/2, 220-228. [Online] Available: http://www.edgelab.ca/publications/JCAL.pdf (Accessed: 10th October, 2004).

Sharp, A (1997), *Object Oriented Thinking* [Online] Available: http://www.iam.unibe.ch/~ducasse/FreeBooks/ByExample/11%20-%20Chapter%209%20-%20Object-Oriente.pdf (Accessed: 22nd July, 2004)

Sheingold, K., Hawkins, J. & Char, C. (1990), *I'm the thinkist, you're the typist: the Interaction of technology and the Social Life of Classrooms,* in O. Boyd-Barrett & E. Scanlon (Eds.) 1990, Computers and Learning, Addison-Wesley, Workingham, England.

Slavin, R.E. (1995) *Cooperative Learning – Theory, Research and Practice,* Allyn and Bacon, Needham Heights, MA.

Soden, R. & Pithers, R.T. (2001) Knowledge Matters in Vocational Problem-Solving: a cognitive view, *Journal of Vocational Education and Training,* 53/2. pp 205 – 222. Also available online: Available: http://archives.math.utk.edu/ICTCM/EP-12/C30/pdf/paper.pdf (Accessed: 12th October, 2004).

Solomon, H. (2002) *Cognitive Load Theory (J. Sweller)* [Online] Available: http://tip.psychology.org/sweller.html (Accessed 27th October, 2004)

Stewart, J., Raybourn, E.M., Bederson, B. & Druin, A. (1998) *When Two Hands are Better Than One: Enhancing Collaboration Using Single Display Groupware* presented to Conference on Human Factors in Computing Systems, LA, CA, USA. [Online] Available: http://www.cs.umd.edu/hcil/pad++/papers/chi-98-sdg/chi-98-sdg.pdf. (Accessed 20th July, 2004).

Sweller, J. (1988) Cognitive Load during problem solving: effects on learning, *Cognitive Science,* 12. pp 2457-285.

Sweller, J. (1999) Instructional design in technical areas. *Australian Education Review, 43.* ACER Press.

Tabbers, H., Martens, R & Van Merrienboer, J. (2000), *Multimedia Instructions and Cognitive Load Theory: Split-attention and modality effects.* Presented at the National Convention of the Association for Educational Communications and Technology, Long Beach, CA. [Online] Available: http://www.ou.nl/otecresearch/publications/Huib/AECT2000%20Huib%20 Tabbers.pdf (Accessed: 10th June, 2004).

Talbott, N. (2003) *Conversant Pairing* [Online] Available: http://www.pairprogramming.com/conversantpairing.htm (Accessed 14th July 2004).

Tindall-Ford, S., Chandler, P. & Sweller, J. (1988) When two sensory modes are better than one. *Journal of Experimental Psychology: Applied, 3,* pp 257-287.

Tiscali Reference (2000) *Mobile Phone* [Online] Available: http://www.tiscali.co.uk/reference/dictionaries/computers/data/m0050806.html (Accessed: 8th December, 2004)

Tuovinen, J.E. (1995) *Cognitive Load and Discovery Learning* [Online] Available: http://www.aare.edu.au/97pap/tuovj113.htm (Accessed: 15th June, 2004).

Van Vliet, H. (2000), *Software Engineering – Principles and Practice,* John Wiley & Sons, West Sussex, England.

Vygotsky, L.S. (1978). *Mind and society: The development of higher mental processes*. Harvard University Press: Cambridge, MA.

Wachowski, A. & Wachowski, L. (1999), *The Matrix,* film. Directed by A. & L. Wachowski.

Wittrock, M.C. (1978). The Cognitive Movement in Psychology, *Educational Psychologist,* 13, pp 15-29.

Wikipedia (c. 2001) *Pair Programming* [Online] Available: http://en.wikipedia.org/wiki/Pair_programming (Accessed 5th May, 2004).

Williams, L. (1999) *But, Isn't That Cheating?* Paper presented at 29th ASEE/IEEE Frontiers in Education Conference. [Online] Available: http://fie.engrng.pitt.edu/fie99/papers/1711.pdf (Accessed: 15th August, 2004).

Williams, L., Kessler, R.R., Cunningham, W. & Jeffries, R. (2000), Strengthening the Case for Pair Programming, *IEE Software* July-August 2000.

Williams, L.A. & Kessler, R.R (2000), *The effects of 'Pair Pressure' and 'Pair Learning' on Software Engineering Education*, [Online] Available: http://www.pairprogramming.com/cseet.pdf (Accessed 12th May, 2004).

Williams, L.A. & Kessler, R.R. (2000), Experimenting with Industry's "Pair-Programming" Model in the Computer Science Classroom, *Journal on Software Engineering Education*, Dec. 2000.

Williams, L. (2000) *The Collaborative Software Process*, PhD Dissertation, Department of Computer Science, University of Utah, USA.

Williams, L.A & Kessler, R.R. (2002) All I Really Wanted to Know About Pair Programming I Learned In Kindergarten, *Communication of the ACM* Vol 43/5. 108-114.

Williams, R. (1995). Self-Directed Work Team: A Competitive Advantage, in *QC Miner Quality Digest,* November 1995. [Online] Available: http://www.qualitydigest.com/nov95/html/self-dir.html (Accessed: 7th August, 2004).

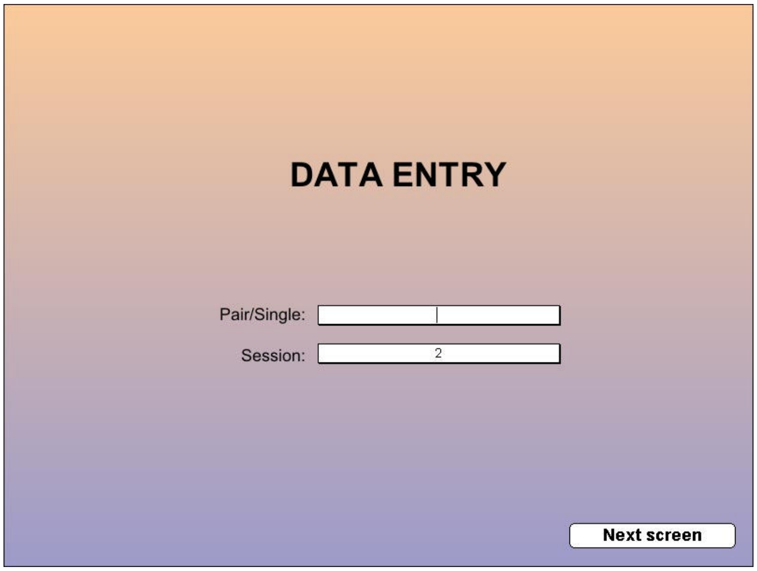
Zari, M. (c. 2004), *Virtual Pair Programming Survey* [Online]. Available: http://www.createsurvey.com/pollfrm?s=3141&magic=w6ZUVHCBg7kTg2h (Accessed 14th August, 2004).

APPENDIX A

"TOWERS" AND "MONSTER MOVE" APPLICATION SCREENSHOTS

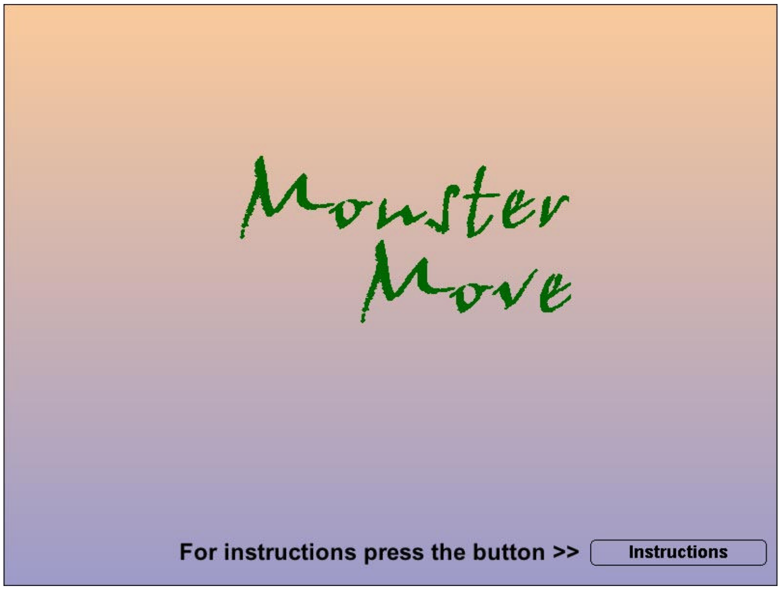
A1	Data entry (both puzzles)
A2	Title screen – Towers of Hanoi
A3	Title screen – Monster Move
A4	Instructions – Towers of Hanoi
A5	Instructions – Monster Move
A6	Game play – Towers of Hanoi
A7	Game play – Monster Move
A8	In context help – Towers of Hanoi
A9	In context help – Monster Move
A10	Game complete – Towers of Hanoi
A11	Game complete – Monster Move

A1 Data Entry (Both puzzles)

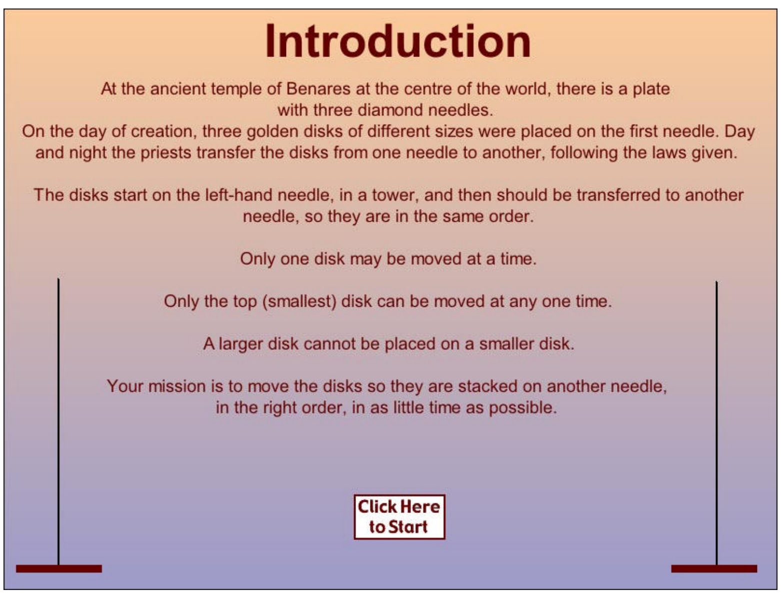


A2 Title Screen – Towers of Hanoi

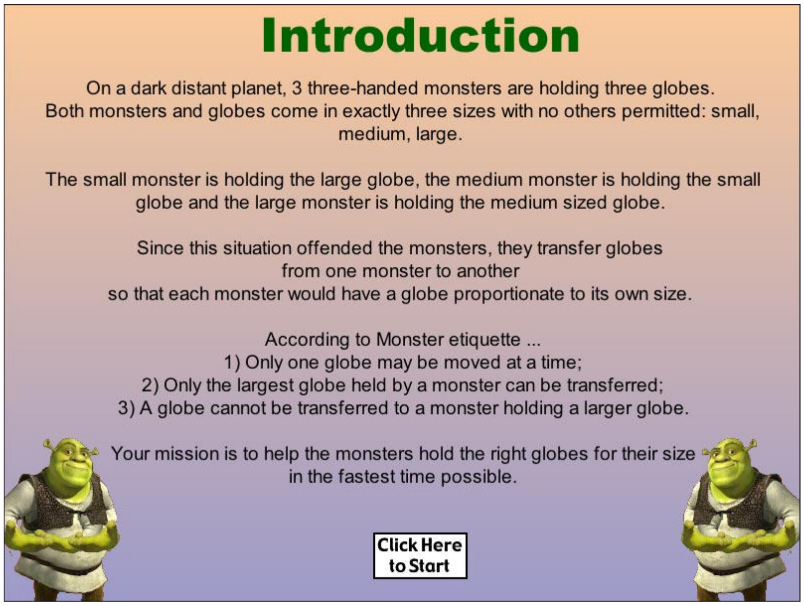
A3 Title Screen – Monster Move



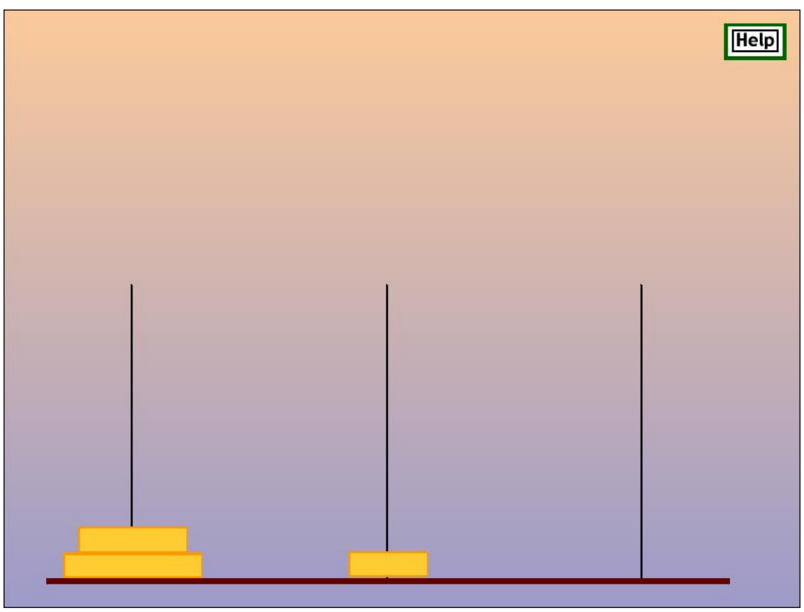
A4 Instructions – Towers of Hanoi



A5 Instructions – Monster Move



A6 Game Play – Towers of Hanoi

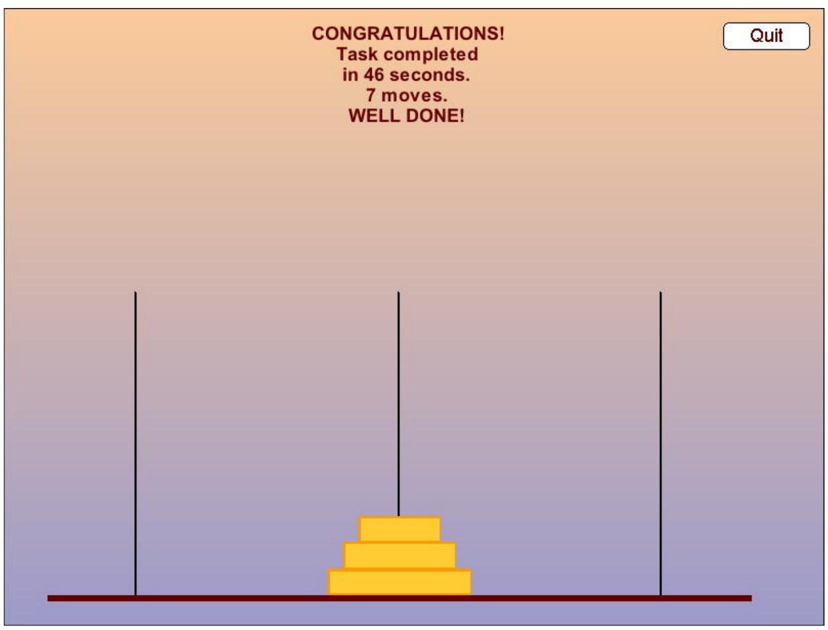


A7 Game Play – Monster Move

A8 In context help – Towers of Hanoi

A9 In context help – Monster Move

A10 Game complete – Towers of Hanoi



A11 Game complete – Monster Move

APPENDIX B

STUDY QUESTIONNAIRES

B1	Original design of questionnaire
B2	Revised questionnaire Part A
B3	Revised questionnaire Part B
B4	Final questionnaire Part A
B5	Final questionnaire Part B

B1 Original Design of Questionnaire

Questionnaire

The following questions are about the activity you just completed on the computer, as well as your experience with computers. Please circle the answer that shows how you feel about the statement made.

1. In the activity I worked with a partner: yes / no

2. I enjoy doing jobs which use a computer.

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

3. I enjoy lessons on the computer.

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

4. I concentrate on a computer when I use one.

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

5. I enjoyed the task

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

6. I enjoy working with a partner on tasks on the computer

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

7. I find it frustrating to work with someone else on a computer.

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

8. The work is easier when working with a partner on a computer

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

9. I wish I could work with a partner more often.

   Disagree — Slightly disagree — Neither agree nor disagree — Slightly agree — Agree

What did you like most about working/not working with a partner?

Thank you for your participation in this study.

B2 Revised Questionnaire Part A

Questionnaire 1

The following questions are about the activity you just completed on the computer, as well as your experience with computers. Please circle the answer that shows how you feel about the statement made.

1. I enjoy doing jobs which use a computer.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

2. I enjoy lessons on a computer.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

3. I concentrate on a computer when I use one.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

4. I enjoyed the task

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

5. I enjoy working with a partner on tasks on the computer.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

6. I find it frustrating to work with someone else on a computer.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

7. The work is easier when working with a partner on a computer.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

8. I wish I could work with a partner more often.

Disagree | Slightly disagree | Neither agree nor disgree | Slightly agree | Agree

B3 Revised Questionnaire Part B

Questionnaire 2

The following questions are about the activity you just completed on the computer, as well as your experience with computers. Please circle the answer that shows how you feel about the statement made.

1. I enjoyed the task.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

2. I enjoy working with a partner on tasks on the computer.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

3. I find it frustrating to work with someone else on a computer.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

4. The work is easier when working with a partner on a computer.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

5. I wish I could work with a partner more often.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

6. Which puzzle did you enjoy solving the most?

   ○ Towers of Hanoi ○ Monster Move

7. *(Only answer this question if you worked with a partner)*
   Which puzzle do you think was solved more easily because you worked with a partner?

   ○ Towers of Hanoi ○ Monster Move

8. What did you like most about working/not working with a partner?

____

____

____

____

____

B4 Final Questionnaire Part A

Questionnaire 1

The following questions are about the puzzle you just completed on the computer, as well as your experience with computers. Please circle the answer that shows how you feel about the statement made.

1. I enjoy doing jobs which use a computer.

○	○	○	○	○
Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

2. I enjoy lessons on a computer.

○	○	○	○	○
Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

3. I enjoyed the puzzle

○	○	○	○	○
Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

4. This puzzle is suitable for working with a partner.

○	○	○	○	○
Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree

B5 Final Questionnaire Part B

Questionnaire 2

The following questions are about the puzzles you just completed on the computer. Please circle the answer that shows how you feel about the statement made.

1. I enjoyed the puzzle.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree
○	○	○	○	○

2. This puzzle is suitable for working with a partner.

Disagree	Slightly disagree	Neither agree nor disgree	Slightly agree	Agree
○	○	○	○	○

3. Which puzzle did you easiest to solve?

○ Towers of Hanoi ○ Monster Move

4. In which puzzle do you think it would be most helpful to have a partner?

○ Towers of Hanoi ○ Monster Move

5. What did you like most about working/not working with a partner?

____

APPENDIX C

Informed Consent Forms

C1 Original consent form (High School)

C2 Revised consent form (Primary School)

C3 Added covernote (Primary School)

C1 Original Consent Form (High School)

Rainalee Mason
Honours student
Bachelor of Multimedia
Southern Cross University
rmason@scu.edu.au

INFORMED CONSENT FORM

Dear Parent or Guardian,

Year 7 students are invited to participate in a study conducted by Southern Cross University entitled *"When are two heads better than one? A study in the effectiveness of paired computing in tasks of differing difficulty"*. This study has been designed by Ms Rainalee Mason, as part of her Honours study in the Bachelor of Multimedia course, in consultation with Dr Graham Cooper, Lecturer, School of Multimedia and Information Technology at Southern Cross University.

Purpose of the Study:

Working in pairs on computing tasks is becoming an increasingly accepted practice. This study will investigate aspects of paired computing which may be affected by task difficulty. The materials that will be used present two logic puzzles and have been approved for such use by the staff and Principal of your school, and by the School of Multimedia and Information Technology at Southern Cross University.

Procedures to be Followed:

A sample of students from Year 7 is being offered the opportunity to participate in this study. Students who participate will be divided into four groups on a random basis. All groups will be presented one of two multimedia puzzles to solve. The groups will differ in the complexity of the puzzle, and whether they are required to work in pairs or individually.

Each student will attend a single session of approximately one period (45 minutes) duration. No data specific to your child will be held. The study relates to method of computer use, and not to individual student performance. Students will, however, be video taped to enable analysis of students' activities and interactions. Sessions will be conducted in the school during the period from 18th Oct to 12th November. Your child will not require any special equipment or preparation for the study.

Possible Discomforts and Risks

Your child will miss up to 45 minutes classroom time. Apart from this, there are no discomforts or risks to your child. Your child will be supervised at all times. The content of the multimedia resources have been fully approved by the staff and Principal of your school and by the School of Multimedia and Information Technology of Southern Cross University.

Your child is not being assessed in any way. The purpose of the study is to determine how increase in efficiency due to paired computing is affected by task difficulty.

Responsibilities of the Researcher

Upon analysing the data collected in this study, Dr Cooper and Ms Mason will be available to present the findings of the study to students, staff, parents, and community members with the intention of increasing knowledge about when to use paired computing practices.

All video tapes and transcripts will be kept for 5 years in secure storage at the University, and then destroyed.

Responsibilities of the Subject

Your child does not require any special equipment or preparation for the study.

Freedom of Consent

If you decide to allow your child to participate, you are free to withdraw your consent and to discontinue his/her participation at any time. However, we would appreciate your letting us know your decision by informing the Principal of the school where possible. Your child maintains the right to discontinue their participation at any time.

Inquiries

We encourage any questions you may have. If you have any questions at any time please feel free to ask us.

Dr Graham Cooper can be contacted during business hours by phone at Southern Cross University on 6659 3327 or by email gcooper@scu.edu.au

Ms Raina Mason can be contacted by email rmason@scu.edu.au

Any complaints or queries regarding this project that cannot be answered by the person responsible for this research project should be forwarded to:

Mr John Russell, Ethics Complaints Officer,

Graduate Research College, Southern Cross University, PO Box 157, Lismore, 2480

Ph: (02) 6620 3705 Fax: (02) 6626 9145 Email: jrussell@scu.edu.au

………

Please keep this consent form for your records after detaching the following permission note. The permission note should be signed by both parent and child and returned to the Principal of the school by Friday 15th October. The Principal will hold all replies in confidence and will allow only students with consent forms to participate in the study.

Signed: ……………………………………………… ………………………………………………

Ms Rainalee Mason Dr Graham Cooper

………………………………………………

Principal

✂ ____

I have read the information above and have consulted with my child/children, who wishes to participate and hereby consent to my child/children ……………………………………………… participating in the study conducted by Southern Cross University entitled *When are two heads better than one? A study in the effectiveness of paired computing in tasks of differing difficulty* as outlined above. I understand that the study will be conducted at the school and no travel is involved.

Signed: ……………………………………………… Date:………………

(Parent or guardian)

Signed: ……………………………………………… Date: ………………

(Child)

Child to complete: *(circle the best answer)*

I use a computer : never / 1-2 times a week / 3-4 times a week / more than 4 times a week

C2 Revised Consent Form (Primary School)

Rainalee Mason
Honours student
Bachelor of Multimedia
Southern Cross University
rmason@scu.edu.au

INFORMED CONSENT FORM

Dear Parent or Guardian,

Year 6 students are invited to participate in a study conducted by Southern Cross University entitled *"When are two heads better than one? A study in the effectiveness of paired computing in tasks of differing difficulty"*. This study has been designed by Ms Rainalee Mason, as part of her Honours study in the Bachelor of Multimedia course, in consultation with Dr Graham Cooper, Lecturer, School of Multimedia and Information Technology at Southern Cross University.

Purpose of the Study:

Working in pairs on computing tasks is becoming an increasingly accepted practice. This study will investigate aspects of paired computing which may be affected by task difficulty. The materials that will be used present two logic puzzles and have been approved for such use by the staff and Principal of your school, and by the School of Multimedia and Information Technology at Southern Cross University.

Procedures to be Followed:

A sample of students from Year 6 is being offered the opportunity to participate in this study. Students who participate will be divided into two groups on a random basis. Both groups will be presented two multimedia puzzles to solve. The groups will differ in whether the students work in pairs or individually.

Each student will attend a single session of up to 45 minutes duration. No data specific to your child will be held. The study relates to method of computer use, and not to individual student performance. Students will, however, be video taped to enable analysis of students' activities and interactions. Sessions will be conducted in the school during the period from 15th November to 19th November. Your child will not require any special equipment or preparation for the study.

Possible Discomforts and Risks

Your child will miss up to 45 minutes classroom time. Apart from this, there are no discomforts or risks to your child. Your child will be supervised at all times. The content of the multimedia resources have been fully approved by the staff and Principal of your school and by the School of Multimedia and Information Technology of Southern Cross University.

Your child is not being assessed in any way. The purpose of the study is to determine how increase in efficiency due to paired computing is affected by task difficulty.

Responsibilities of the Researcher

Upon analysing the data collected in this study, Dr Cooper and Ms Mason will be available to present the findings of the study to students, staff, parents, and community members with the intention of increasing knowledge about when to use paired computing practices.

All video tapes and transcripts will be kept for 5 years in secure storage at the University, and then destroyed.

Responsibilities of the Subject

Your child does not require any special equipment or preparation for the study.

Freedom of Consent

If you decide to allow your child to participate, you are free to withdraw your consent and to discontinue his/her participation at any time. However, we would appreciate your letting us know your decision by informing the Principal of the school where possible. Your child maintains the right to discontinue their participation at any time.

Inquiries

We encourage any questions you may have. If you have any questions at any time please feel free to ask us.
Dr Graham Cooper can be contacted during business hours by phone at Southern Cross University on 6659 3327 or by email gcooper@scu.edu.au
Ms Raina Mason can be contacted by email rmason@scu.edu.au
Any complaints or queries regarding this project that cannot be answered by the person responsible for this research project should be forwarded to:
Mr John Russell, Ethics Complaints Officer,
Graduate Research College, Southern Cross University, PO Box 157, Lismore, 2480
Ph: (02) 6620 3705 Fax: (02) 6626 9145 Email: jrussell@scu.edu.au

....

Please keep this consent form for your records after detaching the following permission note. The permission note should be signed by both parent and child and returned to the school by Friday 12th November. The Principal will hold all replies in confidence and will allow only students with consent forms to participate in the study.

Signed: ....

Ms Rainalee Mason Dr Graham Cooper

....

Principal

I have read the information above and have consulted with my child/children, who wishes to participate and hereby consent to my child/children ....(please print) participating in the study conducted by Southern Cross University entitled *When are two heads better than one? A study in the effectiveness of paired computing in tasks of differing difficulty* as outlined above. I understand that the study will be conducted at the school and no travel is involved.

Signed: .... Date:..................

(Parent or guardian)

Signed: .... Date: ....

(Child)

Child to complete: (circle the best answer)

I use a computer at home: never/ 1-2 times a week/ 3-4 times a week/ more than 4 times/week

C3 Added Covernote (Primary School)

Dear Parent/ Guardian,

Southern Cross University is conducting research into how students use computers, both singly and in pairs. As part of this research, I will be in the school during the week 15th to 19th November, studying how children interact with tasks on the computer. Students from Year 6 are being invited to participate in this study, which involves completing two multimedia puzzles on the computer and answering two anonymous questionnaires.

The study has been fully approved by both Southern Cross University Ethics Committee and the NSW Dept of Education and Training. A pilot study has shown that the time involved for each student is around 20 – 30 minutes. Due to Government regulations, parents/ guardians and students are required to be fully informed as to all aspects of the study, so please take the time to read the attached sheets which provide these details, and return the completed permission slip as soon as possible.

Thank you for your time,

(Ms) Rainalee Mason

APPENDIX D

Researcher's Notes

Hello. My name is Miss Mason. I'm doing some research with the university, on how people work on a computer by themselves and also in pairs.
This afternoon I would like you to do a couple of puzzles on the computer, and also do a couple of questionnaires.

<u>Puzzle 1</u>
On the screen in front of you is a game called Towers of Hanoi. In a minute I want you to read the instructions and then do the puzzle as fast as you can.
<*Instructions to pairs*> You are allowed to talk to each other and help each other during the game
<*instruction to individuals*> You are allowed to think aloud if you like – in fact this might help you.
If you need help during the game there is a Help button you can click and get some help. Are you comfortable? <wait for response> Ok!
When you are ready, click on the instructions button down the bottom of the screen, and tell me when you are finished solving the puzzle.

<u>Questionnaire 1</u>
Could you please fill out this questionnaire for me. There are no right or wrong answers, its just your opinion on how you liked the game and working on a computer.

<*children were instructed to 'quit' the previous game, and then click on the 'Monsters' button at the bottom of the screen*>

<u>Puzzle 2</u>
The second puzzle is called "Monster Move".
When you are ready, click on the "instructions" button. Tell me when you finish solving the puzzle.

<u>Questionnaire 2.</u>
This is the second questionnaire – fill it out as best you can.

<*Children were asked if they have seen the puzzles before*>
Thank you for helping me with this study.

APPENDIX E

Example Transcript of Pair Dialogue:

Legend:		
	Tower	Towers of Hanoi Puzzle
	Monster	Monster Move Puzzle
	R	Student on right of display and keyboard
	L	Student on left of display and keyboard
	(P)	Pointing gesture (to screen)
	(…)	Actions/ emphasis made by student

Tower:

(R operating mouse)

R:	(reads instructions out loud)
R:	(P) while reading instructions
R:	(hand up to face)
L:	".. then put that one over there"
R:	"over there?"
R:	"Ok, we're done"

Monster:

R:	(reads instructions aloud, 3 times)
L:	(P)
R&L:	(hands to face, leaning towards computer)
L:	(P)
L:	"Oh, that's why it didn't work"
R:	"But he's not holding a larger ball"
L:	"Oh"
R:	"Oh, now I get it, that goes to that"
R:	"Whoa, wha..?"
R:	"Yeah, that doesn't work out"
R:	"Oh"
L:	(P) "It's ok" (P) "Put this one there"
L:	"Yeah that one"
R:	"Oh" (quick excited)
R:	"Oh (slower)"
R:	"I seriously don't know where that one goes"
L:	"Ok, does that one go on that one"
R:	"Nuh"
L:	(Rubbing head) (P) "Hang on, does that one go on that one?"
R:	"Ooooh, oh"
R:	(P) Hang on, can that one go there?"
L:	(Shakes head)

R: “Oh, cause you can only transfer…”
L: “Lets go back to the (P)….”
R: (through fingers) “This is hard”
R: (reads instructions aloud) “oh, ok” (Laughs)
R: “So, its like, you can put that there and you can put that there!” (P)
R: “No you can’t” (sigh)
R: “Oh then” (P)
R: “Oh but only the largest can be held so…”
L: “Isn’t the largest one there so the smallest goes there” (leaning towards the screen) (P)
R: “Nah”
R: “You got to transfer it back to the whole thing – the other one” (slouches and sighs)
R: (said to herself) “Only one globe may be transferred at a time”
L: “the small one…?”
R: (reads part of instructions again)
L: (murmurs to herself) “Man, this is hard”
R: “Oh No”
R&L: (Slouched towards screen leaning on elbows)
R: “No” (smiles)
R: “Oh, Yeah!”
L&R: (look at each other smiling)
R: “Yeah we are finished” (to researcher)