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Mathematical skill acquisition: Transfer effects of a computer game based on the components theory of skill acquisition

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Mathematical Skill Acquisition: Transfer Effects of a Computer Game based on the
Components Theory of Skill Acquisition

Jenny Kessell

A report submitted in Partial Fulfilment of the Requirements for the Award of Bachelor
of Arts (Psychology) Honours, Faculty of Computing, Health and Science,

Edith Cowan University

Submitted October, 2008

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Transfer in Mathematical Skill Acquisition

Jenny Kessell

Abstract

Research within the field of mathematical learning has often focused on the extent to which knowledge of particular mathematical skills can facilitate the learning of new and unpracticed mathematical skills. Additionally, it has examined the influence of context on learning and the amount of practice necessary for complex skill acquisition to result. This paper provides a review of the research examining mathematical learning, skill acquisition and transfer of skills in a mathematical context. Pertinent theories in the field of cognitive skill acquisition are examined for their ability to explain transfer of skill. The review focuses on factors that influence the acquisition and transfer of skills, including: the impact of task difficulty on learning; the influence of context on skill retention and transfer; and the effect that understanding the underlying concepts of simple tasks has on the learning of complex tasks. The research evidence suggests that transfer of mathematical skill can occur if given the correct conditions. Learning contexts should be sufficiently difficult to result in enhanced learning, and comprehension of underlying strategies necessary for skilled performance of a task will facilitate performance on simpler tasks. The paper concludes that transfer is dependent on the skill that is learned and the manner it is learned in, and further research is needed to investigate how mathematical learning and skill transfer can be enhanced.

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Transfer in Mathematical Skill Acquisition

The influence of learning is pervasive and affects almost every aspect of human life (Ellis, 1965; Speelman & Kirsner, 2005). Through learning and practice, we acquire and develop new and existing skills, become faster and more efficient at executing these skills, and are able to transfer knowledge about skills learned in particular contexts to novel situations and new tasks (e.g., Ellis, 1965; Haskell, 2001; Speelman & Kirsner, 2005). In fact, learning occurs when we engage in any behaviour that is not innate (Speelman & Kirsner, 2005). Mathematical knowledge is one such skill that is often learned early in life and is important for students to succeed within school education (National Council of Teachers of Mathematics, 2000). Acquiring a sound understanding of mathematics involves understanding the numeric, symbolic, graphical and verbal representations, their associated uses and their connection with each other (Freitag, 1997). Through practice, mathematical knowledge advances and a more complex understanding develops. This may further help facilitate understanding of different and unknown mathematical problems. The reasons for this, as explained by empirical evidence and theoretical concepts in the field of skill acquisition and transfer, are examined in detail throughout this paper. The extent to which knowledge of particular mathematical skills can facilitate the learning of new and unpracticed mathematical skills constitutes the purpose and aim of this review.

The importance of skill transfer

The concept of transfer of learning – the ability to perform successfully in novel conditions - is crucial to all forms of learning (Anderson, 1982; Haskell, 2001). Transfer additionally reduces our world to manageable proportions and gives it familiarity. If

transfer did not occur, everything that was ever experienced would be as if it was being experienced for the first time, every time. Virtually all learning involves retrieving previously learned information and applying it to new situations (Haskell, 2001). We constantly transfer our previously learned skills and behaviours in order to engage in tasks more quickly and efficiently. Transfer is also pervasive - it is found in both intellectual tasks as well as motor tasks (e.g., Arnett, DeLuccia & Gilmartin, 2000; Doane, Sohn & Schreiber, 1999; Phye, 1989; Spelman & Kirsner, 1997). Thus, "transfer of learning... is crucial to all learning from the lowest level of skill to the highest reaches of theoretical thinking" (Haskell, 2001, p.25).

Theories of skill acquisition and transfer

Many theories of skill acquisition have been proposed, each sharing the common idea that practice leads to improved performance and that information learned in one task can be transferred to a new task if certain criteria are met. Generally, they also suggest that a representation of an event (either cognitive, behavioural or environmental) is stored in memory and it is this information that can be retrieved to facilitate performance (e.g., Anderson, 1983; Crossman, 1959; Laird, Newell & Rosenbloom, 1987; Logan, 1988; 1990; Newell, 1990; Rosenbloom, Newell & Laird, 1991; Singley & Anderson, 1989; Spelman & Kirsner, 2005). As a person gains repeated exposure to an event, the memory representation can be retrieved more easily than events with less exposure, and the person begins to develop knowledge representations specifically for how to respond in certain situations (Spelman & Kirsner, 2005). For example, a person learning to add two numbers for the first time will be slower than someone who learnt to add numbers many years ago. The novice may first use counting techniques until they arrive at the

correct solution (e.g., for $2 + 5 = ?$ they may start at 2 and add 1 five times until they arrive at 7) (e.g., Fuchs, Fuchs, Hamlet, Powell, Capizzi & Seethaler, 2006). However after repeated practice, knowledge will have been stored in memory that $2 + 5 = 7$, and they can answer 7 immediately upon seeing $2 + 5 = ?$ because they *remember* the answer – it has been quickly retrieved from memory (e.g., Rickard, Healy & Bourne, 1994). This memory of past events, experiences and acquired skills provides a knowledge base that is enhanced as skills are repeated and practiced. Thus, over time, and experience, this knowledge base expands, skills are improved and performance is enhanced.

Theories of skill acquisition differ in how they consider information to be represented and retrieved from memory and how this impacts performance. There are two major distinctions between such theories: there are those that conceive performance improvement to occur because practice refines the procedures necessary to perform a task; and those that suggest performance occurs because practice strengthens the representations of events in memory making them quicker and more efficient to retrieve. The major theories of skill acquisition include the ACT theory (Anderson 1982, 1983, 1987, 1993; Anderson, Libiere & Lovett, 1998; Singley & Anderson, 1989) and the Instance theory (Logan, 1988, 1990). Additionally, these theories (and others) also account for how knowledge learned in one situation can affect performance in a different situation where exposure has not occurred. It is commonly observed that individuals improve in their ability to learn new tasks when they have been exposed to similar or related tasks (Ellis, 1965). Skill transfer is examined throughout this paper with reference to how it can enhance mathematical learning. It is introduced below with respect to the

different theories of skill acquisition and is expanded on with support of cognitive and mathematical-themed research.

Anderson's ACT theory

Anderson (1982, 1983, 1987, 1993) and Singley and Anderson (1989) created and modified the ACT theory to explain and account for skill acquisition and transfer. Basic to the ACT theory is the concept that an individual receives instructions or information about a skill that becomes encoded in memory as a set of facts about the skill (e.g., a red traffic light is a signal to stop). This is referred to as declarative knowledge. Through practice or repeated exposure, declarative knowledge is converted into procedural knowledge which is a representation of the action that applies in particular situations (e.g., at a red traffic light you stop). Together, production rules are formed that associate a situation with the performance of a specific action. Productions have conditions that specify when certain actions can take place. If the condition of a production rule is satisfied, the production can apply and the action is followed (e.g., IF the traffic light is red, THEN stop).

Each production has a level of strength in working memory that is representative of the frequency with which that production has been successfully applied. The more times a production has been successfully executed, the more it is refined, the stronger it becomes and the faster it can be applied. This continues to occur until the application of productions is automatic and does not require conscious thought or deliberation. Additionally, if many small productions must be executed for a skill to be performed, with repeated practice these productions can be collapsed into fewer, but larger, productions. Thus, frequently practiced skills become quicker and easier at each of their

applications until after extended practice they become automatic and may reach asymptote – a stage where improvement can no longer occur and performance is at its best. Unfortunately, the ACT theory does not specify how much practice is necessary until productions reach automaticity or asymptote (Muller, 1999). This is a limitation of the theory.

In relation to mathematical learning, the ACT theory would suggest that mathematics is learned by forming production rules and creating shortcut strategies of these productions with practice. For example, the problem of $2 \times 5 = 10$ could be understood in terms of the following: The 'x' sign denotes multiplying the numbers within the problem to reach an answer; the two numbers are 2 and 5; adding five twice gives the same answer; 5 and 5 equals 10; therefore 2 multiplied by 5 equal 10. With practice, shortcut strategies can develop and the problem can be solved with the reduced production of: 'x' denotes multiplication, therefore 2 multiplied by 5 equals 10.

Anderson and Singley (1993) suggest that transfer reflects the extent that productions for one task can be applied to additional tasks. Thus, if a new task requires the same, or similar, production rules as were acquired for an old task, performance of the new task will be at least as good as performance as on the old task. If the new task only shares some productions with an old task, performance of the new task will be slower and possibly less accurate than performance on the old task. In relation to the above mathematics example, $3 \times 5 = 15$ would be solved quicker if knowledge had already formed that $2 \times 5 = 10$, than if the product had never been learned. This is because both problems share underlying productions (both the multiplication process and the number 5). Additionally, $8 \times 4 = 32$ would also be quicker to solve than if $2 \times 5 = 10$ and $3 \times 5 =$

15 had never been learned, however $8 \times 4 = 32$ would be solved more slowly than $3 \times 5 = 15$ because although underlying productions are still shared (i.e., the multiplication process), they are not shared to the extent the two latter problems were (i.e., there was no 5 in the problem).

Other production theories of skill acquisition and transfer

Additional production system theories of skill acquisition (e.g., SOAR) have similar explanations of transfer to that of the ACT theory. As a result they will not be expanded on here (for a comprehensive examination of such theories, see Laird, Newell & Rosenbloom, 1987; Newell, 1990; Rosenbloom, Newell & Laird, 1991).

Logan's Instance theory

The underlying concept in Logan's (1988, 1990) Instance theory of skill acquisition is that skilled performance relies on the execution of an algorithm or procedure in order to carry out a task (Touron, Hoyer & Cerella, 2001). Algorithms cannot be changed or enhanced, however each time a task or skill is successfully executed, a representation of this event and the appropriate response(s) is stored in memory as an 'instance'. For example, the problem of $2 \times 5 = 10$ would result in an instance being stored, that 2 multiplied by 5 equals 10. Repeated exposure to a task increases the number of mental representations that exist in memory, allowing for quicker retrieval of task solutions that have multiple mental representations. The process of skill acquisition has been likened to a race, with the algorithm and instances competing to be retrieved the quickest. Initially, the algorithm controls performance as there are few instances to call upon, but the more instances that are held in memory, the quicker they can be retrieved. Thus, improvement in performance occurs as a result of having a larger

number of episodic representations (instances) of past experiences or events to call upon. Automatic performance results only when the retrieval of instances occurs without the execution of the algorithm. A limitation of this theory is its inability to explain how algorithms are initially learned, and how understanding of a task can occur if it has never previously been experienced. According to Logan (1988, 1990), transfer is item specific and only occurs when tasks involve events that have previously been encountered. Therefore although $2 \times 5 = 10$ may be well known, it would not enhance performance on a problem presented as $5 \times 2 = ?$. Research has produced evidence to the contrary (e.g., Doane, Sohn & Schreiber, 1999), therefore the Instance theory has been revised to suggest that parts of instances may be retrieved from memory which can affect performance on tasks where parts of instances may apply, e.g. for the problem of $5 \times 2 = 10$ (Lassaline & Logan, 1993). This revision, however, has not been developed to the same extent as the original Instance theory and so deriving transfer predictions is not possible.

A comparison of the two theories

Speelman and Kirsner (1997) examined the accuracy of the two theories in a study that involved participants solving categorical syllogisms, such as “All of the artists are beekeepers. All of the beekeepers are chemists”, with a solution of “Therefore, all of the artists are chemists”. There were many different problems of this form, each with different elements, and presented with correct and incorrect solutions. Participants observed the premise on a computer screen, given the opportunity to study it for a short period of time, and were then asked to indicate if the presented solution was correct. Elements of presented syllogisms (e.g., artists) were repeated throughout the experiment

in combination with other elements that the participants had not seen. As a result, no syllogism was repeated within the experiment. Applying the Instance theory to this experiment would predict that as no instances are being stored (because the syllogisms were never repeated), syllogism performance should not improve with practice, and would repeatedly rely on an algorithm to solve each premise. Alternatively, the ACT theory suggests that participants will improve their performance on solving the syllogisms – both in speed and accuracy – because practice results in refinement and strengthening of the productions underlying task completion. Results indicated that participants were faster in the test conditions than they were in the practice conditions, despite new syllogism elements being presented. The Instance theory cannot account for an increase in performance speed with non-repeating items. Anderson's ACT theory suggests that if underlying productions can be transferred to new tasks, performance speed will increase with practice. Thus this experiment provides some evidence for the ACT theory being a more comprehensive theory of skill acquisition and transfer.

Rickard, Healy and Bourne (1994) presented evidence to the contrary within a mathematical context. Their experiment involved 12 participants from an introductory psychology course who engaged in forty blocks of multiplication and divisions problems for three practice trials and a test condition. Immediately following the last block of practice on the third day, participants engaged in a test and completed 8 blocks of 36 test questions. In the first 4 blocks, each of the 144 problems that made up the practice sets were presented once, and then presented a second time in the final four blocks. Results determined that when the presented problems in the test blocks were identical to problems presented in the practice blocks, accuracy was relatively good. When presented

problems did not match exactly previously practiced problems, accuracy suffered substantially. The Instance theory suggests that test problems that have exactly the same elements as practice problems will be solved quicker than problems performed by relying on the execution of an algorithm. This was the finding of the study, although it was not reported if performance on novel test problems returned to pre-practice levels (and thus if partial transfer did occur). Additionally, the sample size was small and thus only provides limited support for the Instance theory's ability to accurately explain transfer.

Speelman and Kirsner's (2005) Components Theory of Skill Acquisition and Transfer

Upon examining the ACT and Instance theories of skill acquisition and transfer, Speelman and Kirsner (2005) devised a theory that accounted for a number of acquisition and transfer phenomena that these theories, and others, could not provide (see text for a detailed examination). Speelman and Kirsner's (2005) Components theory suggests that skilled performance of tasks occurs over time by mastering lower level tasks until performance becomes automatic. The theory relies on the idea that there must be enough mental resources available in order to develop or enhance a particular set of skills. As a result, complex behaviours are learnt by mastering simple components of the behaviours first, and moving to more difficult components of the behaviours in a hierarchical pattern. Thus initially, learning new skills or behaviours takes up sufficient mental resources to render engaging in more difficult tasks unsuccessful. When simple components of tasks are mastered and become automatic, the mental resources are freed and thus an individual has the capacity to engage in more complex behaviours. In this sense, as one progresses up the hierarchy of task difficulty, learning does not become more difficult as they have sufficient mental resources free to engage in the task. Additionally, they are able to

transfer the 'old' components they have already mastered to facilitate learning 'new' components of the more complex tasks. Thus, the learning of unknown items is usually experienced in "a context where the rich panoply of pragmatic, thematic and semantic processes are in place" (Speelman & Kirsner, 2005, p.21). In this sense, the theory adopts Singley and Anderson's (1989) notion of skill transfer proposing that when two or more tasks share the same underlying mechanisms for task completion, increasing performance on, or mastering, one task will facilitate performance on the other task. Thus, as in ACT theory, understanding the mathematical problem of $2 \times 5 = 10$ will help facilitate understanding of more difficult problems such as $7 \times 6 = 42$, however $2 \times 5 = 10$ must be understood before such harder problems are attempted. Finally, the Components theory proposes that such principles underlie every form of learning and thus it can be considered a universal theory of cognition and learning. There is currently no evidence to disprove this assertion, and being a new theory, very little empirical evidence exists to support or test it. Research is needed to provide evidence for or against this theory.

Specificity vs. generalisation of transfer

Context is an important concept when examining the transfer of skills. If a test context is identical to the practice context, positive transfer should occur. Alternatively, if the two contexts are extremely different, performance will be significantly reduced (e.g., Arnett, Deluccia & Gilmartin, 2000; Krigolson, Van Gyn, Tremblay & Heath, 2006). This idea has merit in laboratory studies where environments can be manipulated and repeated in identical or almost-identical conditions, but in real life, nothing ever repeats itself in exactly the same way or in exactly the same context (Haskell, 2001). Additionally, defining how two tasks or contexts are 'similar' or 'equivalent' is also met

with difficulties. Krigolson et al. (2006) provided evidence for transfer specificity through a line walking experiment involving forty participants (Krigolson et al., 2006). Individuals practiced walking along a 12 metre linear path in an allocated sensory environment (no-vision, full-vision or visual imagery) and then were tested walking the same path in the no-vision condition. As predicted, those who practiced in the same context as the test condition (no-vision) performed significantly more accurately in the transfer task than either of the other two practice contexts which did not differ significantly from each other. This study provides support for the importance of context in skill transfer; the test task was physically the same as the practice tasks, however a change in sensory environment was enough to interfere with transfer. Research is needed on ways to facilitate skill transfer, and thus 'shortcut' learning, that focuses on how learned skills can be transferred to novel tasks within different contexts without interrupting performance. In particular, mathematical research is needed as skills are taught in many different contexts (e.g., numbers, words, or pictures; verbally, written or on computer) and in many different formats (e.g., diagrams, lines, rows, sentences etc). Mathematical skills could be enhanced significantly if problems could be understood and solved more quickly due to previously learned strategies, regardless of the context or format they are presented in.

Practice effects on transfer: Contextual Interference

Battig (1979) proposed that human memory was influenced by the combined level of task difficulty and the amount of interference from the learning context as well as individual differences in processing. Interference is created by competition from the simultaneous occurrence of additional stimuli or task aspects that require learning

(Schneider, Healy & Bourne, 2002). Battig proposed that difficult tasks learned in high interference conditions would result in initial degraded performance, but at least as good, if not enhanced, retention and transfer compared to easier tasks in non-interfering conditions. This is because items learned within high contextual interference (CI) typically require more processing and thus are learned slowly but thoroughly (Schneider et al., 2002). In high context or difficult tasks, components of whole tasks may be processed simultaneously in working memory in an attempt to learn the task, and these components may facilitate task completion on similar or novel tasks (van Merriënboer et al, 2006). In contrast, learning tasks with low contextual interference commits the components of these simple tasks to working memory, but these components cannot be easily generalised to unfamiliar novel task components. This effect suggests that by practising a series of tasks under circumstances that are more challenging and thus lead to depressed performance during training, the practiced skill can be applied successfully to a greater number of different tasks (Speelman & Kirsner, 2005). It is suggested that the more challenging training conditions lead to a greater understanding of the task, increasing the transferability of the skill. This is an important concept when designing research that aims to investigate learning and transfer of skills.

Contextual interference is often simulated in laboratory settings through the use of blocked and random practice schedules (e.g., Carlson & Yaure, 1990; de Croock & van Merriënboer, 2007; Dunham, Lemke & Moran, 1991; Li & Wright, 2000; Schneider et al, 2002; Shewokis, 1997). Research suggests that random practice schedules facilitate retention and transfer because item-general knowledge is acquired, in contrast to item-specific knowledge (van Merriënboer, Kester & Paas, 2006). A random practice schedule

is suggested to create high contextual interference because the order of presentation of tasks is unpredictable, whereas in a blocked practice schedule the same or similar tasks are presented together in a predictable pattern (low contextual interference) (Barreiros, Figueiredo & Godinho, 2007; Smith & Rudisill, 1993; van Merriënboer, de Croock & Jelsma, 1997). Contextual interference has been demonstrated consistently across many different task types, including computer simulated sporting activities (Shewokis, 1997), counting tasks (Healy, Wohldmann, Parker & Bourne, 2005), system principles and trouble shooting skills (de Croock & van Merriënboer, 2007), problem solving (Carlson & Yaure, 1990), and motor skills (Dunham et al, 1991; Russell & Newell, 2007). The CI effect has also been extended to suggest that any method used to increase difficulty during learning may lead to superior retention and transfer of the learned material, not just manipulation of practice schedules (Schneider et al, 2002; Speelman & Kirsner, 2005). In relation to designing research, the contextual interference effect may be a useful concept to consider, in order to result in better retention and understanding of the underlying concepts being practiced.

Skill transfer in mathematical problem solving

Skill transfer has attracted the attention of many mathematics educators on the basis that mathematics is taught across many different contexts through primary, secondary and tertiary education (Britton, New, Sharma & Yardley, 2005). Mathematics is useful in many different contexts, and much research tends to focus on the ability of children to use arithmetic in everyday life (e.g., Lave, 1988; Nunes, Schliemann & Carraher, 1993). Overall, research has shown that transfer rarely occurs and it has

additionally been suggested that teaching mathematics in a particular context restricts the learned skill to the context it is learned in (Britton, New, Roberts & Sharma, 2007).

Mathematical problem solving refers to the cognitive process of comprehending the relations and goals of a mathematical task that one does not already know how to solve (Jitendra, Haria, Griffin, Leh, Adams & Kaduvettoor, 2007). Research has suggested that comprehension of mathematics skills involves a deep conceptual understanding of connections between numbers and that efficient problem solving practice promotes general mathematical achievement outcomes (Hyde, 2007; Jitendra et al, 2007). Additionally, mathematical performance can be enhanced when learners are not taught specific problem-solving strategies, but are given the opportunity to discover the strategies on their own (Muthukrishna & Borkowski, 1995). This approach can lead to wider generalisation of knowledge and skills, enhancing the probability that transfer will occur. It is also suggested that this technique allows individuals to test different problem solving methods which have personal meaning (because they are self-directed), rather than use problem solving methods which are other-directed and thus impersonal (Boaler, 1993).

Muthukrishna and Borkowski (1995) examined the difference between guided and direct discovery in 106 American third grade mathematics students and concluded that the direct discovery learning contexts resulted in superior skill transfer to novel mathematical problems than did guided discovery. Transfer remained superior even at follow-up testing five weeks later. This is an important implication for future research in skill transfer targeting long term skill acquisition.

A study involving 49 first year university students at the University of Sydney was conducted in order to determine the extent to which students were able to transfer mathematical skills (Britton et al, 2007). High school and university mathematics subject scores were correlated with performance on a mathematical test instrument examining comprehension and graph reading skills, comparison between graphs, interpretation and calculations at a second-year university level. This ensured that it was unlikely the test questions had been previously experienced. Highly significant correlations were found between all university and test variables, suggesting that in understanding the underlying mathematical concepts, the participants were able to apply this knowledge to novel situations. Alongside the previous research on guided and directed discovery learning, this suggests that transfer will most likely occur in situations where underlying mathematical concepts can be discovered with minimal direction or instruction from others.

Research contrasting the effectiveness of learning environments on children's ability to transfer learned mathematical skill was investigated by Boaler (1993). The study was based on the assumption that the nature of an environment that a skill was learned in would determine whether the skill could be transferred to different contexts. The same mathematical content and process was assessed through three different tasks (abstract, fashion and woodwork) with the prediction that students would vary significantly in response to the three tasks. Six questions were given to 50 twelve or thirteen year old students across two schools. Results indicated that students demonstrated a more accurate understanding and application of mathematical concepts when they were supplied in abstract form (such as $\frac{3}{5}$) rather than when they were

presented in a meaningful context (such as three out of five dresses). Despite this, variation in students' performance and procedures for solving problems suggested that "the individual nature of a student's construction of meaning is also an important factor... [and] no context can be assumed to enhance or inhibit understanding for all students" (Boaler, 1993, p.369). It was recommended that the effect context can have upon student's choice of methods and mathematical understanding should always be considered, and that the context mathematics is taught in is capable of influencing students' perceptions, goals and subsequent choice of mathematical procedures.

Number combination skill (arithmetic skill) is essential for higher order performance and research has suggested that comprehending mathematical problems presented in pictorial form (e.g., squares or circles representing amounts) requires greater comprehension than problems presented in numerical form (e.g., $2 \times 3 = ?$) (Fuchs et al, 2006; Lowrie & Diezmann, 2007). Thus, solving mathematical problems written in pictorial form is a more complex task than solving mathematical problems written numerically, although both share similar comprehension strategies such as problem solving, visualisation, and making connections between numbers or amounts (Hyde, 2007). This suggests that the underlying comprehension strategies necessary for skilled performance in solving pictorially-presented mathematical problems should transfer positively to, and enhance performance of, mathematical problems presented in numerical form. Additionally, if arithmetic skill is necessary for higher order mathematical performance, mastering arithmetic skills should facilitate learning of multiplication problems. Further research is needed to support this conclusion.

Implications for further research

The findings of the aforementioned research on mathematical skill acquisition and skill transfer suggest that transfer of mathematical skill can occur if given the correct conditions. Ideally, mathematical learning should not occur under direct instruction, but allow individuals to discover the underlying concepts of the given problems. Learning contexts should be sufficiently difficult to create contextual interference, slowing initial performance but resulting in superior retention and transfer of knowledge. Additionally, through mastering complex tasks, the underlying comprehension strategies necessary for skilled performance of that task should result in positive transfer to, and enhanced performance of, simpler tasks. Speelman and Kirsner's (2005) components theory further recommends that learning occur in a hierarchical manner, with simpler tasks being mastered before complex tasks are attempted. Finally, the learning context can strongly influence the content that is learned and retained, particularly in mathematical learning, and thus should be considered carefully when designing research.

In conclusion, research evidence suggests that skill transfer can and does occur although evidence of mathematical skill transfer is limited. Transfer is dependent on the skill that is learned, how it is learned (i.e., through rote learning, memorisation or through understanding the underlying concepts) and whether relevant knowledge can be applied to novel tasks or problems. More research is needed to investigate how mathematical skill transfer can be enhanced, and in what conditions the learning needs to take place. A research design which applies information previously learned to a novel study incorporating the above recommendations should result in successful, and positive, transfer of skill.

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Investigating Transfer Effects of a Mathematical Computer Game Based on the
Components Theory of Skill Acquisition

Jenny Kessell

Abstract

This study examined mathematical skill transfer facilitated by a mathematical computer game based on Speelman and Kirsner's (2005) Components Theory of Skill Acquisition and Transfer. Two alternative hypotheses were investigated: (1) By mastering mathematical tasks in the experimental computer game, performance would be enhanced on all mathematical problems (multiplication, addition and pictorial) presented in the post-test; and (2) task performance would only be enhanced for the mathematical problems practiced in the computer game. Eighty-four third-grade students from three primary schools in Perth, Western Australia participated in the study. Students engaged in a 5 min pre-test of multiplication, addition and pictorial problems, followed by 30 min of computer game-play of one of three computer games (experimental mathematical game, comparison mathematical game, and game unrelated to mathematics). They then engaged in a 5 min post-test of multiplication, addition and pictorial problems. Score differences between pre- and post-tests were recorded. A significant difference was identified between the control group game and the comparison mathematical game only, indicating that results did not support either hypotheses. Overall, students in the control group performed more successfully than students in the other groups. This finding was contributed to the low power of the test statistic due to low participant numbers, flaws in the experimental computer game, as well as student motivation and enthusiasm. It was concluded that learning is at its best when students have experienced task mastery and are motivated to take on challenges, however, the study needs to be repeated with more participants and after levels in the experimental computer game are amended.

Keywords: Mathematics; Transfer; Components Theory; Computer Games

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Investigating Transfer Effects of a Mathematical Computer Game Based on the Components Theory of Skill Acquisition

Introduction

Mathematical knowledge is an acquired skill that is important for successful performance within school education (National Council of Teachers of Mathematics, 2000). Basic mathematical skills tend to be taught to children during early to middle childhood, and improve with practice as students develop a complex understanding over time. Upon understanding basic mathematical concepts, students can apply these skills in order to aid their understanding of more complex, unfamiliar problems. This application of previously learned information to novel tasks is termed skill transfer (Anderson, 1982, Haskell, 2001). The purpose of this study was to examine the current theoretical explanations of skill transfer within a mathematical context. In particular the newer Components Theory of Skill Acquisition and Transfer (Speelman & Kirsner, 2005) was identified as having little empirical evidence supporting or opposing it. As a result, this theory became the focus for the study.

Skill transfer is crucial to all forms of learning as it reduces our environment into manageable proportions and gives it familiarity (Anderson, 1982; Haskell, 2001).

Virtually all that is learned occurs through the adaptation and application of previously learned information into new situations (Haskell, 2001). Transfer occurs in the learning of motor tasks (e.g., Arnett, DeLuccia & Gilmartin, 2000) as frequently as it occurs in intellectual tasks (e.g. Doane, Sohn & Schreiber, 1999; Phye, 1989; Speelman & Kirsner, 1997). The manner in which learning both occurs and is enhanced has been subject to many theories; the two most distinct being the ACT theory (Anderson, 1982, 1983, 1987,

1993; Singley & Anderson, 1989) and the Instance theory (Logan, 1988, 1990; Lassaline & Logan, 1993). These are expanded on below. To some extent, each theory explains the phenomenon of skill transfer whereby previously learned skills enhance performance on novel tasks if specific criteria are met. Each theory, however, differs in its explanations of transfer. Generally, the theories agree that some representation of an event, task or skill is stored in memory and can be retrieved when necessary to facilitate performance on a task, but each vary in their suggestion on how these processes occur at a cognitive level. Additional cognitive learning theorists (e.g., Crossman, 1959; Laird, Newell & Rosenbloom, 1991; Newell, 1990; Rosenbloom, Newell & Laird, 1991) also predict how skill transfer occurs, however, their explanations generally do not differ sufficiently from the aforementioned theories to warrant additional discussion.

Theoretical Explanations of Learning and Transfer

The ACT theory explains that skills are mentally represented as production rules (or 'productions') that associate a situation with the performance of a specific action (Anderson, 1982, 1983, 1987, 1993; Singley & Anderson, 1989). Productions have conditions that specify when particular actions are necessary. If the condition of a production rule is satisfied, the production can apply and the associated action will follow. The greater the frequency with which a production rule is applied (that is, the more times the production is successfully executed), the greater its strength in working memory. Productions with greater strength tend to be more refined and can be applied to situations faster than production rules that are infrequently used.

In relation to mathematical learning, the ACT theory would explain learning through: (1) initially understanding simple concepts; (2) making rules of these concepts

(e.g., in $2 \times 5 = ?$, the 'x' sign denotes multiplication, and when positioned between two numbers it means to multiply those numbers by each other); and (3) developing shortcut strategies with practice. Transfer then occurs to the extent that production rules for one task can be applied to additional tasks (Anderson & Singley, 1993). Where production rules are the same for old and new tasks, performance of the new task will be at least as good as performance on the old task. Where only some production rules apply, performance on the new task will be slower and possibly less accurate than performance on the old task.

The Instance theory suggests that skilled performance relies on the successful execution of an algorithm, and each appropriate response to a task or skill is represented in memory as an 'instance' (Logan, 1988, 1990; Touron, Hoyer & Cerella, 2001). The greater the number of successful responses to a task, the greater the number of stored instances and the quicker they can be retrieved. This results in faster task performance, with automatic performance occurring when a task can be completed without the execution of an algorithm. Logan (1988, 1990) initially proposed that transfer was item specific and could only occur when tasks involve events that have previously been encountered. Thus, two problems that are essentially the same but differ in the format of presentation (e.g., $2 \times 5 = 10$ and $5 \times 2 = ?$) would not facilitate performance on each other, according to this theory. Research has revealed evidence to the contrary (e.g., Doane, Sohn & Schreiber, 1999) and the theory was revised to suggest parts of instances could be retrieved from memory to affect performance on tasks where parts of tasks were similar (Lassaline & Logan, 1993). Despite this revision, the Instance theory was not re-developed to the extent where deriving transfer predictions could be possible.

An Australian study of 139 students compared the Instance and ACT theories' ability to explain performance in repeating and non-repeating tasks (syllogisms) finding that performance speed on test tasks was quicker than in practice tasks, despite the presentation of new syllogisms in the test task (Speelman & Kirsner, 1997). The Instance theory could not account for an increase in performance speed with non-repeating task items. The ACT theory could explain this result through the transfer of underlying production rules. Thus, the experiment provided evidence for the ACT theory being a more comprehensive theory of skill acquisition and transfer.

In contrast, an American study presented evidence to the contrary within a mathematical context. Rickard, Healy and Bourne (1994) engaged 12 participants (a notably small sample size) in blocks of multiplication and division problems and determined that when test sets matched practice sets performance accuracy was relatively good. When test problems did not match exactly with the practice problems, accuracy suffered substantially. The ACT theory would suggest performance on novel test problems should occur at higher-than-baseline levels because of the application of underlying production rules, however this was not demonstrated (although actual performance scores were not indicated and may have been above pre-practice levels).

The Instance theory suggests that only those tasks sharing the same elements as earlier tasks will be solved quicker than novel tasks relying on the execution of an algorithm, supporting what this study found. The limitations of sample size and performance scores must be considered, however the study still provided some support for the Instance theory's ability to explain transfer.

Both the ACT and Instance theories are limited in their ability to explain transfer across all tasks and skills. As a result, Speelman and Kirsner (2005) developed the Components Theory of Skill Acquisition and Transfer. This theory suggested that skilled performance of tasks occurs over time by mastering lower level tasks until performance is automatic. It proposed there must be sufficient mental resources available in order to develop a particular set of skills, therefore, complex behaviours can only be learnt upon learning the simple components of the behaviours first. When simple components have been mastered, more complex tasks can be attempted, moving up task difficulty levels in a hierarchical manner. The theory additionally suggested that learning complex tasks is not more difficult than learning simple tasks if the components of simple tasks have been mastered. By mastering simple tasks, sufficient mental resources become available to attempt more complex tasks. If tasks are too difficult, the theory suggests that this is because simple components have not yet been mastered.

The Components theory explained transfer as occurring when the 'old' components of mastered tasks can help facilitate the learning of 'new' components within more complex tasks. It essentially extended Singley and Anderson's (1989) ACT theory of skill transfer in that, when two or more tasks share similar underlying mechanisms necessary for task completion, increasing performance on, or mastering, one task will facilitate performance on the other. The Components theory proposed that its principles underlie every form of learning and thus can be considered a universal theory of cognition and learning. There is, however, a paucity of research examining this theory and such claims therefore need to be investigated thoroughly.

Factors Affecting Transfer: The Importance of Context

Transfer tends to be context-specific in that if a test context is identical to the practice context, skill transfer will occur. Alternatively, if the two contexts are extremely different, transfer will be hindered and performance on the second task will be significantly reduced (e.g., Arnett et al., 2000; Krigolson, Van Gyn, Tremblay & Heath, 2006). Few tasks outside laboratory studies, however, are repeated in exactly the same way or context (Haskell, 2001), and thus research is needed to explore ways of facilitating skill transfer despite contextual differences between tasks. Mathematical skills in particular tend to be taught in many different contexts (e.g., numbers, words, pictures; verbal, written or displayed on computer) and in many different formats (e.g., diagrams, rows, lines, sentences, etc.). Such mathematical skills may be enhanced significantly if problems could be understood and solved more efficiently due to previously learned strategies, regardless of the presentation context or format. Research is needed to investigate ways to facilitate skill transfer and 'short cut' learning that focuses on transferring learned skills to novel tasks without interrupting performance. This study aimed to augment knowledge in this area.

Contextual Interference

The level of task difficulty, individual differences and the interference from the learning context all tend to influence human memory (Battig, 1979). Interference from the learning context occurs due to competition from simultaneous aspects of tasks that require learning (Schneider, Healy & Bourne, 2002). In particular, difficult tasks learned in high interference conditions result in initial degraded performance, but long term enhanced retention and transfer, compared to tasks learned in non-interfering conditions

(Battig, 1979). This is suggested to occur because skills learned in high contextual interference (CI) typically require greater processing and thus are learned more slowly but thoroughly and may facilitate task completion on similar or novel tasks (Schneider et al., 2002; van Merriënboer, Kester & Paas, 2006). Additionally, whole components of tasks are learned rather than specific components. Task skills learned in low CI conditions tend to be item-specific and are not transferred easily because the components learned cannot be easily generalised to unfamiliar novel tasks (van Merriënboer et al., 2006). Numerous studies have supported this claim across many different task types (e.g., Carlson & Yaure, 1990; de Croock & van Merriënboer, 2007; Dunham, Lemke & Moran; Healy, Wohldmann, Parker & Bourne, 2005; Russell & Newell, 2007; Shewokis, 1997). Thus, the evidence suggests that by practising a series of tasks under circumstances that are more challenging, the practiced skill can ultimately be applied to a greater number of tasks (Speelman & Kirsner, 2005). This finding was considered when designing the current study.

Mathematical Learning and Transfer

It has been suggested that teaching mathematics in specific contexts restricts the learned skill to the context in which it was taught (Britton, New, Roberts & Sharma, 2007). With mathematical research generally finding that transfer rarely occurs across contexts (e.g., Boaler, 1993), such a suggestion may have merit. However mathematical skills are used throughout primary, secondary and tertiary education, and as some mathematical knowledge is useful for developing further understanding, transfer must be occurring to some extent (Britton, New, Sharma & Yardley, 2005).

An Australian study comparing 49 university students' mathematics scores with their high school mathematics scores found significant correlations between students' performance across the two settings (Britton et al., 2007). This suggested that in understanding the underlying mathematical concepts, students were able to apply this knowledge to novel situations, effectively engaging in skill transfer. Thus, perhaps a thorough understanding of the underlying concepts enhances performance on novel tasks because general, rather than specific, task knowledge can be applied.

Arithmetic skills (number combination) are necessary for higher order performance (e.g., multiplication) and research has suggested that comprehending mathematical problems presented pictorially (e.g., squares or circles representing amounts) enables greater comprehension of mathematics than problems presented numerically (e.g., $2 \times 3 = ?$) (Fuchs et al., 2006; Lowrie & Diezmann, 2007). Both problem types share similar comprehension strategies such as visualisation and drawing connections between numbers or amounts, however pictorial mathematical problems are suggested to help students identify and understand underlying connections to a greater extent than numerical problems (Hyde, 2007). Applying the concepts of skill transfer, by mastering the underlying comprehension strategies for solving pictorially-presented mathematical problems, performance on numerically presented problems (a more complex task) should be enhanced. Additionally, if arithmetic skill is necessary for higher order mathematical performance, mastering arithmetic skills should facilitate learning of multiplication problems. Little research has tested this suggestion, therefore, the present study aimed to determine whether improving performance on pictorial tasks improves arithmetic performance, in turn improving performance on multiplication skills.

The Present Study

As indicated earlier, there are many gaps in the literature surrounding mathematical skill transfer. Additionally, few of the existing studies have centred their approach on cognitive theories in order to explain their findings. Speelman and Kirsner's (2005) Components theory was identified as a new theory within the cognitive field and one that needed to be empirically tested. As a result, a mathematically-oriented computer game ("Blast the Germs") was designed by Speelman (2008a) based on the Components Theory of Skill Acquisition and Transfer. Research surrounding the presentation of mathematical problems highlighted the value of presenting problems pictorially rather than numerically, and thus all problems in the game were presented as such. The rationale of the game, based on the relevant research, was that individuals would develop complex skills by applying simple skills to complex tasks and developing shortcut strategies. A game that recognised this process through the presentation of tasks that increased in complexity, and was speed-based to encourage the discovery of shortcuts, was proposed to lead to fast development of complex skills, provided the presented tasks were not exceptionally difficult. Thus, the aim of the study was to determine whether students playing Blast the Germs would engage in skill transfer to a greater extent than students playing a numerical-problem based mathematical game ("Daisy Maths") and students playing an unrelated game ("Turtle Odyssey").

Based on the existing literature, two alternative hypotheses were investigated. The first proposed that by mastering mathematical tasks in Blast the Germs, performance would be enhanced on all mathematical problems (multiplication, addition and pictorial) presented in the post-test. This hypothesis was based on the principle that pictorially-

presented mathematical problems require greater comprehension (and are thus more complex) than numerically-presented problems (Fuchs et al., 2006; Lowrie & Diezmann, 2007). The contextual interference effect also indicates that learning complex tasks in complex conditions results in enhanced learning on simpler tasks because whole components of tasks are learned rather than single components (Battig, 1979; Schneider et al., 2002; van Merriënboer et al., 2006). It was suggested that challenging training conditions would lead to a greater understanding of the task, increasing the transferability of the skills. Thus, in the case of Blast the Germs, practice of the pictorial mathematical problems within each game level under complex conditions (speed) would improve the participants' ability to apply the skills required to solve the numerical problems in the post-test, resulting in increased task performance.

The alternative hypothesis proposed that task performance would only be enhanced for the mathematical problems practiced in the computer game. Thus from pre- to post-test, Blast the Germs participants would perform better at pictorial problems; Daisy Maths participants would perform better at numerically-presented addition problems; and Turtle Odyssey participants would show no improvement in performance. This finding would support research indicating skill transfer rarely occurs, or occurs poorly, across different contexts (Arnett et al., 2000; Krigolson et al., 2006).

Method

Participants

Eighty-four year three students (46 females, 38 males; aged 7 to 8 years) from three primary schools in Perth, Western Australia consented to participate in the research. Mathematical ability differed across participants, however, the study focused on their

skill improvement not overall ability, and thus base-rate performance was not controlled for.

Design

The study utilised a 3 x 2 factorial design. The computer game type was an independent variable with three levels: irrelevant to maths (Turtle Odyssey); experimental mathematical game (Blast the Germs); and a comparison mathematical game (Daisy Maths). Type of test measuring mathematical ability was the second independent variable, with two levels: pre-test and post-test. Improvement was measured by administering the pre-test prior to commencement of the computer game, a post-test after the games' completion and recording the score difference across problem types.

Materials

The pre- and post-tests each consisted of 72 questions, alternating between multiplication problems (e.g., $3 \times 7 = \underline{\quad}$) between the 0 and 12 times-table; addition problems (e.g., $2 + 9 = \underline{\quad}$); and pictorial problems (e.g., $***** = \underline{\quad}$). Two versions of the tests were created (see Appendix A) and counterbalanced to ensure test order did not affect overall scores. The order students completed the maths booklets, the game type played, and their name and gender were recorded. This also ensured that if consent was withdrawn after participating, the student's data could be located and removed.

Three computer games were obtained for the study: (1) Blast the Germs (donated by its creator); (2) Daisy Maths (freeware); and (3) Turtle Odyssey (purchased online). The design and purpose of each game is described below.

1. Blast the Germs, designed by Speelman (2008a), is based on the Components Theory of Skill Acquisition and designed for children in grades 1 to 3 who have only a basic comprehension of mathematics. A collection of joined red dots (the “germ cells” collectively making a “germ”) move around the computer screen, gaining speed as levels and accuracy increases (see Figure 1).

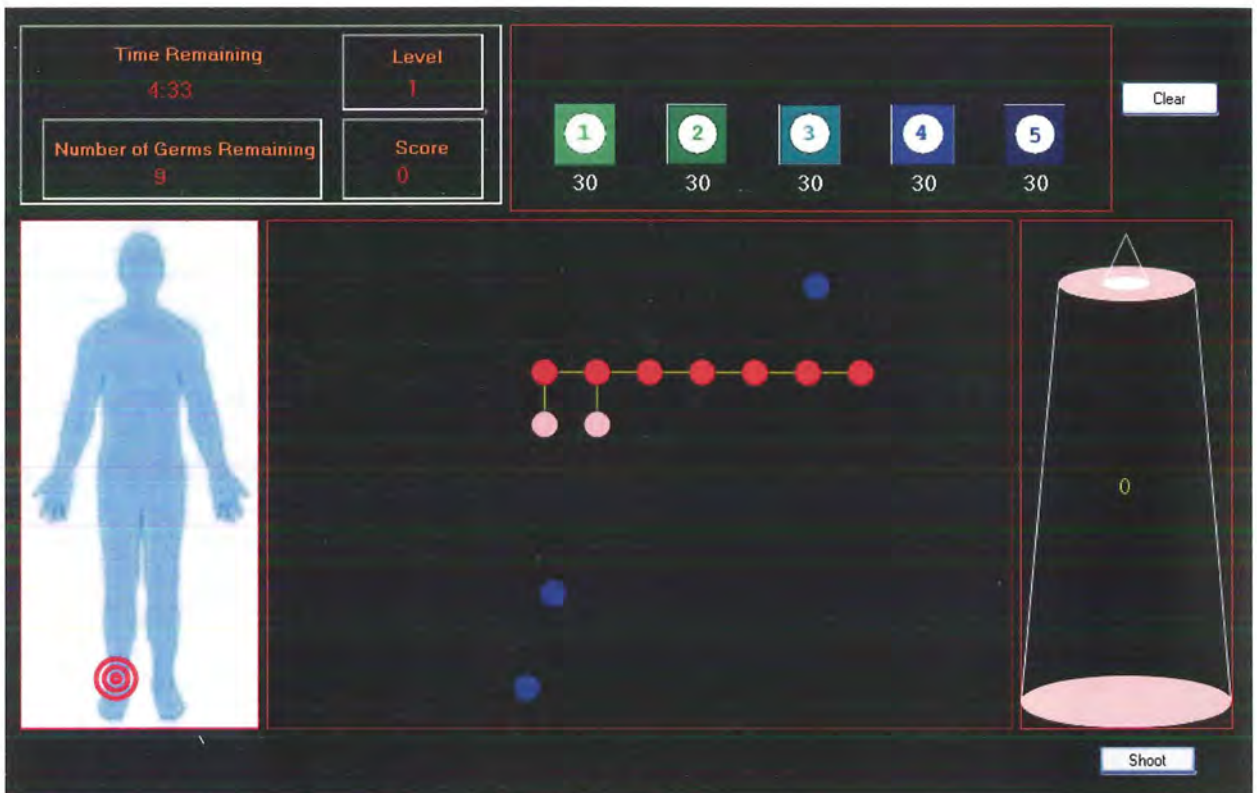


Fig. 1 A screen capture of Blast the Germs’ game display

There are a number of different coloured dots (“healthy cells”) also moving around the screen, and if these connect with the germ, the germ size increases by the number of cells it collides with. At the top of the screen are blocks of numbers (ranging from 1 to 5), and at the right hand side of the screen is a cylindrical “gun”. The role of the player is to count the number of cells in the germ and use the cursor to drag enough number blocks to add up to the number of cells in the germ. For example, if the germ is comprised of 7 cells, the player could drag a 5 and a 2, or seven 1s, or a 3 and a 4, etc.

into the gun. They then click the 'shoot button' on the screen and the gun blasts the germ. On the left hand side of the screen is a human silhouette with a red target indicating which level the player is in. The target begins at the feet and finishes at the head.

The game designer described the theoretical underpinning and role of the software with the following:

The aim of this game is to help users develop faster mathematical skills, particularly those involved in counting, addition and multiplication. On the basis that practice can lead to faster performance, and that fast performance can facilitate acquisition of higher level skills, users are presented with problems across 5 levels of difficulty. Within each level, the speed of movement of germs increases, so that faster performance is required with each subsequent problem to avoid germs growing too large. There are a number of problems needed to be solved. As defaults, there are 20 problems in each of level 1, 2 and 3 and there are 10 problems in each of level 4 and 5. (Speelman, 2008b, p. 3).

2. Daisy Maths (Harding, 2004) is a free to download software program designed to assist students in mathematics through practicing 'drill' mathematics. The game consists of 13 activities, consisting of 13 to 33 groups of mathematical problems.

Although the game offers multiplication, addition, subtraction, division and pictorial problems, as well as problems on angles, decimals, fractions, graph axes and clock faces, for the purposes of the study only numerically presented addition problems were used.

Figure 2 displays a screen capture of different addition problem types. In Daisy Maths, the player is presented with mathematical problems (e.g., $3 + 5 = \underline{\quad}$) to which they fill in the corresponding answer. They can check the accuracy of their responses by clicking

a ‘smiley face’ in the top right hand corner of the screen. Additionally, they can ‘scramble’ the presented problems, producing a new set of problems for solving by clicking the curved arrows in the top right hand of the screen. The underlying rationale for the game is that mathematical skills will improve through practice. Activities 4 (problems 13-16); 5 (15-17); 6 (16-18 and 21-22); 7 (15-18 and 21-22); and 8 (16-18 and 21-22) were utilised for the purposes of this study.

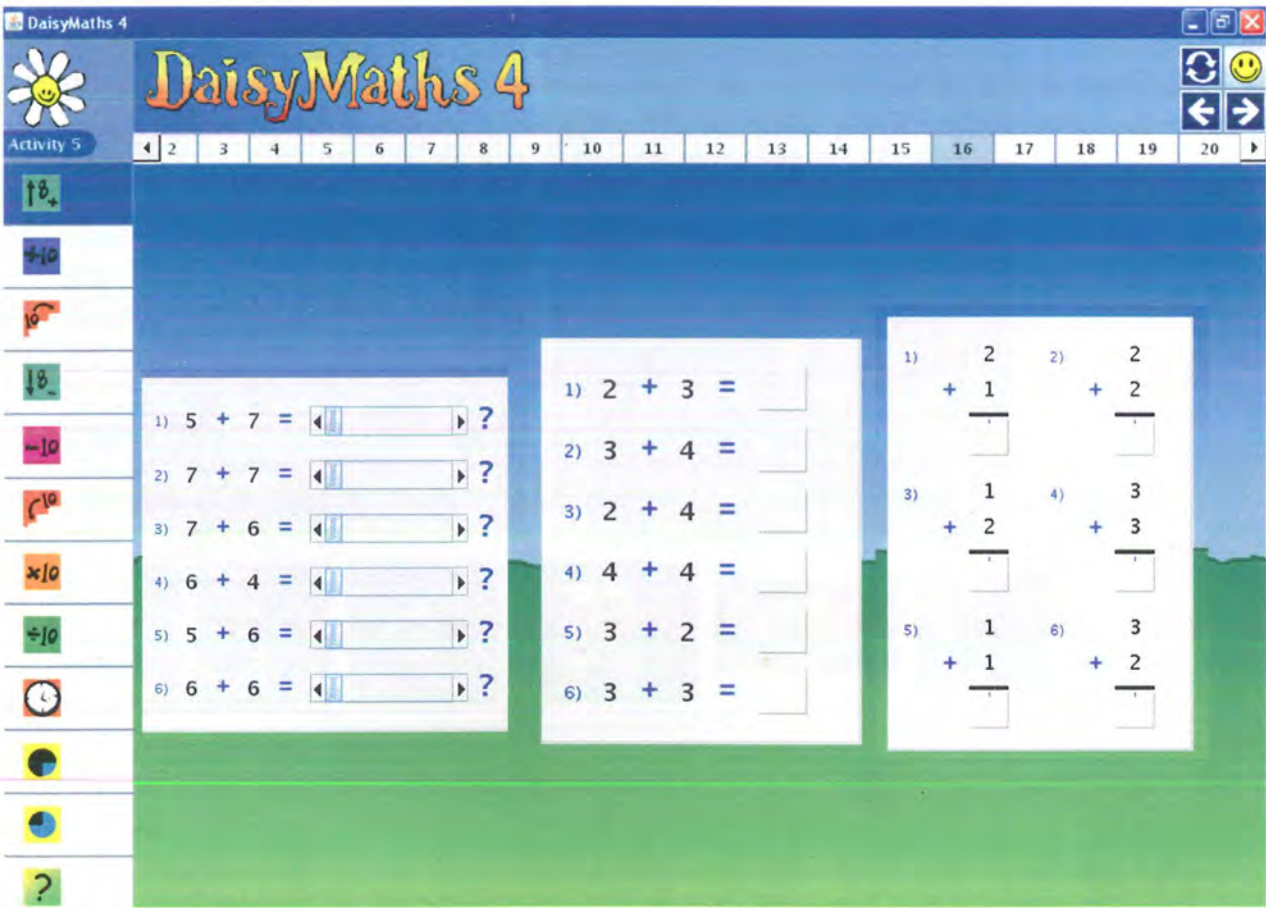


Fig. 2 A screen capture of Daisy Maths with additional problem formats included

3. Turtle Odyssey (Realore Studios, 2004) was obtained by purchasing the game from the designer’s website. Permission was granted to make duplicate copies for the purpose of the study. Turtle Odyssey was selected as an interactive game unrelated to

maths to act as a control for the mathematical games. The game is based on the underwater quest of a turtle to find his stolen shell, collect treasures and defeat the ‘bad guys’ along his journey. A screen capture of the game levels and the ‘bad guys’ is presented in Figure 3.



Fig. 3 A screen capture of different Turtle Odyssey levels and the “bad guys”.

Procedure

Ethics approval for the project was obtained from the Edith Cowan University Human Research Ethics Committee; the Catholic Education Office; and the Department of Education and Training. The primary schools were targeted out of convenience due to their proximity to each other and the researcher, and were invited in writing to become involved in the study. Consent letters were distributed to the primary schools, the parents

and the students. Students were required to consent personally, but also gain parental consent for their participation. The school principal and year three teachers (the targeted year group) were also required to consent prior to the commencement of the research.

Each data collection session took approximately one hour and occurred during class time. Student numbers differed per session, depending on the number of available computers and the number of available students. Computers varied between the school-issued computers and the researchers' personal laptops. Each computer, regardless of type, had the same controls (keyboard/mouse) to ensure no student was disadvantaged. Two participating schools required one session each; one school required three sessions. Schools were allocated only one game type where possible as it was anticipated that students who were aware their friends were playing an alternative game, particularly a 'more fun' game, could create an 'unfair' and distracting environment. By keeping game type consistent per school, we anticipated reducing student distress. However in an attempt to create even group sizes, one school was allocated two game types.

Students were given a bright coloured pacer pencil and a maths booklet, and were informed that their task was to complete as many problems as they could within a 5 min period. It was emphasised that they were not expected to complete the booklet and any question they could not answer they could skip. Three practice mathematical problems were explained and completed by the students who were able to ask any questions prior to commencing work on the test problems. They then spent 5 min filling out the maths booklet. Upon completion of the pre-test time period, participants were moved to a computer whereby they received instructions on playing the game (see Appendix B). Daisy Maths participants received an additional instruction sheet to refer to (also see

Appendix B). Each student was allocated 30 min of game-play. At the conclusion of this time, students were given another maths booklet (if they had initially completed Booklet A, they were given Booklet B, and vice-versa). It was explained to the students that this booklet was to be completed in the same manner as the first booklet. They were given 5 min to answer as many questions as they could. At the end of the 5 min period, the booklets were collected and students were able to keep their pencil as a thankyou for their participation. Completed maths booklets were then scored for the number of correct answers for each problem type (multiplication, addition and pictorial). These scores were recorded, and the booklets stored separately to the participant detail sheets to ensure confidentiality was maintained.

Results

Data was entered and analysed using the statistical software package SPSS. Due to school and time restrictions, group sizes were unequal with the maths groups having higher numbers (Daisy Maths, $n = 31$; Blast the Germs, $n = 31$) than the Turtle Odyssey group ($n = 22$). Initially, descriptive statistics on the pre-test scores demonstrated a higher overall mathematical ability in the control group ($M=32.68$, $SD=12.81$) than Daisy Maths participants ($M=23.94$, $SD=12.01$) and Blast the Germs participants ($M=23.94$, $SD=11.96$). A one-way ANOVA indicated that this difference was significant ($F(2, 83) = 4.17$, $p < .05$, $r = .31$). Due to this, and the unequal group sizes, extra variance in the dataset may have overshadowed any post-test improvement in the experimental groups and initial repeated measures ANOVA and ANCOVA analyses on mathematical skill improvement yielded non-significant results. Data was thus reanalysed only measuring test score differences from pre- to post-tests.

Three one-way ANOVAs were conducted to compare the mean pre- and post-test score differences for each problem type (multiplication, addition and pictorial) across the three different groups. Alpha was set at .05 and the assumption of homogeneity of variance was not violated ($p > .05$). The overall power of the ANOVAs was low ($\beta = .55$) (see Appendix C). Mean difference scores of problem types for each computer game group are displayed in Figure 4.

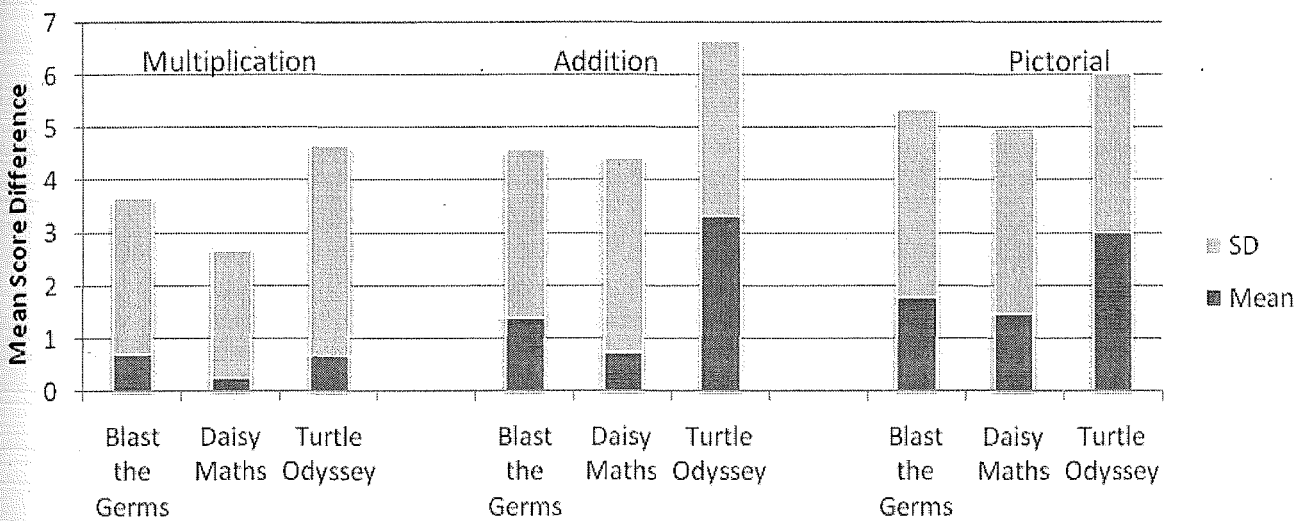


Fig. 4 Mean score differences and standard deviation of problem types for each computer game participant group.

Multiplication Scores

The ANOVA on multiplication scores indicated no significant differences between the mean score differences across the three groups ($p > .05$, $r = .07$). However in examining the mean scores, there were noteworthy differences seen across the three groups (see Figure 4). The Germs and Turtle groups demonstrated little difference from each other ($M = .71$, $SD = 2.95$; $M = .68$, $SD = 3.04$ respectively), however the Daisy group scores were much lower ($M = .26$, $SD = 2.41$).

Addition Scores

The ANOVA on addition scores indicated a significant difference ($F(2, 83) = 3.86, p < .05, r = .29$) between the mean score differences of problem types across the three groups. Post hoc analysis using Tukey's HSD was conducted to make multiple comparisons between group types. A significant difference was found between the Daisy and Turtle groups ($p < .05$) only. All other comparisons were non-significant. Figure 4 portrays the mean scores for the three group types, with the Turtle group showing the greatest score difference ($M=3.32, SD=3.32$), followed by the Germs group ($M=1.32, SD=3.17$), and with a substantially lower score, the Daisy group ($M=.74, SD=3.66$).

Pictorial Scores

The final ANOVA on pictorial scores indicated no significant differences between the mean score differences across the three groups ($p > .05, r = .22$). Descriptive statistics indicated the Turtle group had the greatest score difference ($M=3.0, SD=3.01$); with the Germs and Daisy groups demonstrating closer scores ($M=1.77, SD=3.58; M=1.45, SD=3.53$ respectively). Figure 4 above demonstrates this difference visually.

Discussion

The results of the study failed to support either of the two hypotheses. The first hypothesis predicted that by mastering mathematical tasks in Blast the Germs, performance would be enhanced on all mathematical problems. The results indicated that although Blast the Germs participants did improve to a small extent across all mathematical problems, they did not improve to a greater extent than Daisy Maths and Turtle Odyssey participants. In fact, Blast the Germs participants improved to a lesser

extent than Turtle Odyssey participants, although showed greater improvement than the Daisy Maths group.

The second hypothesis alternatively proposed that task performance would only be enhanced for the mathematical problems practiced in the computer game. Again, this was not supported as participants overall improved across all three problem types. As already mentioned, Daisy Maths participants showed the least improvement of mathematical scores in the post-test compared to the pre-test, followed by Blast the Germs, followed by Turtle Odyssey.

Statistical Power and Effect Sizes

Overall, the statistical power of the study was low, suggesting there was a 55% chance of detecting an effect if one genuinely existed. Cohen (1988, 1992) suggests experimenters should aim to reach a power level of .8, or an 80% chance of detecting a genuine effect. In order to do this, the ANOVA power tables in Statistical Table M of Appendix D (Runyon, Coleman & Pittenger, 2000, see Appendix C) suggest a minimum participant cohort of 50 people per group. As a result, it is recommended that replications of this study increase the sample size to increase the statistical power of the study.

The effect size of the problem types additionally was low. A very small effect was found for multiplication scores, indicating multiplication difference scores accounted for less than 1% of the overall variance. A medium effect size was found for addition scores, indicating addition difference scores accounted for approximately 9% of the overall variance. A small to medium effect was also found for pictorial scores, indicating that pictorial score differences accounted for more than 1% but less than 9% of the overall variance. It is anticipated that by increasing the overall power of the study by increasing

participant numbers, a greater overall effect size will be found for mathematical problem types.

Post-test Improvement

The most surprising result was that overall, Turtle Odyssey participants showed the greatest mathematical score improvement and showed significantly greater improvement in addition problems than Daisy Maths participants. This was an unexpected finding as these participants had no mathematical practice between pre- and post-tests. However, Blast the Germs participants showed the next greatest score improvement, followed by those who played Daisy Maths, although no other significant differences were found. Several explanations may account for this finding, including student motivation, game-play time, and problems within the study's design. These explanations are expanded on below, and improvements for Blast the Germs and experiment replications are suggested.

Explaining Turtle Odyssey Participants' Results: Student Motivation

As previously stated, Turtle Odyssey participants outperformed either mathematical computer game group participants. Upon observing participants playing Turtle Odyssey, however, all students demonstrated excitement and enthusiasm as indicated by their physical reactions and verbal comments as they 'found treasures', 'defeated bad-guys' or achieved level completion. Research has suggested that intrinsic motivation may increase as a result of feeling task-mastery from completing game levels or conquering game challenges (Egenfeldt-Nielsen, 2007). As a result, students probably completed the 30 min game-playing time period with high levels of interest, enthusiasm and motivation. Quinn (2005, cited in Jong, Shang, Lee & Lee, 2008) suggests that

learning is at its best when it is interesting, challenging or interactive. Although the post-test did not fit these criteria, Turtle Odyssey did, and as a result it is predicted that the students attempted the post-test questions with greater enthusiasm and feelings of task mastery than the other computer game participants.

Also supporting this prediction are the Blast the Germs participants' results. These students were observed to be enthusiastic, motivated and competitive throughout their game-play as indicated by their discussions with students sitting nearby and their comparisons with each other of the levels they had completed. Their overall results were lower than those playing Turtle Odyssey, but higher than those playing Daisy Maths. It is a possibility, on the theory that motivation was a factor, that Blast the Germs participants scored lower than Turtle Odyssey participants because the majority of participants completed all Blast the Germs levels prior to the 30 min time period completion. As a result, the game was re-started and students repeated the game, starting again from the beginning. This may have reduced their motivation and enthusiasm as they were then engaging in a task they had already completed, reducing its challenging component and their feelings of task mastery. As a result, it is suggested these students attempted the post-test questions with less enthusiasm and vigour than the Turtle Odyssey participants.

Following this trend also, were the results of the Daisy Maths group participants. These participants scored the lowest of the three groups, but were observed to be notably less enthusiastic and complaining of boredom after about 15 min into game-play. Additionally, many students (and interestingly more male students than female) were also observed to have difficulty maintaining attention on the game and appeared more distracted by elements of the research environment (such as other people in the room, and

other student's activities). Such an observation was anticipated because of the nature of the game being drill-mathematics and not interactive or stimulating. Additionally, students who completed all tasks within Daisy Maths were asked to repeat problem types they had already attempted, however to select the 'scramble' button so different combinations of problems were attempted. The addition problem types were within the capabilities of the students, and did not appear to be challenging them. At the end of the 30 min game play, students were observed to be showing minimal enthusiasm and high levels of distraction. They also showed minimal enthusiasm when instructed to begin the post-test (as indicated by their groans).

Research has suggested that these participants' reactions are indicators of mental fatigue, defined as "a psychophysiological state resulting from sustained or previous mental effort" (van der Linden & Eling, 2006, p. 395). We suggest that the sustained mental effort was the students' attempt to stay on task however the lack of stimulation from the game, as well as the unchallenging addition problems, made their attempts more difficult, leading to a state of mental fatigue. Literature on mental fatigue indicates that although automatic information processing is relatively unaffected, students will show increased resistance against further effort (van der Linden & Eling, 2006). This finding might indicate that Daisy Maths participants, as a result of mental fatigue and lack of enthusiasm, only attempted mathematical problems in the post-test that they already knew the answer to (automatically processed) or that took minimal effort to work out, in a subconscious effort to reduce mental exertion. This would help explain why their scores were lower than Blast the Germs and Turtle Odyssey participants who may have attempted a greater number, and more difficult, mathematical post-test questions. Further

supporting this idea was that Daisy Maths participants showed greater improvement in post-test pictorial scores than in their addition and multiplication scores. The pictorial tasks involved counting – a task the students would be able to perform easily – and thus minimal mental effort would be needed to solve these problems. As a result it is suggested that Daisy Maths participants experienced mental fatigue as a result of their attempts to stay on-task in unstimulating, easy conditions, and as a result became bored and distracted and unwilling to attempt to solve challenging problems.

Blast the Germs: Game Design

Several flaws in the game design of Blast the Germs were noted throughout the experiment. This is not surprising as this study was the first time the computer game had been tested, however these flaws may have affected the overall results of this game's participants. The main flaw was the time it took for the students to complete all levels. It had been anticipated that 30 min was more than sufficient for students to play the game but not complete it. However as the level difficulty increased and the 'germ' size increased drastically (as did the number of healthy cells the germ could collide with), students stopped counting the number of cells in the germ and began simply reducing its size as quickly as they could. This was achieved by dragging multiple blocks of 5s into the game gun and blasting the germ until it became a manageable size to count. In this sense, participants were creating their own short-cut strategies in order to master the task at hand, however the short-cut strategies chosen were not enhancing their learning. The underlying strategies of the game (i.e., counting) were forgotten or ignored, as students concentrated more on 'playing' the game. As a result of these shortcut strategies, the game was completed much more quickly than it would have been if students had counted

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the germ cells. Their shortcut strategies hastened level completion but did not result in increased learning.

It is recommended that future versions of Blast the Germs take this finding into consideration, and either reduce task difficulty in the higher levels, or alter task difficulty, such as reducing the time component rather than increasing germ size. If the time component was reduced and the germ was of a challenging, but not too difficult size, players would still have a task of increased difficulty, but one that was possible to solve in the given time restraints. Additionally, the number of germs per level could be increased, as could the number of levels. This would ensure game completion took much longer. It would also allow the game to be played over multiple sessions before its completion.

A comparison of Blast the Germs and Daisy Maths

Universally, participants appeared to enjoy playing Blast the Germs more than participants playing Daisy Maths. This was indicated by their enthusiasm and behaviour observed by the researcher. This suggests Blast the Germs has the potential to be a useful learning tool, however needs to be amended to increase the length of time taken to complete the game, and to decrease the difficulty in the higher levels. It also suggests that educational computer games with a 'fun' and challenging component are more effective than games that are based on 'drill' learning or repetition.

Game-Play Time

It is acknowledged that the 30 min of game-play is a short exposure time to anticipate significant improvement in task skills. Unfortunately, a longer training period was beyond the capacity of this project, and is recognised as a limitation of the design.

Thirty minutes was sufficient to complete the game and as mentioned above, it is recommended that future versions of the game extend the number of problems presented in each level, allowing the game to be completed only after several game-play sessions. It is anticipated that doing so would enable greater skill improvement to occur.

Theoretical Implications

This study supported research suggesting skill transfer does occur, and occurs to some extent across different contexts. Performance in the post-test was greater than performance in the pre-test, despite no problem being repeated, indicating that students understood the underlying concepts to problems and were using these to solve novel problems. As a result, some support can be given to the ACT theory's account of underlying productions as necessary for skill transfer to occur. As no problem was repeated from pre- to post-test, the Instance theory is not able to account for this improvement.

This study was not able to comprehensively provide support for or against the Components Theory of Skill Acquisition and Transfer, as was its original aim. Problems with the computer game design meant that simple tasks were mastered, however complex tasks were not, as a direct result of the participants developing their own shortcut strategies to master the game. This meant the more complex skills were not attempted, and thus not learned or mastered. Interestingly, however, Blast the Germs participants showed a greater improvement in multiplication scores than did the other groups. This may suggest that the underlying strategies learned by mastering the simpler tasks transferred successfully to enhance performance on more difficult problems

(multiplication problems). This finding needs further investigation and a study replication using a greater number of participants is warranted.

The study did support research indicating that mathematical problems presented pictorially enable understanding of the underlying connection between numbers more so than those presented numerically. Overall, students performed more successfully in solving pictorial problems than they did numerical problems (with the exception of addition problems for Turtle Odyssey participants). It was predicted that if solving pictorially-presented problems enhanced understanding of mathematical problems, mastering the levels in Blast the Germs (which only presented pictorial problems) would enhance performance on all numerically presented problems. Although this occurred to a small extent, improvement was not statistically significant. Again, this finding might change if the study was to be repeated with a greater number of participants, and also if the levels and difficulty in Blast the Germs were revised.

Overall Conclusions

The improvement on post-test scores that occurred across all three computer game groups indicated that the use of computer games to enhance learning does have a positive effect on task performance. The study provided anecdotal support for the benefits of student motivation and enthusiasm when attempting tasks, as well as the benefits of presenting challenging, but not too difficult, problems for solving. It appeared that student performance was at its highest when they were motivated, had a sense of task-mastery, and were engaged, or had engaged, in a challenging task. Some evidence was presented for the transfer of skills occurring across contexts, as student test performance increased across all problem types; addition, multiplication and pictorial. It is

recommended that any generalisation of these results occurs with great caution, as the study needs to be replicated with a greater number of participants to increase the statistical power and effect of the findings. It is suggested that a replication of the study with at least fifty participants per group, and using a revised version of Blast the Germs with more problems per level and more levels per game, will result in a greater difference in mean score differences across game types.

Legal Acknowledgments

The author would like to acknowledge that the experiment detailed in this paper complied with the laws of Western Australia in which it was performed in 2008, and also with the requirements set out by the ethics committees.

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Appendix A

Maths Booklets A and B

Maths Booklet

A

1	<input type="checkbox"/>	2	<input type="checkbox"/>	<input type="checkbox"/>
M	<input type="checkbox"/>	F	<input type="checkbox"/>	<input type="checkbox"/>
1	<input type="checkbox"/>	2	<input type="checkbox"/>	3 <input type="checkbox"/>

Practice Questions

1. $1 \times 4 =$ _____

Multiply 1 and 4

2. $2 + 3 =$ _____

Add 2 and 3

3.  = _____

How many smiley faces are there?

ANSWERS




1. 4

2. 5

3. 5


1. $4 \times 2 =$ _____

2. $7 + 5 =$ _____

3. 

 = _____




4. $5 \times 4 =$ _____

5. $11 + 7 =$ _____

6. 
 = _____


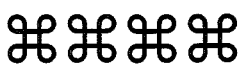
7. $10 \times 10 =$ _____

8. $3 + 2 = \underline{\hspace{2cm}}$

9. 

 =

10. $8 \times 3 = \underline{\hspace{2cm}}$

11. $22 + 5 = \underline{\hspace{2cm}}$

12. 
 =

13. $9 \times 2 = \underline{\hspace{2cm}}$

14. $13 + 8 = \underline{\hspace{2cm}}$

15. $\begin{array}{ccc} \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \\ \bigcirc & & \end{array} = \underline{\hspace{2cm}}$

16. $10 \times 4 = \underline{\hspace{2cm}}$

17. $25 + 25 = \underline{\hspace{2cm}}$

18. $\begin{array}{cccc} \star & \star & \star & \star \\ \star & \star & \star & \star \\ \star & \star & \star & \star \end{array} = \underline{\hspace{2cm}}$

19. $12 \times 6 = \underline{\hspace{2cm}}$

20. $12 + 15 = \underline{\hspace{2cm}}$

21. $\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow$
 \uparrow
 $\uparrow \uparrow \uparrow \uparrow \uparrow \uparrow = \underline{\hspace{2cm}}$

22. $7 \times 5 = \underline{\hspace{2cm}}$

23. $18 + 9 = \underline{\hspace{2cm}}$

24. 😊😊
 😊😊
 $\text{😊😊😊😊} = \underline{\hspace{2cm}}$

25. $5 \times 11 = \underline{\hspace{2cm}}$

26. $23 + 27 = \underline{\hspace{2cm}}$

27.



$$\begin{array}{cccccc} \star & \star & \star & \star & \star & \star \\ \star & \star & \star & \star & & \\ \star & \star & \star & \star & \star & \star \end{array} = \underline{\hspace{2cm}}$$

28.

$$3 \times 3 = \underline{\hspace{2cm}}$$

29.

$$7 + 18 = \underline{\hspace{2cm}}$$

30.



$$\begin{array}{ccc} \star & \star & \star \\ \star & \star & \star \\ \star & & \end{array} = \underline{\hspace{2cm}}$$

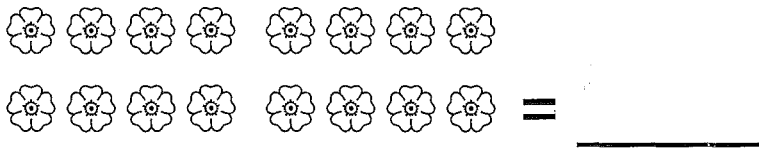
31.

$$12 \times 12 = \underline{\hspace{2cm}}$$

32.

$$1 + 5 = \underline{\hspace{2cm}}$$

33.



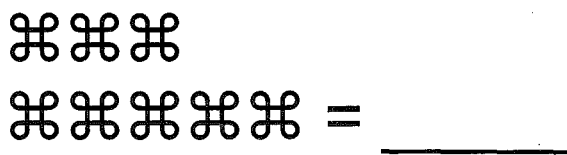
34.

$$6 \times 9 = \underline{\hspace{2cm}}$$

35.

$$2 + 2 = \underline{\hspace{2cm}}$$

36.



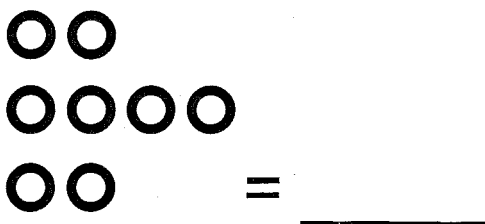
37.

$$8 \times 5 = \underline{\hspace{2cm}}$$

38.

$$21 + 1 = \underline{\hspace{2cm}}$$

39.



40. $7 \times 12 =$ _____

41. $9 + 9 =$ _____

42. $\begin{array}{cc} \star & \star \\ \star & \star \\ \star & \star \\ \star & \star \end{array} =$ _____

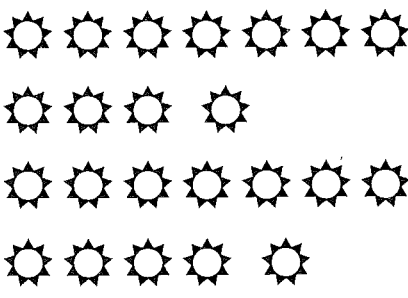
43. $6 \times 2 =$ _____

44. $12 + 10 =$ _____

45. $\begin{array}{ccccc} \text{😊} & \text{😊} & \text{😊} & \text{😊} & \text{😊} \\ \text{😊} & \text{😊} & & & \\ \text{😊} & \text{😊} & \text{😊} & \text{😊} & \\ \text{😊} & \text{😊} & & & \end{array} =$ _____

46. $8 \times 1 =$ _____

47. $43 + 4 =$ _____

48.  = _____

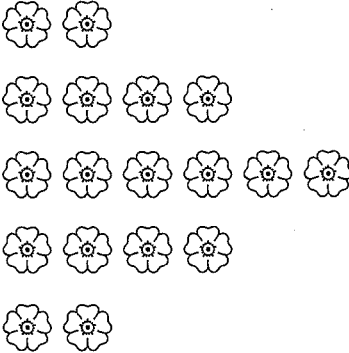
49. $3 \times 3 =$ _____

50. $16 + 10 =$ _____

51.  = _____

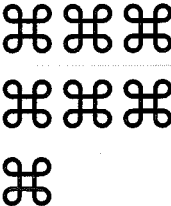
52. $6 \times 8 =$ _____

53. $25 + 11 = \underline{\hspace{2cm}}$

54.  $= \underline{\hspace{2cm}}$

55. $2 \times 4 = \underline{\hspace{2cm}}$

56. $25 + 7 = \underline{\hspace{2cm}}$

57.  $= \underline{\hspace{2cm}}$

58. $6 \times 2 = \underline{\hspace{2cm}}$

59. $12 + 4 =$ _____

60. $\begin{array}{c} \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \bigcirc \\ \bigcirc \bigcirc \bigcirc \\ \bigcirc \bigcirc \bigcirc \bigcirc \end{array} =$ _____

61. $3 \times 1 =$ _____

62. $23 + 2 =$ _____

63. $\begin{array}{c} \star \star \star \star \star \star \\ \star \star \star \star \star \star \end{array} =$ _____

64. $2 \times 5 =$ _____

65. $4 + 4 =$ _____

66. $\uparrow \uparrow$
 $\uparrow \uparrow$
 $\uparrow \uparrow \quad \uparrow \uparrow$
 $\uparrow \uparrow$
 $\uparrow \uparrow \quad = \underline{\hspace{2cm}}$

67. $3 \times 5 = \underline{\hspace{2cm}}$

68. $6 + 10 = \underline{\hspace{2cm}}$

69. $\begin{array}{cccccc} \ast \ast \ast \ast \ast \ast \\ \ast \ast \ast \ast \ast \ast \ast \ast \ast \ast \ast \\ \ast \ast \ast \end{array} = \underline{\hspace{2cm}}$

70. $4 \times 7 = \underline{\hspace{2cm}}$

71. $20 + 3 = \underline{\hspace{2cm}}$

72.


 = _____

Maths Booklet

B

1

2

M

F

1

2

3

Practice Questions

1. $1 \times 4 = \underline{\hspace{2cm}}$

Multiply 1 and 4

2. $2 + 3 = \underline{\hspace{2cm}}$

Add 2 and 3

3. $\text{☺☺☺☺☺} = \underline{\hspace{2cm}}$

How many smiley faces are there?

ANSWERS





1. 4

2. 5

3. 5









1. $8 \times 3 =$ _____

2. $1 + 4 =$ _____

3. 

  $=$ _____

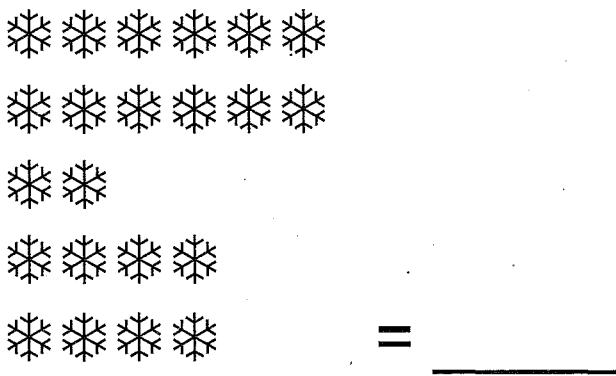
4. $12 \times 0 =$ _____

5. $2 + 7 =$ _____

6.   
   
 $=$ _____

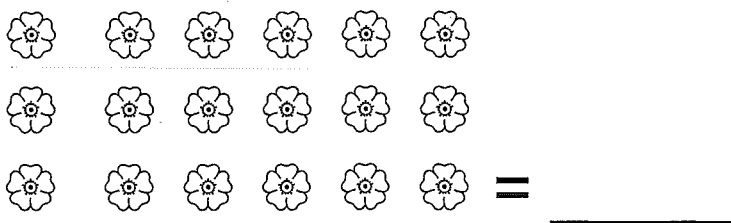
7. $11 \times 10 =$ _____

8. $2 + 8 =$ _____

9. 
 $2 + 6 =$ _____

10. $7 \times 6 =$ _____

11. $2 + 2 =$ _____

12. 
 $3 \times 6 =$ _____

13. $8 \times 8 =$ _____

14. $19 + 3 = \underline{\hspace{2cm}}$

15. $\begin{array}{cccccc} \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ \text{H} & & \text{H} & & \text{H} & \\ \text{H} & & \text{H} & & \text{H} & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \\ \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \end{array} = \underline{\hspace{2cm}}$

16. $9 \times 3 = \underline{\hspace{2cm}}$

17. $50 + 1 = \underline{\hspace{2cm}}$

18. $\begin{array}{cc} \bigcirc & \bigcirc & \bigcirc & \bigcirc & \bigcirc \\ \bigcirc & \bigcirc & \bigcirc & \bigcirc & \bigcirc \end{array} = \underline{\hspace{2cm}}$

19. $5 \times 7 = \underline{\hspace{2cm}}$

20. $3 + 2 = \underline{\hspace{2cm}}$

21. $\begin{array}{cccccc} \star & \star & \star & \star & \star & \star \\ \star & \star & \star & \star & & \\ \star & \star & & & & \end{array} = \underline{\hspace{2cm}}$




22. $6 \times 3 = \underline{\hspace{2cm}}$

23. $3 + 12 = \underline{\hspace{2cm}}$

24. $\begin{array}{cccc} \odot & & & \\ \odot & \odot & \odot & \\ \odot & \odot & \odot & \odot \end{array} = \underline{\hspace{2cm}}$





25. $12 \times 12 = \underline{\hspace{2cm}}$

26. $15 + 10 = \underline{\hspace{2cm}}$

27.    = _____

28. $3 \times 8 =$ _____

29. $0 + 13 =$ _____

30.     = _____

31. $11 \times 3 =$ _____

32. $30 + 10 =$ _____

33. ⌘⌘
 $\text{⌘} = \underline{\hspace{2cm}}$

34. $4 \times 1 = \underline{\hspace{2cm}}$

35. $15 + 3 = \underline{\hspace{2cm}}$

36. ○○○ ○○
 ○○○
 $\text{○○○ ○○} = \underline{\hspace{2cm}}$

37. $10 \times 0 = \underline{\hspace{2cm}}$

38. $14 + 6 = \underline{\hspace{2cm}}$

39. $\begin{array}{c} \star \\ \star \star \star \star \\ \star \end{array} = \underline{\hspace{2cm}}$

40. $4 \times 6 = \underline{\hspace{2cm}}$

41. $4 + 6 = \underline{\hspace{2cm}}$

42. $\begin{array}{c} \uparrow \quad \uparrow \uparrow \uparrow \\ \uparrow \uparrow \\ \uparrow \quad \uparrow \uparrow \uparrow \end{array} = \underline{\hspace{2cm}}$

43. $2 \times 7 = \underline{\hspace{2cm}}$




44. $7 + 5 = \underline{\hspace{2cm}}$

45. 

 = _____





46. $5 \times 1 =$ _____

47. $4 + 5 =$ _____

48. 

 = _____

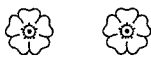

49. $5 \times 1 =$ _____

50. $7 + 7 =$ _____

51. 


 = _____

52. $2 \times 9 =$ _____

53. $8 + 21 =$ _____

54. 
 = _____

55. $3 \times 9 =$ _____

56. $23 + 6 =$ _____

57. ⌘⌘⌘⌘⌘
 $\text{⌘⌘} \quad \text{⌘⌘} = \underline{\hspace{2cm}}$

58. $9 \times 3 = \underline{\hspace{2cm}}$

59. $50 + 30 = \underline{\hspace{2cm}}$

60. $\bigcirc \bigcirc \bigcirc \bigcirc \bigcirc = \underline{\hspace{2cm}}$

61. $4 \times 3 = \underline{\hspace{2cm}}$

62. $23 + 13 = \underline{\hspace{2cm}}$

63. $\begin{array}{cccccc} \bullet & \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & & \\ \bullet & \bullet & \bullet & & & \end{array} = \underline{\hspace{2cm}}$

64. $6 \times 3 =$ _____

65. $26 + 4 =$ _____

66. $\begin{array}{cccccc} \star & \star & \star & \star & \star & \star \\ \star & \star & \star & \star & \star & \star & \star & \star & \star & \star \\ \star & \star & & & & & & & & \end{array} =$ _____

67. $5 \times 5 =$ _____

68. $52 + 8 =$ _____

69. $\begin{array}{cccc} \text{❄} & \text{❄} & \text{❄} & \text{❄} \\ \text{❄} & \text{❄} & \text{❄} & \text{❄} \\ \text{❄} & \text{❄} & \text{❄} & \text{❄} \end{array} =$ _____

70. $2 \times 6 =$ _____

71. $40 + 5 = \underline{\hspace{2cm}}$

72. $\begin{array}{c} \text{☺☺☺☺} \\ \text{☺☺☺☺☺☺☺☺} \\ \text{☺☺☺☺☺☺☺☺☺☺} = \underline{\hspace{2cm}} \end{array}$

Appendix B – Computer Game Instructions

Turtle Odyssey Verbal Instructions

Hello. How is everyone today. My name is Leah Bowman, I'm Gill Hirst and I'm Jenny Kessell (*order to be as most convenient on day*). We come from Edith Cowan University and we are doing a project which you have said you want to help us with. We are going to start by having you all do a maths booklet. We are going to give you 5 minutes to answer as many questions as possible. Just try your best and if you get stuck on a problem and can't work out the answer, just leave it blank and go on to the next question.

If you turn the page over to the first page of the booklet you will see some example questions. For the first question you just need to times two numbers to get the answer, for example $1 \times 4 = 4$, so you write the answer 4 on the line next to the question. The next question wants you add two numbers together, so $2 + 3 = 5$. The last one you need to write down how many pictures there are and write the number on the line e.g. there are 5 pictures so write 5 on the line.

Does anyone have any questions?

Is everyone ready to start? Alright, you can start answering the questions in the booklet.
5mins - Can everyone please put down your pencils.

-- collect books and start game --

Now we are going to let you play a computer game called Turtle Odyssey for 30 minutes. Can you double click the turtle picture on the screen. The game is about a turtle who is looking for his lost shell. The more treasures he finds the more points he gets. To make him jump, press the spacebar and to make him walk use the arrow keys. There is a circle on the bottom corner of the screen. This is the turtle's oxygen and you can't let it run out. There are bubble makers in the game and if you stand on one it refills his oxygen which is a good thing to do if it gets low. You won't be able to finish the game but you can play until we tell you to stop. This game you have to play by yourself without talking to anyone else. Does anyone have any questions?

Now click on start. Now click on new game and you can begin.

30mins -- Ok can everyone please stop playing.

Your final task is to do another maths booklet like the first one but with different questions. Are there any questions? Okay, everyone can start now.

5mins - Can everyone please put your pencils down now? Okay. Thankyou very much everyone for helping us with our project. The pencil is yours to keep as a thankyou to everyone for helping us out!

Blast the Germs Verbal Instructions

Hello. How is everyone today. My name is Leah Bowman, I'm Gill Hirst and I'm Jenny Kessell (*order to be as most convenient on day*). We come from Edith Cowan University and we are doing a project which you have said you want to help us with. We are going to start by having you all do a maths booklet. We are going to give you 5 minutes to answer as many questions as possible. Just try your best and if you get stuck on a problem and can't work out the answer, just leave it blank and go on to the next question.

If you turn the page over to the first page of the booklet you will see some example questions. For the first question you just need to times two numbers to get the answer, for example $1 \times 4 = 4$, so you write the answer 4 on the line next to the question. The next question wants you add two numbers together, so $2 + 3 = 5$. The last one you need to write down how many pictures there are and write the number on the line e.g. there are 5 pictures so write 5 on the line.

Does anyone have any questions?

Is everyone ready to start? Alright, you can start answering the questions in the booklet.
5mins - Can everyone please put down your pencils.

-- collect books and start game --

Now we are going to let you play a computer game called Blast the Germs for 30 minutes. If everyone can look at these screens (*we will demonstrate while explaining*). In the middle is a Germ which is surrounded by lots of healthy cells. If the Germ touches a healthy cell, then the healthy cell gets stuck to the Germ, making the cell get unhealthy and the Germ get bigger! Your job is to count how many cells or circles are in the Germ, drag enough numbers from this top section into the Germ Blaster (*like this*) and blast the Germ. If you make a mistake and don't have enough numbers in your Germ Blaster, some of the Germ stays on the screen and you have to count again and blast it again. If have too many numbers in your Germ Blaster, you can't shoot the Germ. You have to click on the pointy bit at the top of the Germ Blaster and this will delete 1 off the total number (*like this*).

When you blast a Germ, another Germ appears. As you move up higher levels, the target on the person moves up as well. In higher levels, the Germ will move quickly and there will be more healthy cells that can be infected. As long as you keep counting how many cells/circles there are in the Germ and making that number in the Germ Blaster, you will keep blasting the Germ.

Does anyone have any questions? If you have any questions while you are playing please put up your hand.

Can everyone please sit at a computer and wait for us to start the game for us.

****start game****

30mins -- Ok can everyone please stop playing.

Your final task is to do another maths booklet like the first one but with different questions. Are there any questions? Okay, everyone can start now.

5mins - Can everyone please put your pencils down now? Okay. Thankyou very much everyone for helping us with our project. The pencil is yours to keep as a thankyou to everyone for helping us out!

Daisy Maths Verbal Instructions

Hello. How is everyone today. My name is Leah Bowman, I'm Gill Hirst and I'm Jenny Kessell (*order to be as most convenient on day*). We come from Edith Cowan University and we are doing a project which you have said you want to help us with. We are going to start by having you all do a maths booklet. We are going to give you 5 minutes to answer as many questions as possible. Just try your best and if you get stuck on a problem and can't work out the answer, just leave it blank and go on to the next question.

If you turn the page over to the first page of the booklet you will see some example questions. For the first question you just need to times two numbers to get the answer, for example $1 \times 4 = 4$, so you write the answer 4 on the line next to the question. The next question wants you add two numbers together, so $2 + 3 = 5$. The last one you need to write down how many pictures there are and write the number on the line e.g. there are 5 pictures so write 5 on the line.

Does anyone have any questions?

Is everyone ready to start? Alright, you can start answering the questions in the booklet.

5mins - Can everyone please put down your pencils.

-- collect books and start game --

Now we are going to let you play a computer game called Daisy Maths for 30 minutes. In Daisy Maths you are given different maths problems which you need to work out and type in the answer (*demonstrate*). If you click on the daisy in the top right hand corner, you can check to see if your answers were right. If you click the circle-arrows, different maths problems appear. You can also click on any of the numbers at the top that you can see to get problems written differently. When you have done all the different problems types – so you have answered maths questions in number 13, 14, 15, 16, 17 and 18, and want to try some harder problems, put your hand up and we will move you up a level to try harder questions.

Does anyone have any questions? If you have any questions while you are playing please put up your hand.

Can everyone please sit at a computer and wait for us to start the game for us.

****start game****

30mins -- Ok can everyone please stop playing.

Your final task is to do another maths booklet like the first one but with different questions. Are there any questions? Okay, everyone can start now.

5mins - Can everyone please put your pencils down now? Okay. Thankyou very much everyone for helping us with our project. The pencil is yours to keep as a thankyou to everyone for helping us out!

Daisy Maths Instructions to hand out to Participants

The activities and levels for you to play include:

Activities and Levels

Activity 4 13, 14, 15, 16

Activity 5 15, 16, 17

Activity 6 16, 17, 18 and 21, 22

Activity 7 15, 16, 17, 18 and 21, 22

Activity 8 16, 17, 18 and 21, 22.

Remember if you have pictures and not numbers, you are on the wrong problem. Keep checking the level you are at.

Appendix C

F-critical Value and ANOVA Power Table (Runyon, Coleman & Pittenger, 2000)

Table J
Critical Values of the F-Ratio

The obtained *F* is significant at a given level if it is equal to or *greater than* the value shown in the table. 0.05 (light row) and 0.01 (dark row) points for the distribution of *F*.

The values shown are the right tail of the distribution obtained by dividing the larger variance estimate by the smaller variance estimate. To find the complementary left or lower tail for a given *df* and α -level, reverse the degrees of freedom and find the reciprocal of that value in the *F*-table. For example, the value cutting off the top 5% of the area for 7 and 12 *df* is 2.92. To find the cutoff point of the bottom 5% of the area, find the tabled value of the $\alpha = 0.05$ level for 12 and 7 *df*. This value is 3.57. The reciprocal is $1/3.57 = 0.28$. Thus 5% of the area falls *at or below* an *F* = 0.28.

ble J (continued)

		Degrees of freedom for numerator																							
		1	2	3	4	5	6	7	8	9	10	11	12	14	16	20	24	30	40	50	75	100	200	500	∞
Degrees of freedom for denominator	36	4.11 7.39	3.26 5.25	2.86 4.38	2.63 3.89	2.48 3.58	2.36 3.35	2.28 3.18	2.21 3.04	2.15 2.94	2.10 2.86	2.06 2.78	2.03 2.72	1.89 2.62	1.93 2.54	1.87 2.43	1.82 2.35	1.78 2.26	1.72 2.17	1.69 2.12	1.65 2.04	1.62 2.00	1.59 1.94	1.56 1.90	1.55 1.87
	38	4.10 7.35	3.25 5.21	2.85 4.34	2.62 3.86	2.46 3.54	2.35 3.32	2.26 3.15	2.19 3.02	2.14 2.91	2.09 2.82	2.05 2.75	2.02 2.69	1.96 2.59	1.92 2.51	1.85 2.40	1.80 2.32	1.76 2.22	1.71 2.14	1.67 2.08	1.63 2.00	1.60 1.97	1.57 1.90	1.54 1.86	1.53 1.84
	40	4.08 7.31	3.23 5.18	2.84 4.31	2.61 3.83	2.45 3.51	2.34 3.29	2.25 3.12	2.18 2.99	2.12 2.88	2.07 2.80	2.04 2.73	2.00 2.66	1.95 2.56	1.90 2.49	1.84 2.37	1.79 2.29	1.74 2.20	1.69 2.11	1.66 2.05	1.61 1.97	1.59 1.94	1.55 1.88	1.53 1.84	1.51 1.81
	42	4.07 7.27	3.22 5.15	2.83 4.29	2.59 3.80	2.44 3.49	2.32 3.26	2.24 3.10	2.17 2.96	2.11 2.86	2.06 2.77	2.02 2.70	1.90 2.64	1.94 2.54	1.89 2.46	1.82 2.35	1.78 2.26	1.73 2.17	1.68 2.08	1.64 2.02	1.60 1.94	1.57 1.91	1.54 1.85	1.51 1.80	1.49 1.78
	44	4.06 7.24	3.21 5.12	2.82 4.26	2.58 3.78	2.43 3.46	2.31 3.24	2.23 3.07	2.16 2.94	2.10 2.84	2.05 2.75	2.01 2.68	1.98 2.62	1.92 2.52	1.88 2.44	1.81 2.32	1.76 2.24	1.72 2.15	1.66 2.06	1.63 2.09	1.58 1.92	1.56 1.88	1.52 1.82	1.50 1.78	1.48 1.75
	46	4.05 7.21	3.20 5.10	2.81 4.24	2.57 3.76	2.42 3.44	2.30 3.22	2.22 3.05	2.14 2.92	2.09 2.82	2.04 2.73	2.00 2.66	1.97 2.60	1.91 2.50	1.87 2.42	1.80 2.30	1.75 2.22	1.71 2.13	1.65 2.04	1.62 1.98	1.57 1.90	1.54 1.86	1.51 1.80	1.48 1.76	1.46 1.72
	48	4.04 7.19	3.19 5.08	2.80 4.22	2.56 3.74	2.41 3.42	2.30 3.20	2.21 3.04	2.14 2.90	2.08 2.80	2.03 2.71	1.99 2.64	1.96 2.58	1.90 2.48	1.86 2.40	1.79 2.28	1.74 2.20	1.70 2.11	1.64 2.02	1.61 1.96	1.56 1.88	1.53 1.84	1.50 1.78	1.47 1.73	1.45 1.70
	50	4.03 7.17	3.18 5.06	2.79 4.20	2.56 3.72	2.40 3.41	2.29 3.18	2.20 3.02	2.13 2.88	2.07 2.78	2.02 2.70	1.98 2.62	1.95 2.56	1.90 2.46	1.85 2.39	1.78 2.26	1.74 2.18	1.69 2.10	1.63 2.00	1.60 1.94	1.55 1.86	1.52 1.82	1.48 1.76	1.46 1.71	1.44 1.68
	55	4.02 7.12	3.17 5.01	2.78 4.16	2.54 3.68	2.38 3.37	2.27 3.15	2.18 2.98	2.11 2.85	2.05 2.75	2.00 2.66	1.97 2.59	1.93 2.53	1.88 2.43	1.83 2.35	1.76 2.23	1.72 2.15	1.67 2.06	1.61 1.96	1.58 1.90	1.52 1.82	1.50 1.78	1.46 1.71	1.43 1.66	1.41 1.64
	60	4.00 7.08	3.15 4.98	2.76 4.13	2.52 3.65	2.37 3.34	2.25 3.12	2.17 2.95	2.10 2.82	2.04 2.72	1.99 2.63	1.95 2.56	1.92 2.50	1.86 2.40	1.81 2.32	1.75 2.20	1.70 2.12	1.65 2.03	1.59 1.93	1.56 1.87	1.50 1.79	1.48 1.74	1.44 1.68	1.41 1.63	1.39 1.60
	65	3.99 7.04	3.14 4.95	2.75 4.10	2.51 3.62	2.36 3.31	2.24 3.09	2.15 2.93	2.08 2.79	2.02 2.70	1.98 2.61	1.94 2.54	1.90 2.47	1.85 2.37	1.80 2.30	1.73 2.18	1.68 2.09	1.63 2.00	1.57 1.90	1.54 1.84	1.49 1.76	1.46 1.71	1.42 1.64	1.39 1.60	1.37 1.56
	70	3.98 7.01	3.13 4.92	2.74 4.08	2.50 3.60	2.35 3.29	2.23 3.07	2.14 2.91	2.07 2.77	2.01 2.67	1.97 2.59	1.93 2.51	1.89 2.45	1.84 2.35	1.79 2.28	1.72 2.15	1.67 2.07	1.62 1.98	1.56 1.88	1.53 1.82	1.47 1.74	1.45 1.69	1.40 1.62	1.37 1.56	1.35 1.53
	80	3.96 6.96	3.11 4.88	2.72 4.04	2.48 3.56	2.33 3.25	2.21 3.04	2.12 2.87	2.05 2.74	1.99 2.64	1.95 2.55	1.91 2.48	1.88 2.41	1.82 2.32	1.77 2.24	1.70 2.11	1.65 2.03	1.60 1.94	1.54 1.84	1.51 1.78	1.45 1.70	1.42 1.65	1.38 1.57	1.35 1.52	1.32 1.49
	100	3.94 6.90	3.09 4.82	2.70 3.98	2.46 3.51	2.30 3.20	2.19 2.99	2.10 2.82	2.03 2.69	1.97 2.59	1.92 2.51	1.88 2.43	1.85 2.36	1.79 2.26	1.75 2.19	1.68 2.06	1.63 1.98	1.57 1.89	1.51 1.79	1.48 1.73	1.42 1.64	1.39 1.59	1.34 1.51	1.30 1.46	1.28 1.43
	125	3.92 6.84	3.07 4.78	2.68 3.94	2.44 3.47	2.29 3.17	2.17 2.95	2.08 2.79	2.01 2.65	1.95 2.56	1.90 2.47	1.86 2.40	1.83 2.33	1.77 2.23	1.72 2.15	1.65 2.03	1.60 1.94	1.55 1.85	1.49 1.75	1.45 1.68	1.39 1.56	1.36 1.54	1.31 1.46	1.27 1.40	1.25 1.37
	150	3.91 6.81	3.06 4.75	2.67 3.91	2.43 3.44	2.27 3.13	2.16 2.92	2.07 2.76	2.00 2.62	1.94 2.53	1.89 2.44	1.85 2.37	1.82 2.30	1.76 2.20	1.71 2.12	1.64 2.00	1.59 1.91	1.54 1.83	1.47 1.72	1.44 1.66	1.37 1.56	1.34 1.51	1.29 1.43	1.25 1.37	1.22 1.33
	200	3.89 6.76	3.04 4.71	2.65 3.88	2.41 3.41	2.26 3.11	2.14 2.90	2.05 2.73	1.98 2.60	1.92 2.50	1.87 2.41	1.83 2.34	1.80 2.28	1.74 2.17	1.69 2.09	1.62 1.97	1.57 1.88	1.52 1.79	1.45 1.69	1.42 1.62	1.35 1.53	1.32 1.48	1.26 1.39	1.22 1.33	1.19 1.28
	400	3.86 6.70	3.02 4.66	2.62 3.83	2.39 3.36	2.23 3.06	2.12 2.85	2.03 2.69	1.96 2.55	1.90 2.46	1.85 2.37	1.81 2.29	1.78 2.23	1.72 2.12	1.67 2.04	1.60 1.92	1.54 1.84	1.49 1.74	1.42 1.64	1.38 1.57	1.32 1.47	1.28 1.42	1.22 1.32	1.16 1.24	1.13 1.19
	1000	3.85 6.66	3.00 4.62	2.61 3.80	2.38 3.34	2.22 3.04	2.10 2.82	2.02 2.66	1.95 2.53	1.89 2.43	1.84 2.34	1.80 2.26	1.76 2.20	1.70 2.09	1.65 2.01	1.58 1.89	1.53 1.81	1.47 1.71	1.41 1.61	1.36 1.54	1.30 1.44	1.26 1.38	1.19 1.28	1.13 1.19	1.08 1.11
	∞	3.84 6.64	2.99 4.60	2.60 3.78	2.37 3.32	2.21 3.02	2.09 2.80	2.01 2.64	1.94 2.51	1.88 2.41	1.83 2.32	1.79 2.24	1.75 2.18	1.69 2.07	1.64 1.99	1.57 1.87	1.52 1.79	1.46 1.69	1.40 1.59	1.35 1.52	1.28 1.41	1.24 1.36	1.17 1.25	1.11 1.15	1.00 1.00

Table M
Power of ANOVA

This table presents the power for the F -ratio. Each section represents the degrees of freedom for the numerator (e.g., the degrees of freedom for the effect or $k - 1$). Power is presented for sample sizes of 5 to 100, α levels of $\alpha = .01$, $\alpha = .05$, and $\alpha = .10$; and for effect sizes of $f = .1$ (small effect), $f = .25$ (medium effect), and $f = .40$ (large effect). The F_c column represents the critical value of F required to reject the null hypothesis.

To use the table, locate the section that represents the appropriate degrees of freedom. Next select the column that represents the α level you plan to use and the effect size you predict. That column of values represents the power for the sample size indicated for each row. For example, if you plan to conduct an ANOVA wherein the degrees of freedom in the numerator are 5, $\alpha = .05$, $f = .25$, and $n = 20$, then the predicted power is .52.

The entry $**$ represents a value of power greater than .99.

DEGREES OF FREEDOM NUMERATOR = 2												
$\alpha = .01$					$\alpha = .05$				$\alpha = .10$			
n	F_c	.10	.25	.40	F_c	.10	.25	.40	F_c	.10	.25	.40
5	6.927	.01	.03	.07	3.885	.06	.11	.22	2.807	.12	.20	.34
10	5.488	.01	.06	.21	3.354	.07	.20	.45	2.511	.13	.31	.59
15	5.149	.02	.11	.38	3.220	.08	.29	.64	2.434	.15	.42	.76
20	4.998	.02	.17	.55	3.159	.09	.38	.78	2.398	.17	.52	.87
25	4.913	.02	.23	.69	3.124	.10	.47	.87	2.376	.19	.60	.93
30	4.858	.03	.30	.80	3.101	.12	.55	.93	2.365	.21	.68	.96
35	4.819	.03	.37	.87	3.085	.13	.62	.96	2.355	.23	.74	.98
40	4.791	.04	.44	.92	3.074	.15	.68	.98	2.348	.25	.79	.99
45	4.770	.05	.50	.95	3.065	.16	.74	.99	2.343	.26	.83	**
50	4.752	.05	.56	.97	3.058	.18	.79	.99	2.339	.28	.87	**
100	4.677	.13	.92	**	3.026	.32	.98	**	2.321	.45	.99	**

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